DOCKET NO. 070674-EI

CERTIFICATION OF

PUBLIC SERVICE COMMISSION ADMINISTRATIVE RULES

FILED WITH THE

DEPARTMENT OF STATE

I do hereby certify:

/x/ (1) That all statutory rulemaking requirements of Chapter 120, F.S., have been complied with; and

/x/ (2) There is no administrative determination under subsection 120.56(2), F.S., pending on any rule covered by this certification; and

/x/ (3) All rules covered by this certification are filed within the prescribed time limitations of paragraph 120.54(3)(e), F.S. They are filed not less than 28 days after the notice required by paragraph 120.54(3)(a), F.S., and;

/x/ (a) Are filed not more than 90 days after the notice; or

/ / (b) Are filed not more than 90 days after the notice not including days an administrative determination was pending; or

/ / (c) Are filed more than 90 days after the notice, but not less than 21 days nor more than 45 days from the date of publication of the notice of change; or

/ / (d) Are filed more than 90 days after the notice, but not less than 14 nor more than 45 days after the adjournment of the final public hearing on the rule; or

/ / (e) Are filed more than 90 days after the notice, but within 21 days after the date of receipt of all material authorized to be submitted at the hearing; or

_/ /_ (f) Are filed more than 90 days after the notice, but within 21 days after the date the transcript was received by this agency; or

_/ /_ (g) Are filed not more than 90 days after the notice, not including days the adoption of the rule was postponed following notification from the Joint Administrative Procedures Committee that an objection to the rule was being considered; or

_/ /_ (h) Are filed more than 90 days after the notice, but within 21 days after a good faith written proposal for a lower cost regulatory alternative to a proposed rule is submitted which substantially accomplishes the objectives of the law being implemented; or

_/ /_ (i) Are filed more than 90 days after the notice, but within 21 days after a regulatory alternative is offered by the small business ombudsman.

Attached are the original and two copies of each rule covered by this certification. The rules are hereby adopted by the undersigned agency by and upon their filing with the Department of State.

<u>Rule No.</u>

25-6.065

Under the provision of subparagraph 120.54(3)(e)6., F.S., the rules take effect 20 days from the date filed with the Department of State or a later date as set out below:

Effective: ______________________________
(month) (day) (year)

ANN COLE
Commission Clerk

RG

____
Number of Pages Certified

25-6.065 Interconnection and Net Metering of Customer-Owned Renewable Generation

(1) Application and Scope. The purpose of this rule is to promote the development of small customer-owned renewable generation, particularly solar and wind energy systems; diversify the types of fuel used to generate electricity in Florida; lessen Florida's dependence on fossil fuels for the production of electricity; minimize the volatility of fuel costs; encourage investment in the state; improve environmental conditions; and, at the same time, minimize costs of power supply to investor-owned utilities and their customers. This rule applies to all investor-owned utilities, except as otherwise stated in subsection (10).

(2) Definitions. As used in this rule, the term

(a) "Customer-owned renewable generation" means an electric generating system located on a customer's premises that is primarily intended to offset part or all of the customer's electricity requirements with renewable energy. The term "customer-owned renewable generation" does not preclude the customer of record from contracting for the purchase, lease, operation, or maintenance of an on-site renewable generation system with a third-party under terms and conditions that do not include the retail purchase of electricity from the third party.

(b) "Gross power rating" means the total manufacturer's AC nameplate generating capacity of an on-site customer-owned renewable generation system that will be interconnected to and operate in parallel with the investor-owned utility's distribution facilities. For inverter-based systems, the AC nameplate generating capacity shall be calculated by multiplying the total installed DC nameplate generating capacity by .85 in order to account for losses during the conversion from DC to AC.

(c) "Net metering" means a metering and billing methodology whereby customer-owned renewable generation is allowed to offset the customer's electricity consumption on-site.

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(d) "Renewable energy," as defined in Section 377.803, Florida Statutes, means electrical, mechanical, or thermal energy produced from a method that uses one of more of the following fuels or energy sources: hydrogen, biomass, solar energy, geothermal energy, wind energy, ocean energy, waste heat, or hydroelectric power.

(3) Standard Interconnection Agreements. Each investor-owned utility shall, within 30 days of the effective date of this rule, file for Commission approval a Standard Interconnection Agreement for expedited interconnection of customer-owned renewable generation, up to 2 MW, that complies with the following standards:

(a) IEEE 1547 (2003) Standard for Interconnecting Distributed Resources with Electric Power Systems;

(b) IEEE 1547.1 (2005) Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems; and

(c) UL 1741 (2005) Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources.

(d) A copy of IEEE 1547 (2003), ISBN number 0-7381-3720-0, and IEEE 1547.1 (2005), ISBN number 0-7381-4737-0, may be obtained from the Institute of Electric and Electronic Engineers, Inc. (IEEE), 3 Park Avenue, New York, NY, 10016-5997. A copy of UL 1741 (2005) may be obtained from COMM 2000, 1414 Brook Drive, Downers Grove, IL 60515.

(4) Customer Qualifications and Fees.

(a) To qualify for expedited interconnection under this rule, customer-owned renewable generation must have a gross power rating that:

1. does not exceed 90% of the customer's utility distribution service rating; and

2. falls within one of the following ranges:

Tier 1 - 10 kW or less;

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Tier 2 – greater than 10 kW and less than or equal to 100 kW; or

Tier 3 – greater than 100 kW and less than or equal to 2 MW.

(b) Customer-owned renewable generation shall be considered certified for interconnected operation if it has been submitted by a manufacturer to a nationally recognized testing and certification laboratory, and has been tested and listed by the laboratory for continuous interactive operation with an electric distribution system in compliance with the applicable codes and standards listed in subsection (3).

(c) Customer-owned renewable generation shall include a utility-interactive inverter, or other device certified pursuant to subsection (4)(b) that performs the function of automatically isolating the customer-owned generation equipment from the electric grid in the event the electric grid loses power.

(d) For Tiers 1 and 2, provided the customer-owned renewable generation equipment complies with subsections (4)(a) and (b), the investor-owned utility shall not require further design review, testing, or additional equipment other than that provided for in subsection (6). For Tier 3, if an interconnection study is necessary, further design review, testing and additional equipment as identified in the study may be required.

(e) Tier 1 customers who request interconnection of customer-owned renewable generation shall not be charged fees in addition to those charged to other retail customers without self-generation, including application fees.

(f) Along with the Standard Interconnection Agreement filed pursuant to subsection (3), each investor-owned utility may propose for Commission approval a standard application fee for Tiers 2 and 3, including itemized cost support for each cost contained within the fee.

(g) Each investor-owned utility may also propose for Commission approval an Interconnection Study Charge for Tier 3.

(h) Each investor-owned utility shall show that their fees and charges are cost-based

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and reasonable. No fees or charges shall be assessed for interconnecting customer-owned renewable generation without prior Commission approval.

(5) Contents of Standard Interconnection Agreement. Each investor-owned utility's customer-owned renewable generation Standard Interconnection Agreement shall, at a minimum, contain the following:

(a) A requirement that customer-owned renewable generation must be inspected and approved by local code officials prior to its operation in parallel with the investor-owned utility to ensure compliance with applicable local codes.

(b) Provisions that permit the investor-owned utility to inspect customer-owned renewable generation and its component equipment, and the documents necessary to ensure compliance with subsections (2) through (4). The customer shall notify the investor-owned utility at least 10 days prior to initially placing customer equipment and protective apparatus in service, and the investor-owned utility shall have the right to have personnel present on the in-service date. If the customer-owned renewable generation system is subsequently modified in order to increase its gross power rating, the customer must notify the investor-owned utility by submitting a new application specifying the modifications at least 30 days prior to making the modifications.

(c) A provision that the customer is responsible for protecting the renewable generating equipment, inverters, protective devices, and other system components from damage from the normal and abnormal conditions and operations that occur on the investor-owned utility system in delivering and restoring power; and is responsible for ensuring that customer-owned renewable generation equipment is inspected, maintained, and tested in accordance with the manufacturer's instructions to ensure that it is operating correctly and safely.

(d) A provision that the customer shall hold harmless and indemnify the investor-

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owned utility for all loss to third parties resulting from the operation of the customer-owned renewable generation, except when the loss occurs due to the negligent actions of the investor-owned utility. A provision that the investor-owned utility shall hold harmless and indemnify the customer for all loss to third parties resulting from the operation of the investor-owned utility's system, except when the loss occurs due to the negligent actions of the customer.

(e) A requirement for general liability insurance for personal and property damage, or sufficient guarantee and proof of self-insurance, in the amount of no more than $1 million for Tier 2, and no more than $2 million for Tier 3. The investor-owned utility shall not require liability insurance for Tier 1. The investor-owned utility may include in the Interconnection Agreement a recommendation that Tier 1 customers carry an appropriate level of liability insurance.

(f) Identification of any fees or charges approved pursuant to subsection (4).

(6) Manual Disconnect Switch

(a) Each investor-owned utility's customer-owned renewable generation Standard Interconnection Agreement may require customers to install, at the customer's expense, a manual disconnect switch of the visible load break type to provide a separation point between the AC power output of the customer-owned renewable generation and any customer wiring connected to the investor-owned utility's system. Inverter-based Tier 1 customer-owned renewable generation systems shall be exempt from this requirement, unless the manual disconnect switch is installed at the investor-owned utility's expense. The manual disconnect switch shall be mounted separate from, but adjacent to, the meter socket and shall be readily accessible to the investor-owned utility and capable of being locked in the open position with a single investor-owned utility padlock.

(b) The investor-owned utility may open the switch pursuant to the conditions set forth in subsection (6)(c), isolating the customer-owned renewable generation, without prior notice to the customer. To the extent practicable, however, prior notice shall be given. If prior notice is not given, the utility shall at the time of disconnection leave a door hanger notifying the customer that their customer-owned renewable generation has been disconnected, including an explanation of the condition necessitating such action. The investor-owned utility shall reconnect the customer-owned renewable generation as soon as the condition necessitating disconnection is remedied.

(c) Any of the following conditions shall be cause for the investor-owned utility to disconnect customer-owned renewable generation from its system:

1. Emergencies or maintenance requirements on the investor-owned utility's electric system;

2. Hazardous conditions existing on the investor-owned utility system due to the operation of the customer's generating or protective equipment as determined by the investor-owned utility;

3. Adverse electrical effects, such as power quality problems, on the electrical equipment of the investor-owned utility's other electric consumers caused by the customer-owned renewable generation as determined by the investor-owned utility;

4. Failure of the customer to maintain the required insurance coverage.

(7) Administrative Requirements.

(a) Each investor-owned utility shall maintain on its website a downloadable application for interconnection of customer-owned renewable generation, detailing the information necessary to execute the Standard Interconnection Agreement. Upon request the investor-owned utility shall provide a hard copy of the application within 5 business days.

(b) Within 10 business days of receipt of the customer's application, the investor-owned utility shall provide written notice that it has received all documents required by the Standard Interconnection Agreement or indicate how the application is deficient. Within 10

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business days of receipt of a completed application, the utility shall provide written notice verifying receipt of the completed application. The written notice shall also include dates for any physical inspection of the customer-owned renewable generation necessary for the investor-owned utility to confirm compliance with subsections (2) through (6), and confirmation of whether a Tier 3 interconnection study will be necessary.

(c) The Standard Interconnection Agreement shall be executed by the investor-owned utility within 30 calendar days of receipt of a completed application. If the investor-owned utility determines that an interconnection study is necessary for a Tier 3 customer, the investor-owned utility shall execute the Standard Interconnection Agreement within 90 days of a completed application.

(d) The customer must execute the Standard Interconnection Agreement and return it to the investor-owned utility at least 30 calendar days prior to beginning parallel operations and within one year after the utility executes the Agreement. All physical inspections must be completed by the utility within 30 calendar days of receipt of the customer's executed Standard Interconnection Agreement. If the inspection is delayed at the customer's request, the customer shall contact the utility to reschedule an inspection. The investor-owned utility shall reschedule the inspection within 10 business days of the customer's request.

(8) Net Metering.

(a) Each investor-owned utility shall enable each customer-owned renewable generation facility interconnected to the investor-owned utility's electrical grid pursuant to this rule to net meter.

(b) Each investor-owned utility shall install, at no additional cost to the customer, metering equipment at the point of delivery capable of measuring the difference between the electricity supplied to the customer from the investor-owned utility and the electricity generated by the customer and delivered to the investor-owned utility's electric grid.

(c) Meter readings shall be taken monthly on the same cycle as required under the otherwise applicable rate schedule.

(d) The investor-owned utility shall charge for electricity used by the customer in excess of the generation supplied by customer-owned renewable generation in accordance with normal billing practices.

(e) During any billing cycle, excess customer-owned renewable generation delivered to the investor-owned utility's electric grid shall be credited to the customer's energy consumption for the next month's billing cycle.

(f) Energy credits produced pursuant to subsection (8)(e) shall accumulate and be used to offset the customer's energy usage in subsequent months for a period of not more than twelve months. At the end of each calendar year, the investor-owned utility shall pay the customer for any unused energy credits at an average annual rate based on the investor-owned utility's COG-1, as-available energy tariff.

(g) When a customer leaves the system, that customer's unused credits for excess kWh generated shall be paid to the customer at an average annual rate based on the investor-owned utility's COG-1, as-available energy tariff.

(h) Regardless of whether excess energy is delivered to the investor-owned utility's electric grid, the customer shall continue to pay the applicable customer charge and applicable demand charge for the maximum measured demand during the billing period. The investor-owned utility shall charge for electricity used by the customer in excess of the generation supplied by customer-owned renewable generation at the investor-owned utility's otherwise applicable rate schedule. The customer may at their sole discretion choose to take service under the investor-owned utility's standby or supplemental service rate, if available.

(9) Renewable Energy Certificates. Customers shall retain any Renewable Energy Certificates associated with the electricity produced by their customer-owned renewable

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generation equipment. Any additional meters necessary for measuring the total renewable electricity generated for the purposes of receiving Renewable Energy Certificates shall be installed at the customer's expense, unless otherwise determined during negotiations for the sale of the customer's Renewable Energy Certificates to the investor-owned utility.

(10) Reporting Requirements. Each electric utility, as defined in Section 366.02(2), Florida Statutes, shall file with the Commission as part of its tariff a copy of its Standard Interconnection Agreement form for customer-owned renewable generation. In addition, each electric utility shall report the following, by April 1 of each year.

(a) Total number of customer-owned renewable generation interconnections as of the end of the previous calendar year;

(b) Total kW capacity of customer-owned renewable generation interconnected as of the end of the previous calendar year;

(c) Total kWh received by interconnected customers from the electric utility, by month and by year for the previous calendar year;

(d) Total kWh of customer-owned renewable generation delivered to the electric utility, by month and by year for the previous calendar year; and

(e) Total energy payments made to interconnected customers for customer-owned renewable generation delivered to the electric utility for the previous calendar year, along with the total payments made since the implementation of this rule.

(f) For each individual customer-owned renewable generation interconnection:

1. Renewable technology utilized;

2. Gross power rating;

3. Geographic location by county; and

4. Date interconnected.

(11) Dispute Resolution. Parties may seek resolution of disputes arising out of the

interpretation of this rule pursuant to Rule 25-22.032, F.A.C, Customer Complaints, or Rule 25-22.036, F.A.C., Initiation of Formal Proceedings.

Specific Authority 350.127(2), 366.05(1), 366.92, FS. Law Implemented 366.02(2), 366.04(2)(c), (5), (6), 366.041, 366.05(1), 366.81, 366.82(1),(2), 366.91(1),(2), 366.92, FS. History–New 2-11-02, Amended ___________.

InterconnectionNetMeteringRule.rg.doc

Rule No. 25-6.065
Docket No. 070674-EI

SUMMARY OF RULE

The rule amendments require investor-owned utilities (IOUs) to file for approval with the Commission, and offer customers a standard interconnection agreement for the expedited interconnection of customer-owned renewable generation systems. The rule amendments also establish the procedures for net metering, including the treatment of net excess generation monthly and annually and identify processes for dispute resolution. Reporting requirements are applicable to all electric utilities, including municipals and electric cooperatives, for customers with interconnected renewable generation and net metered customers.

SUMMARY OF HEARINGS ON THE RULE

The Commission considered comments filed to the proposed rule at its March 4, 2008 agenda conference. The Commission made no changes to the rule as a result of that hearing.

FACTS AND CIRCUMSTANCES JUSTIFYING THE RULE

Since the existing rule was adopted in 2002, the Commission has increasingly addressed issues related to renewable energy. In 2007, the Commission initiated efforts to further encourage renewable generation, beginning with a workshop on January 19, 2007, wherein the Commission collected information from a wide-range of interested persons, including: renewable generators, environmentalists, Florida utilities, and financial experts. In particular, the Commission heard speakers on: (1) the current status of renewables in Florida, (2) possible strategies to further encourage renewables, and (3) facilitating financing of renewable generation projects. Based on the information gained during the workshop, and at two subsequent workshops held in April 2007, and two rule development workshops held on August 30, 2007, and October 15, 2007, the Commission is pursuing further efforts to encourage the deployment of renewable generation in Florida, including these rule amendments on expedited interconnection and net metering of customer-owned renewable generating facilities, as well as an exploration of a renewable portfolio standard for Florida.

CERTIFICATION OF

MATERIALS INCORPORATED BY REFERENCE

IN RULES FILED WITH THE DEPARTMENT OF STATE

Pursuant to Rule 1S-1.005, Florida Administrative Code, I do hereby certify that the attached are true and correct copies of the following materials incorporated by reference in Rule No. 25-6.065. Under the provisions of subparagraph 120.54(3)(e)(6), F.S., the attached materials take effect 20 days from the date filed with the Department of State, or a later date as specified in the rule.

IEEE 1547 (2003) Standard for Interconnecting Distributed Resources With Electric Power Systems

IEEE 1547.1 (2005) Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

UL 1741 (2005) Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

ANN COLE
Commission Clerk

Number of Pages Certified

RG

UL 1741

ISBN 0-7629-0421-6

Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

Underwriters Laboratories Inc. (UL)
333 Pfingsten Road
Northbrook, IL 60062-2096

UL Standard for Safety for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741

First Edition, Dated May 7, 1999

Revisions: This Standard contains revisions through and including November 7, 2005.

Summary of Topics:

The revisions dated November 7, 2005 include a revised title. The previous title, Inverters, Converters, and Controllers for Use in Independent Power Systems, has been revised to Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources. In addition, the revisions dated November 7, 2005 were issued to incorporate the following revised requirements:

1. Clarification of the Inclusion of Interconnection Equipment for Stand-Alone and Utility-Connected Systems

2. Clarification of Grounding Requirements

3. Clarification of Converter Requirements

4. Clarification of Ground-Fault Detector/Interrupter (GFDI) Requirements for Photovoltaic Equipment, Including Revisions in Accordance with the NEC

5. Revisions in Accordance with the NEC Including a Clarification of Screw Engagement, Markings for Conductor Temperature Limitations, and the Deletion of "Natural" from "Natural Gray"

6. Replacement of the Utility-Interconnection Requirements and Tests with References to the Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1

Announcement Bulletin(s): This Standard contains the announcement bulletin(s) dated May 7, 1999. The announcement bulletin is located at the end of the Standard.

UL Standards for Safety are developed and maintained in the Standard Generalized Markup Language (SGML). SGML -- an international standard (ISO 8879-1986) -- is a descriptive markup language that describes a document's structure and purpose, rather than its physical appearance on a page. Due to formatting differences resulting from the use of UL's new electronic publishing system, please note that additional pages (on which no requirements have been changed) may be included in revision pages due to relocation of existing text and reformatting of the Standard.

Text that has been changed in any manner is marked with a vertical line in the margin. Changes in requirements are marked with a vertical line in the margin and are followed by an effective date note indicating the date of publication or the date on which the changed requirement becomes effective.

The following table lists the future effective dates with the corresponding references.

Future Effective Date	References
May 7, 2007	1.1A, 5.1.5, 30.1.13, 31.1, 31.2, Table 31.1, 31.9, 31.10, Section 32A, 38.2, 39.1 – 39.6, Section 40, 45.1.1, 45.2.2, 45.4.2, Table 45.1, Table 45.2, 45.4.3, Section 45.5, 46.1.1, Section 46.2 – Section 46.4, Section 47.8, Table 62.1, 63.4, 63.5, 63.15, 64.5, 64.15, 64.16, 65.2.1, 65.2.8, 66.3, and 66.4

The new requirements are substantially in accordance with UL's Proposal(s) on this subject dated July 5, 2005.

The UL Foreword is no longer located within the UL Standard. For information concerning the use and application of the requirements contained in this Standard, the current version of the UL Foreword is located on ULStandardsInfoNet at: http://ulstandardsinfonet.ul.com/ulforeword.html

The master for this Standard at UL's Northbrook Office is the official document insofar as it relates to a UL service and the compliance of a product with respect to the requirements for that product and service, or if there are questions regarding the accuracy of this Standard.

Revisions of UL Standards for Safety are issued from time to time. A UL Standard for Safety is current only if it incorporates the most recently adopted revisions.

UL provides this Standard "as is" without warranty of any kind, either expressed or implied, including but not limited to, the implied warranties of merchantability or fitness for any purpose.

In no event will UL be liable for any special, incidental, consequential, indirect or similar damages, including loss of profits, lost savings, loss of data, or any other damages arising out of the use of or the inability to use this Standard, even if UL or an authorized UL representative has been advised of the possibility of such damage. In no event shall UL's liability for any damage ever exceed the price paid for this Standard, regardless of the form of the claim.

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Purchasers of the electronic versions of UL's Standards for Safety agree to defend, indemnify, and hold UL harmless from and against any loss, expense, liability, damage, claim, or judgement (including reasonable attorney's fees) resulting from any error or deviation introduced while purchaser is storing an electronic Standard on the purchaser's computer system.

If a single-user version electronic Standard was purchased, one copy of this Standard may be stored on the hard disk of a single personal computer, or on a single LAN file-server or the permanent storage device of a multiple-user computer in such a manner that this Standard may only be accessed by one user at a time and for which there is no possibility of multiple concurrent access.

If a multiple-user version electronic Standard was purchased, one copy of the Standard may be stored on a single LAN file-server, or on the permanent storage device of a multiple-user computer, or on an Intranet server. The number of concurrent users shall not exceed the number of users authorized.

Electronic Standards are intended for on-line use, such as for viewing the requirements of a Standard, conducting a word search, and the like. Only one copy of the Standard may be printed from each single-user version of an electronic Standard. Only one copy of the Standard may be printed for each authorized user of a multiple-user version of an electronic Standard. Because of differences in the computer/software/printer setup used by UL and those of electronic Standards purchasers, the printed copy obtained by a purchaser may not look exactly like the on-line screen view or the printed Standard.

An employee of an organization purchasing a UL Standard can make a copy of the page or pages being viewed for their own fair and/or practical internal use.

The requirements in this Standard are now in effect, except for those paragraphs, sections, tables, figures, and/or other elements of the Standard having future effective dates as indicated in the note following the affected item. The prior text for requirements that have been revised and that have a future effective date are located after the Standard, and are preceded by a "SUPERSEDED REQUIREMENTS" notice.

New product submittals made prior to a specified future effective date will be judged under all of the requirements in this Standard including those requirements with a specified future effective date, unless the applicant specifically requests that the product be judged under the current requirements. However, if the applicant elects this option, it should be noted that compliance with all the requirements in this Standard will be required as a condition of continued Listing and Follow-Up Services after the effective date, and understanding of this should be signified in writing.

This Standard consists of pages dated as shown in the following checklist:

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1-4A	November 7, 2005
4B-5	January 17, 2001
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25	May 7, 1999
26-30	January 17, 2001
31-32	November 7, 2005
33	January 17, 2001
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36	January 17, 2001
37-38	May 7, 1999
39-40B	January 17, 2001
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44	November 7, 2005
44A-44B	January 17, 2001
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No Text on This Page

UL 1741

Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

Before November 7, 2005, the title for UL 1741 was Standard for Inverters, Converters, and Controllers for Use in Independent Power Systems.

First Edition

May 7, 1999

An effective date included as a note immediately following certain requirements is one established by Underwriters Laboratories Inc.

Revisions of this Standard will be made by issuing revised or additional pages bearing their date of issue. A UL Standard is current only if it incorporates the most recently adopted revisions, all of which are itemized on the transmittal notice that accompanies the latest set of revised requirements.

ISBN 0-7629-0421-6

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INTRODUCTION

1 Scope

1.1 These requirements cover inverters, converters, charge controllers, and interconnection system equipment (ISE) intended for use in stand-alone (not grid-connected) or utility-interactive (grid-connected) power systems. Utility-interactive inverters, converters, and ISE are intended to be operated in parallel with an electric power system (EPS) to supply power to common loads.

1.1 revised November 7, 2005

1.1A For utility-interactive equipment, these requirements are intended to supplement and be used in conjunction with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1.

Added 1.1A effective May 7, 2007

1.2 These requirements cover AC modules that combine flat-plate photovoltaic modules and inverters to provide AC output power for stand-alone use or utility-interaction, and power systems that combine other alternative energy sources with inverters, converters, charge controllers, and interconnection system equipment (ISE), in system specific combinations.

1.2 revised November 7, 2005

1.3 These requirements also cover power systems that combine independent power sources with inverters, converters, charge controllers, and interconnection system equipment (ISE) in system specific combinations.

1.3 revised November 7, 2005

1.4 The products covered by these requirements are intended to be installed in accordance with the National Electrical Code, NFPA 70.

1.4 added January 17, 2001

1.5 Deleted November 7, 2005

2 Glossary

2.1 In the text of this standard, the term "unit" refers to any product covered by this Standard. For the purpose of this Standard, the definitions in 2.2– 2.43 apply.

2.1 effective November 7, 2000

2.2 AC MODULE – The smallest complete unit that includes solar cells, optics, inverters, and other components, excluding tracking devices, intended to generate ac power from sunlight.

2.2 effective November 7, 2000

2.3 BARRIER – A part inside an enclosure that reduces access to a part that involves a risk of fire, electric shock, injury to persons, or electrical energy-high current levels.

2.3 effective November 7, 2000

2.4 BRANCH CIRCUIT – The portion of the building wiring system beyond the final overcurrent protective device in the power-distribution panel that protects the ac output of the field-wiring terminals in a permanently connected unit.

2.4 effective November 7, 2000

2.5 BYPASS SOURCE – A branch circuit or generator to which the load is connected when the power conversion portion of the inverter is not supplying power to the load.

2.5 effective November 7, 2000

2.6 CHARGE CONTROLLER – A device intended to control the charging process of storage batteries used in photovoltaic power systems.

2.6 effective November 7, 2000

2.7 CLASS 2 TRANSFORMER – A step-down transformer complying with the applicable requirements in the Standard for Class 2 and Class 3 Transformers, UL 1585.

2.7 effective November 7, 2000

2.8 CONTROL CIRCUIT – A circuit that carries low-voltage, limited-energy (LVLE) electric signals and not main power, voltage or current.

2.8 revised January 17, 2001

2.8A CONVERTER – A device that accepts ac or dc power input and converts it to another form of ac or dc power. For the purposes of this standard and unless otherwise specified, ac output converters intended to directly supply power to loads are to be subjected to all of the requirements for inverters.

2.8A revised November 7, 2005

2.9 DC GROUND FAULT DETECTOR/INTERRUPTER – A device that provides protection for photovoltaic arrays by detecting a ground fault and interrupting the fault path in the dc circuit.

2.9 effective November 7, 2000

2.10 DEGREE OF PROTECTION – The extent of protection provided by an enclosure against access to parts which involve a risk of injury to persons, ingress of foreign solid objects, and/or ingress of water as verified by standardized test methods.

2.10 effective November 7, 2000

2.11 DISCONNECT DEVICE – A device that disconnects the conductors of a circuit from a supply, source, utility, or load.

2.11 effective November 7, 2000

2.11A ELECTRIC POWER SYSTEM (EPS) – Equipment or facilities that deliver electric power to a load. The most common example of an EPS is an electric utility.

2.11A added November 7, 2005

2.12 ENCLOSURE – A surrounding case constructed to provide a degree of protection against:

a) The accessibility of a part that potentially involves a risk of fire, electric shock or injury to persons, or

b) The risk of propagation of flame, sparks, and molten metal initiated by an electrical disturbance occurring within.

2.12 effective November 7, 2000

2.13 FIELD-WIRING LEAD – A lead to which a supply, load, or other wire is intended to be connected by an installer.

2.13 effective November 7, 2000

2.14 FIELD-WIRING TERMINAL – A terminal to which a supply, load, or other wire is intended to be connected by an installer.

2.14 effective November 7, 2000

2.15 FIXED UNIT – A unit that is intended to be permanently connected mechanically and electrically and only able to be detached by the use of a tool.

2.15 revised January 17, 2001

2.16 GROUNDED CONDUCTOR – A system or circuit conductor that is intentionally grounded.

2.16 effective November 7, 2000

2.17 GUARD – A part outside of the enclosure that reduces access to a component involving a risk of injury to persons. See Enclosures and Guards, Section 34.

2.17 effective November 7, 2000

2.17A INTERCONNECTION SYSTEM EQUIPMENT (ISE) – A component or system of components that performs protective and control functions used to interconnect a distributed resource to an EPS.

2.17A added November 7, 2005

2.18 INVERTER – An electronic device that changes dc power to ac power.

2.18 effective November 7, 2000

2.19 ISLANDING PROTECTION – Protection against the continuous operation of the inverter and part of the utility load while isolated from the remainder of the electric utility system.

2.19 effective November 7, 2000

2.20 ISOLATED CIRCUIT – A circuit having an isolation transformer or isolating components such as optically or magnetically coupled devices.

2.20 effective November 7, 2000

2.21 ISOLATION TRANSFORMER – A transformer having its primary winding electrically isolated from its secondary winding and constructed so that there is no electrical connection – under normal and overload conditions – between the primary and secondary windings, between the primary winding and the core, or between separate adjacent secondary windings, where such connection results in a risk of fire or electric shock.

2.21 effective November 7, 2000

2.22 KNOCKOUT – A portion of the wall of an enclosure so fashioned that it is capable of being readily removed by a hammer, screwdriver, and pliers at the time of installation in order to provide an opening or hole for the attachment of an auxiliary device, raceway, cable, or fitting.

2.22 effective November 7, 2000

2.23 LIMITED-ENERGY (LE) CIRCUIT – An ac or dc circuit having a voltage not exceeding 1000 volts and the energy limited to 100 volt-amperes by:

a) The secondary winding of a transformer,

b) One or more resistors complying with 29.10, or

c) A regulating network complying with 29.11.

2.23 effective November 7, 2000

2.24 LIVE PART – An electrically conductive part within a unit that during intended use has a potential difference with respect to earth ground.

2.24 effective November 7, 2000

2.25 LOW-VOLTAGE, LIMITED-ENERGY (LVLE) CIRCUIT – A circuit involving an ac voltage of not more than 30 volts rms (42.4 volts peak) or a dc voltage of not more than 60 volts and supplied by:

a) An inherently limited Class 2 transformer or a not inherently limited Class 2 transformer and an overcurrent protective device that is:

1) Not of the automatic reclosing type,

2) Trip-free from the reclosing mechanism, and

3) Not readily interchangeable with a device of a different rating or the device is marked in accordance with 64.7.

b) A combination of an isolated transformer secondary winding and one or more resistors or a regulating network complying with 29.11 that complies with all the performance requirements for an inherently limited Class 2 transformer or power source; or

c) A battery that is isolated from the primary circuit or a combination of a battery, including the battery charging circuit of a unit that is isolated from the primary circuit, and one or more resistors or a regulating network complying with 29.11.

2.25 revised January 17, 2001

2.25A MANUFACTURER-SPECIFIED EXTERNAL ISOLATION TRANSFORMER – A manufacturer-specified isolation transformer that is external to the product, but which is always required for proper operation of the product. For example, when an isolation transformer is required to prevent circulating ground current in installations that have a grounded conductor in the ac or dc input power circuit.

2.25A added November 11, 2005

2.26 MAXIMUM SYSTEM VOLTAGE – The open-circuit voltage (Voc) of the photovoltaic module or panel multiplied by the temperature correction factor specified in Article 690.7 of the National Electrical Code, ANSI/NFPA 70 for crystalline and multi-crystalline silicon photovoltaic modules and panels. The maximum system voltage is equal to the Voc for amorphous silicate and thin film photovoltaic modules and panels.

2.26 revised January 17, 2001

2.27 OPEN-CIRCUIT VOLTAGE (Voc) – The maximum no load output voltage of a photovoltaic module or panel at standard test conditions (STC). See 2.39.

2.27 effective November 7, 2000

2.27A Deleted November 7, 2005

2.28 PERMANENTLY CONNECTED UNIT – A unit connected to the electrical supply by means other than a supply cord and an attachment plug.

2.28 effective November 7, 2000

2.29 PRESSURE TERMINAL CONNECTOR – A terminal that accomplishes the connection of one or more conductors by means of pressure without the use of solder. Examples of pressure terminal connectors are:

a) Barrel and setscrew type,

b) Crimp-type barrel, or

c) Clamping plate and screw type.

2.29 effective November 7, 2000

2.30 PRIMARY CIRCUIT – Wiring and components that are conductively connected to a branch circuit.

2.30 effective November 7, 2000

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2.31 PULSE-WIDTH MODULATED (PWM) CHARGING – A charge control method that enables the photovoltaic current to bring the battery voltage to constant voltage type regulation using pulse width modulated control by setting the voltage regulation reconnect (V_{rr}) setpoint photovoltaic array closer to the disconnect (V_r) using pulse-width-modulated control circuitry. Based on the rate of switching, the overall current is able to taper similar to the constant voltage type regulation.

2.31 effective November 7, 2000

2.32 RISK OF ELECTRICAL ENERGY- HIGH CURRENT LEVEL – The capability for damage to property or injury to persons, other than by electric shock, from available electrical energy existing between a live part and an adjacent dead metal part or between live parts of different polarity, where there is a potential of 2 volts or more and:

a) An available continuous power level of 240 volt-amperes or more, or

b) A reactive energy level of 20 joules or more.

For example, a tool, or other metal, short-circuiting a component that is able to result in a burn or a fire when enough energy is available at the component to vaporize, melt, or more than warm the metal.

2.32 effective November 7, 2000

2.33 SAFETY CIRCUIT – Any primary or secondary circuit that is used to reduce the risk of fire, electric shock, injury to persons, or electrical energy - high current levels. A safety interlock circuit, for example, is a safety circuit.

2.33 revised January 17, 2001

2.34 SAFETY INTERLOCK – A means relied upon to reduce the accessibility to an area that involves a risk of electric shock, electrical energy - high current levels, or injury to persons until the risk has been removed, or to automatically remove the risk when access is gained.

2.34 effective November 7, 2000

2.35 SECONDARY CIRCUIT – A circuit supplied from a secondary winding of an isolation transformer.

2.35 effective November 7, 2000

2.36 SERIES CHARGE CONTROLLER – A control element for battery charging that is in series with a photovoltaic array and a battery. The control element usually operates in an on/off mode, a pulse-width modulated (PWM) mode, or a linear control mode. The control element is usually a solid state switching device or a mechanical relay.

2.36 effective November 7, 2000

2.37 SERVICE PERSONNEL – Trained persons having familiarity with the construction and operation of the equipment and the risks involved.

2.37 effective November 7, 2000

2.38 STAND-ALONE INVERTER – An inverter intended to supply a load and does not provide power back to the electric utility.

2.38 effective November 7, 2000

2.39 STANDARD TEST CONDITIONS (STC) – Test conditions consisting of:

a) 100 mW/cm^2 irradiance,

b) AM 1.5 spectrum, and

c) 25°C (77°F) cell temperature.

2.39 effective November 7, 2000

2.40 TOOL – A screwdriver, coin, key, or any other object that is usable to operate a screw, latch, or similar fastening means.

2.40 effective November 7, 2000

2.40A TOTAL HARMONIC DISTORTION (THD)– The ratio of the root-mean-square (rms) of the harmonic content to the root-mean-square value of the fundamental quantity, expressed as a percentage.

THD = [(sum of squares of amplitudes of all harmonics)/(square of amplitude of fundamental)]$^{1/2}$X 100

2.40A added January 17, 2001

2.41 UTILITY-INTERACTIVE INVERTER – An inverter intended for use in parallel with an electric utility to supply common loads and sometimes deliver power to the utility.

2.41 effective November 7, 2000

2.42 VOLTAGE REGULATION (V_r) SETPOINT – The maximum battery voltage that a charge controller enables the battery to reach under charging conditioners. At this voltage the charge controller discontinues charging or begins to minimize the charging current to the battery.

2.42 effective November 7, 2000

2.43 VOLTAGE REGULATION RECONNECT (V_{rr}) SETPOINT – The battery voltage at which the charge controller reconnects the array to the battery when it has been disconnected at the V_r setpoint.

2.43 effective November 7, 2000

3 General

3.1 Components

3.1.1 Except as indicated in 3.1.2, a component of a product covered by this standard shall comply with the requirements for that component. See Appendix A for a list of standards covering components commonly used in the products covered by this Standard.

3.1.1 effective November 7, 2000

3.1.2 A component is not required to comply with a specific requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product covered by this standard, or

b) Is superseded by a requirement in this standard.

3.1.2 revised January 17, 2001

3.1.3 A component shall be used in accordance with its rating established for the intended conditions of use.

3.1.3 revised January 17, 2001

3.1.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

3.1.4 revised January 17, 2001

3.2 Units of measurement

3.2.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

3.2.1 revised January 17, 2001

3.3 References

3.3.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

3.3.1 revised January 17, 2001

CONSTRUCTION

4 General

Section 4 effective November 7, 2000

4.1 A unit intended to operate at rated voltages of 50 volts or less shall operate as intended in both grounded and ungrounded circuits.

4.2 Converters shall be subjected to all of the requirements for inverters.

4.2 added November 7, 2005

5 Frame and Enclosure

5.1 General

Section 5.1 effective November 7, 2000

5.1.1 A unit shall be provided with an enclosure that houses all current-carrying parts. The enclosure shall protect the various parts of the unit against mechanical damage from forces external to the unit. The parts of the enclosure that are required to be in place to comply with the requirements to reduce the risk of fire, electric shock, injury to persons shall comply with the applicable enclosure requirements specified in this Standard.

5.1.2 The frame or chassis of a unit shall not be relied upon to carry current during normal operation.

Exception: As provided in the Exception to 20.12.

5.1.3 A part, such as a dial or nameplate that is a part of the enclosure shall comply with the enclosure requirements.

5.1.4 An enclosure other than a Type 1 (indoor use only) shall comply with Environmental Rated Enclosures, Section 5.9, or the requirements for the respective Type in the Standard for Enclosures for Electrical Equipment, UL 50.

5.1.5 Sheet-metal screws threading directly into metal shall not be used to attach a cover, door, or other part that is to be removed to install field wiring or for operation of the equipment. Machine screws, self-tapping machine screws, and thread forming screws are able to thread directly into sheet-metal when they allow for at least two full threads of screw engagement.

Revised 5.1.5 effective May 7, 2007

5.1.6 Sheet-metal screws mounting internal components that are not removed for installation or operation are able to thread directly into metal.

5.2 Access covers

Section 5.2 effective November 7, 2000

5.2.1 For a unit used as a load center, a cover that gives access to a fuse or other overload-protective device, the functioning of which requires renewal shall be hinged. A hinged cover is also required for a unit when it is required to open the cover in connection with normal operation of the unit. The cover shall not depend solely upon screws or other similar means requiring the use of a tool to hold it closed; however, it shall be provided with a spring latch or catch, or a hand operable captive fastener. Live parts shall not be accessible when the cover is open.

Exception No. 1: A cover is not required to be provided with a hinge when the only overload-protective devices enclosed are:

> *a) Supplementary types in control circuits and the protective device and the circuit loads are within the same enclosure,*
>
> *b) Supplementary types rated 2 amperes or less for loads not exceeding 100 volt-amperes,*
>
> *c) Extractor fuses having an integral enclosure, or*
>
> *d) Protective devices connected in a low-voltage, limited-energy (LVLE) circuit.*

Exception No. 2: A cover is not required to be provided with a hinge for an enclosure that contains no user-serviceable or -operable parts and which is provided with a marking in accordance with 64.6.

5.2.2 With reference to 5.2.1, a door or cover giving access to a fuse shall comply with the requirements for doors and covers, in the Standard for Industrial Control Equipment, UL 508.

5.3 Cast metal enclosures

Section 5.3 effective November 7, 2000

5.3.1 The thickness of cast metal for an enclosure shall not be less than indicated in Table 5.1.

Exception: Cast metal of lesser thickness is usable where the enclosure complies with Compression Test, Section 60.

Table 5.1
Thickness of cast-metal enclosures

Use, or dimension of area involved	Minimum thickness, mm (inch)			
	Die-cast metal		Cast metal other than die-cast type	
Area of 154.8 cm^2(24 in^2) or less and having no dimension greater than 152 mm (6 inches)	1.6[a]	(1/16)	3.2	(1/8)
Area greater than 154.8 cm^2(24 in^2) or having any dimension greater than 152 mm (6 inches)	2.4	(3/32)	3.2	(1/8)
At a threaded conduit hole	6.4	(1/4)	6.4	(1/4)
At an unthreaded conduit hole	3.2	(1/8)	3.2	(1/8)

[a] The area limitations for metal 1.6 mm (1/16 inch) thick are attainable by the provision of reinforcing ribs subdividing a larger area.

5.4 Sheet metal enclosures

5.4.1 The thickness of a sheet-metal enclosure shall not be less than that specified in Tables 5.2 and 5.3; however, uncoated steel shall not be less than 0.81 mm (0.032 inch) thick, zinc-coated steel shall not be less than 0.86 mm (0.034 inch) thick, and nonferrous metal shall not be less than 1.14 mm (0.045 inch) thick at points at which a wiring system is to be connected.

Exception: Sheet metal of lesser thickness is usable where the enclosure complies with Compression Test, Section 60.

5.4.1 effective November 7, 2000

5.4.2 *Deleted January 17, 2001*

5.4.3 With reference to Tables 5.2 and 5.3, a supporting frame is a structure consisting of angles, channels, or folded rigid sections of sheet metal that is rigidly attached to and has similar outside dimensions as the enclosure surface and that has the torsional rigidity to resist the bending moments that result when the enclosure surface is deflected. A construction that has equivalent reinforcing is one that is as rigid as one built with a frame of angles or channels.

5.4.3 effective November 7, 2000

Table 5.2
Thickness of sheet metal for enclosures, carbon steel or stainless steel

Table 5.2 effective November 7, 2000

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness, mm (inch)			
Maximum width,[b]		Maximum length,[c]		Maximum width,[b]		Maximum length,[c]		Uncoated		Coated	
cm	(inch)	cm	(inch)	cm	(inch)	cm	(inch)				
10.2	(4.0)	Not limited		15.9	(6.25)	Not limited		0.51[d]	(0.020)	0.58[d]	(0.023)
12.1	(4.75)	14.6	(5.75)	17.1	(6.75)	21.0	(8.25)				
15.2	(6.0)	Not limited		24.1	(9.5)	Not limited		0.66[d]	(0.026)	0.74[d]	(0.029)
17.8	(7.0)	22.2	(8.75)	25.4	(10.0)	31.8	(12.5				
20.3	(8.0)	Not limited		30.5	(12.0)	Not limited		0.81	(0.032)	0.86	(0.034)
22.9	(9.0)	29.2	(11.5)	33.0	(13.0)	40.6	(16.0)				
31.8	(12.5	Not limited		49.5	(19.5)	Not limited		1.07	(0.042)	1.14	(0.045)
35.6	(14.0	45.7	(18.0)	53.3	(21.0)	63.5	(25.0)				
45.7	(18.0)	Not limited		68.6	(27.0)	Not limited		1.35	(0.053)	1.42	(0.056)
50.8	(20.0)	63.5	(25.0)	73.7	(29.0)	91.4	(36.0)				
55.9	(22.0)	Not limited		83.8	(33.0)	Not limited		1.52	(0.060)	1.60	(0.063)
63.5	(25.0)	78.7	(31.0)	88.9	(35.0)	109.2	(43.0)				
63.5	(25.0)	Not limited		99.1	(39.0)	Not limited		1.70	(0.067)	1.78	(0.070)
73.7	(29.0)	91.4	(36.0)	104.1	(41.0)	129.5	(51.0)				
83.8	(33.0)	Not limited		129.5	(51.0)	Not limited		2.03	(0.080)	2.13	(0.084)
103.4	(38.00	119.4	(47.0)	137.2	(54.0)	167.6	(66.0)				
106.7	(42.0)	Not limited		162.6	(64.0)	Not limited		2.36	(0.093)	2.46	(0.097)
119.4	(47.0)	149.9	(59.0)	172.7	(68.0)	213.4	(84.0)				
132.1	(52.0)	Not limited		203.2	(80.0)	Not limited		2.74	(0.108)	2.82	(0.111)
152.4	(60.0)	188.0	(74.0)	213.4	(84.0)	261.6	(103.0)				
160.0	(63.0)	Not limited		246.4	(97.0)	Not limited		3.12	(0.123)	3.20	(0.126)
185.4	(73.0)	228.6	(90.0)	261.6	(103.0)	322.6	(127.0)				

[a] See 5.4.3 and 5.4.4.

[b] The width is the smaller dimension of a rectangular sheet metal piece that is part of an enclosure. In some cases, adjacent surfaces of an enclosure have supports in common and are made of a single sheet.

[c] "Not limited" applies only where the edge of the surface is flanged at least 12.7 mm (1/2 inch) or fastened to adjacent surfaces not normally removed in use.

[d] Sheet steel for an enclosure intended for outdoor use shall not be less than 0.86 mm (0.034 inch) thick for coated metal and not less than 0.81 mm (0.032 inch) thick for uncoated metal.

Table 5.3
Thickness of sheet metal for enclosures, aluminum, copper, or brass

Table 5.3 effective November 7, 2000

Without supporting frame[a]				With supporting frame or equivalent Reinforcing[a]					
Maximum width[b], cm	(inch)	Maximum length[c], cm	(inch)	Maximum width[b], cm	(inch)	Maximum length[c], cm	(inch)	Minimum thickness, mm	(inch)
7.6	(3.0)	Not limited		17.8	(7.0)	Not limited		0.58[d]	(0.023)
8.9	(3.5)	10.2	(4.0)	21.6	(8.5)	24.1	(9.5)		
10.2	(4.0)	Not limited		25.4	(10.0)	Not limited		0.74	(0.029)
12.7	(5.0)	15.2	(6.0)	26.7	(10.5)	34.3	(13.5)		
15.2	(6.0)	Not limited		35.6	(14.0)	Not limited		0.91	(0.036)
16.5	(6.5)	20.3	(8.0)	38.1	(15.0)	45.7	(18.0)		
20.3	(8.0)	Not limited		48.3	(19.0)	Not limited		1.14	(0.045)
24.1	(9.5)	29.2	(11.5)	53.3	(21.0)	63.5	(25.0)		
30.5	(12.0)	Not limited		71.1	(28.0)	Not limited		1.47	(0.058)
35.6	(14.0)	40.6	(16.0)	76.2	(30.0)	94.0	(37.0)		
45.7	(18.0)	Not limited		106.7	(42.0)	Not limited		1.91	(0.075)
50.8	(20.0)	63.5	(25.0)	114.3	(45.0)	139.7	(55.0)		
63.5	(25.0)	Not limited		152.4	(60.0)	Not limited		2.41	(0.095)
73.7	(29.0)	91.4	(36.0)	162.6	(64.0)	198.1	(78.0)		
94.0	(37.0)	Not limited		221.0	(87.0)	Not limited		3.10	(0.122)
106.7	(42.0)	134.6	(53.0)	236.2	(93.0)	289.6	(114.0)		
132.1	(52.0)	Not limited		312.4	(123.0)	Not limited		3.89	(0.152)
152.4	(60.0)	188.0	(74.0)	330.2	(130.0)	406.4	(160.0)		

[a] See 5.4.3 and 5.4.4.

[b] The width is the smaller dimension of a rectangular sheet metal piece that is part of an enclosure. In some cases, adjacent surfaces of an enclosure have supports in common and are made of a single sheet.

[c] "Not limited" applies only where the edge of the surface is flanged at least 12.7 mm (1/2 inch) or fastened to adjacent surfaces not normally removed in use.

[d] Sheet copper, brass, or aluminum for an enclosure intended for outdoor use shall not be less than 0.74 mm (0.029 inch) thick.

5.4.4 With reference to 5.4.3 and Tables 5.2 and 5.3, a construction does not have a supporting frame when it is:

a) An enclosure formed or fabricated from sheet metal,

b) A single sheet with single formed flanges or formed edges,

c) A single sheet that is corrugated or ribbed, or

d) An enclosure surface loosely attached to a frame, for example, by spring clips.

5.4.4 effective November 7, 2000

5.5 Nonmetallic enclosures

5.5.1 A polymeric enclosure or polymeric part of an enclosure shall comply with the requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C. See 5.5.3.

Exception: A polymeric enclosure which complies with the Standard for Enclosures for Electrical Equipment, UL 50, is not required to be investigated for compliance with UL 746C.

5.5.1 effective November 7, 2000

5.5.2 Where an electrical instrument, such as a meter, forms part of the enclosure, the face or the back of the instrument housing, or both together, shall comply with the requirements for an enclosure.

Exception: A meter complying with the Standard for Electrical Analog Instruments – Panelboard Type, UL 1437, complies with this requirement.

5.5.2 effective November 7, 2000

5.5.3 The requirement in 5.5.1 does not apply to a nonmetallic part that forms part of the enclosure under any one of the following conditions:

a) The part covers an opening that has no dimension greater than 25.4 mm (1 inch) and the part is made of a material Classed as V-0, V-1, V-2, or HB, in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94,

b) The part is made of a material Classed V-0, V-1, V-2, or HB and covers an opening which does not give access to the user, when the part is removed, to live parts involving a risk of fire, electric shock, or electric energy - high current levels or moving parts.

c) The part covers an opening that has no dimension greater than 101.6 mm (4 inches) and the part is made of a material Classed as V-0, V-1, V-2, or HB, and there is no source of a risk of fire closer than 4 inches from the surface of the enclosure, or

d) The part is made of a material Classed V-0, V-1, V-2, or HB and there is a barrier or a device that forms a barrier made of a material Classed V-0 between the part and a source of a risk of fire.

Exception: A part of a component is not required to be Classed V-0, V-1, V-2, or HB when it complies with the flammability requirements applicable to the component. See Components, Section 3.1.

5.5.3 revised January 17, 2001

5.5.4 A nonmetallic enclosure intended for connection to a rigid conduit system shall comply with the Polymeric Enclosure Rigid Metallic Conduit Connection Tests in the Standard for Enclosures for Electrical Equipment, UL 50.

5.5.4 effective November 7, 2000

5.6 Openings covered by glass

Section 5.6 effective November 7, 2000

5.6.1 Glass covering an opening shall comply with 5.6.2, shall be secured in place so that it is not readily displaced in service, and shall provide mechanical protection for the enclosed parts.

5.6.2 Glass for an opening:

a) Not more than 102 mm (4 inches) in any dimension shall not be less than 1.6 mm (1/16 inch) thick,

b) Glass for an opening other than described in (a) and not more than 929 cm^2(144 square inches) in area and having no dimension greater than 305 mm (12 inches), shall not be less than 3.2 mm (1/8 inch) thick, and

c) Glass used to cover an area greater than described in (b) shall not be less than 3.2 mm thick and:

1) Shall be of a nonshattering or tempered type that, when broken, complies with the Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1984 (R1994), or

2) Shall withstand a 3.38 joules (2-1/2 ft-lbf) impact from a 50.8-mm (2-inch) diameter, 535 gram (1.18 pound) steel sphere without cracking or breaking to the extent that a piece is dislodged from its normal position.

5.7 Openings for wiring system connections

Section 5.7 effective November 7, 2000

5.7.1 Where threads for the connection of conduit are tapped all the way through a hole in an enclosure wall, or where an equivalent construction is employed, there shall not be less than three, or more than five threads in the metal; and the construction of the enclosure shall be such that a conduit bushing is attachable as intended. Where threads for the connection of conduit are not tapped all the way through a hole in an enclosure wall, conduit hub, or a similar component; there shall not be less than 3-1/2 threads in the metal, and there shall be a smooth, rounded inlet hole for the conductors equivalent to that provided by a standard conduit bushing and the hole shall have an internal diameter that corresponds with the applicable trade size of rigid conduit.

5.7.2 Clamps and fasteners for the attachment of conduit, electrical metallic tubing, armored cable, nonmetallic flexible tubing, nonmetallic-sheathed cable, service cable, or equivalent, that are supplied as a part of an enclosure shall comply with the Standard for Fittings for Conduit and Outlet Boxes, UL 514B.

5.7.3 A knockout in a sheet-metal enclosure shall be secured and shall be removable without undue deformation of the enclosure.

5.7.4 A knockout shall be provided with a flat surrounding surface so a conduit bushing of the corresponding size seats as intended. A knockout intended to be used for installation purposes, shall be located so that installation of a bushing does not result in spacings between uninsulated live parts and the bushing of less than required in Spacings, Section 24.

5.7.5 In measuring a spacing between an uninsulated live part and a bushing installed in a knockout as specified in 5.7.4, it is to be assumed that a bushing having the dimensions specified in Table 5.4 is in place, in conjunction with a single locknut installed on the outside of the enclosure.

Table 5.4
Knockout or hole sizes and dimensions of bushings

Trade size of conduit, Inch	Knockout or hole diameter		Bushing dimensions			
			Overall diameter		Height	
	mm	(inch)	mm	(inch)	mm	(inch)
1/2	22.2	(7/8)	25.4	(1)	9.5	(3/8)
3/4	27.8	(1-3/32)	31.4	(1-15/64)	10.7	(27/64)
1	34.5	(1-23/64)	40.5	(1-19/32)	13.1	(33/64)
1-1/4	43.7	(1-23/32)	49.2	(1-15/16)	14.3	(9/16)
1-1/2	50.0	(1-31/32)	56.0	(2-13/64)	15.1	(19/32)
2	62.7	(2-15/32)	68.7	(2-45/64)	15.9	(5/8)
2-1/2	76.2	(3)	81.8	(3-7/32)	19.1	(3/4)
3	92.1	(3-5/8)	98.4	(3-7/8)	20.6	(13/16)
3-1/2	104.8	(4-1/8)	112.7	(4-7/16)	23.8	(15/16)
4	117.5	(4-5/8)	126.2	(4-31/32)	25.4	(1)
4-1/2	130.2	(5-1/8)	140.9	(5-35/64)	27.0	(1-1/16)
5	142.9	(5-5/8)	158.0	(6-7/32)	30.2	(1-3/16)
6	171.5	(6-3/4)	183.4	(7-7/32)	31.8	(1-1/4)

5.7.6 For an enclosure not provided from the factory with conduit openings or knockouts, spacings not less than the minimum required in this Standard shall be provided between uninsulated live parts and a conduit bushing installed at any location on the enclosure. Permanent marking on the enclosure, a template, or a full-scale drawing furnished with the unit is usable to limit such a location.

5.7.7 A plate or plug for an unused conduit opening or other hole in the enclosure shall have a thickness not less than:

a) 0.36 mm (0.014 inch) for steel or 0.48 mm (0.019 inch) for nonferrous metal for a hole having a 6.4-mm (1/4-inch) maximum dimension, and

b) 0.69-mm (0.027-inch) steel or 0.81-mm (0.032-inch) nonferrous metal for a hole having a 34.9-mm (1-3/8-inch) maximum dimension.

A closure for a larger hole shall have a thickness equal to that required for the enclosure of the unit or a standard knockout seal shall be used. Such plates or plugs shall be securely mounted.

5.7.8 An opening in an environmental rated enclosure shall be closed with components having the applicable environmental ratings as specified in Table 5.5.

Table 5.5
Openings in environmental rated enclosures

Enclosure Type	Openings shall be closed by components rated for enclosure types
2	2, 3, 3R, 3S, 4, 4X, 6, 6P, 12, 12K, 13
3	3S, 4, 4X, 6, 6P
3R	3, 3S, 4, 4X, 6, 6P
3S	3, 4, 4X, 6, 6P
4	4, 4X, 6, 6P
4X	4X
6	6, 6P
6P	6P
12, 12K	12, 12K, 13
13	13

5.8 Openings for ventilation

Section 5.8 effective November 7, 2000

5.8.1 General

5.8.1.1 The enclosure of a unit shall be constructed to protect the unit against the emission of flame, molten metal, flaming or glowing particles, or flaming drops from the enclosure.

5.8.2 Ventilation openings in enclosure bottoms

5.8.2.1 The requirement in 5.8.1.1 necessitates a complete noncombustible bottom or a construction employing individual noncombustible barriers as specified in Figure 5.1, under components, groups of components, or assemblies.

Exception No. 1: Ventilation openings provided in the bottom of an enclosure meet the intent of the requirement where noncombustible baffle plates are provided to obstruct or deflect materials from falling directly from the interior of the unit onto the supporting surface or other locations under the unit. An example of a baffle that meets the intent of this requirement is illustrated in Figure 5.2.

Exception No. 2: Ventilation openings provided in the bottom of an enclosure meet the intent of the requirement where the openings are covered by a perforated metal plate as described in Table 5.6, or where a galvanized or stainless steel screen having a 14- by 14-mesh per 25.4 mm (1 inch) constructed of wire with a diameter of 0.5 mm (0.018 inch) minimum is used.

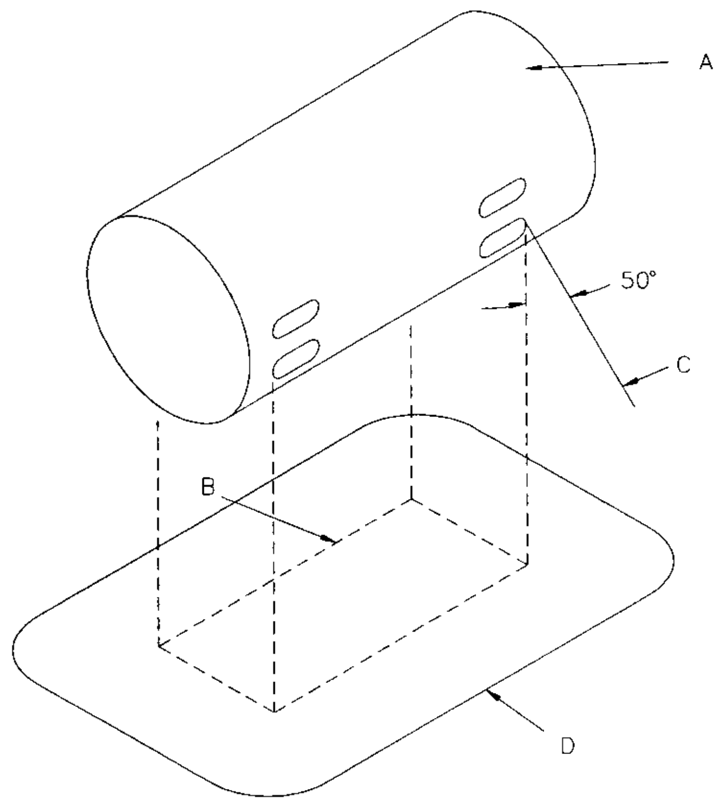
Exception No. 3: The bottom of the enclosure under areas containing only materials Classed V-1 or better in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, are able to have openings no larger than 6.4 mm (1/4 inch) square. Openings that are not square shall not have an area greater than 40 mm^2 (1/16 square inch).

Exception No. 4: Ventilation openings without limitation on their size and number that comply with 9.7 meet the intent of the requirement where the openings are only in the bottom panel in areas:

- *a) That contain only wires, cables, plugs, receptacles, and transformers, and*
- *b) In areas that contain low-voltage, limited-energy (LVLE) circuits.*

Exception No. 5: Ventilation openings are provided in the bottom of an enclosure meet the intent of the requirement where the openings incorporate an expanded metal mesh as described in 5.8.5.

Figure 5.1
Baffle plates



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NOTES –

A. The entire component under which a barrier (flat or dished with or without a lip or other raised edge) of noncombustible material is to be provided. The sketch (Figure 5.1) is of an enclosed component with ventilation openings showing that the protective barrier is required only for those openings through which flaming parts are able to be emitted. When the component or assembly does not have its own noncombustible enclosure, the area to be protected is the entire area occupied by the component or assembly.

B. Projection of the outline of the area of A that requires a bottom barrier vertically downward onto the horizontal plane of the lowest point on the outer edge D of the barrier.

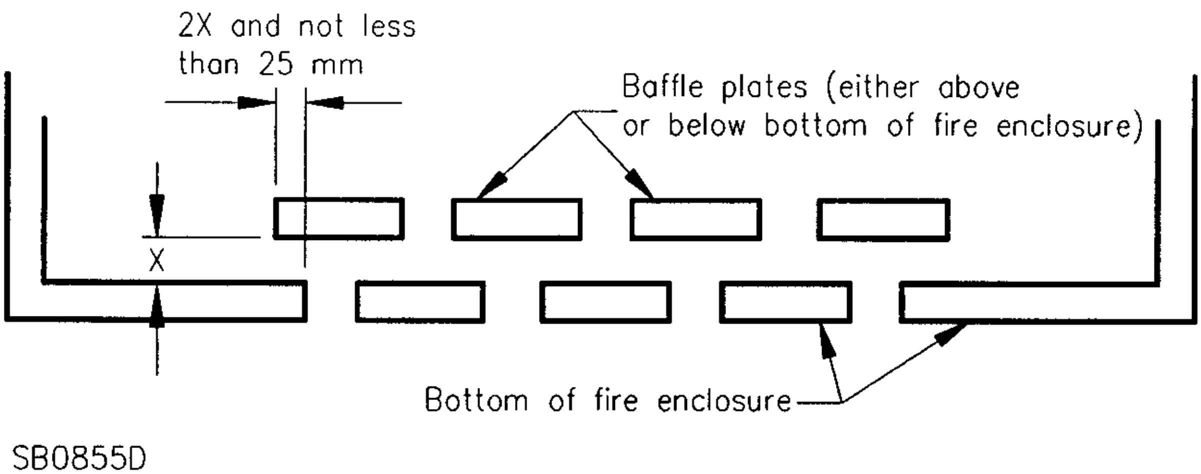
C. Inclined line that traces out an area D on the horizontal plane of the barrier. Moving around the perimeter of the area B that requires a bottom barrier, this line projects at a 50-degree angle from the line extending vertically at every point around the perimeter of A and is oriented to trace out the largest area; however, an angle less than 50 degrees complies where the barrier or portion of the bottom cover contacts a vertical barrier or side panel of noncombustible material, or where the horizontal extension of the barrier B to D exceeds 152 mm (6 inches).

D. Minimum outline of the barrier; however, the extension B to D is not required to exceed 152 mm (6 inches) (flat or dished with or without a lip or other raised edge). The bottom of the barrier is able to be flat or formed in any manner where every point of area D is at or below the lowest point on the outer edge of the barrier.

Table 5.6
Perforated metal plates for enclosure bottom

Minimum thickness, mm	(inch)	Maximum diameter of holes, mm	(inch)	Minimum spacings of holes center to center, mm	(inch)
0.66	(0.026)	1.14	(0.045)	1.70	(0.067), or
				233 holes per 645 mm^2(1 $inch^2$)	
0.66	(0.026)	1.19	(0.047)	2.36	(0.093)
0.76	(0.030)	1.14	(0.045)	1.70	(0.067)
0.76	(0.030)	1.19	(0.047)	2.36	(0.093)
0.81	(0.032)	1.91	(0.075)	3.18	(0.125), or
				72 holes per 645 mm^2(1 $inch^2$)	
0.89	(0.035)	1.90	(0.075)	3.18	(0.125)
0.91	(0.036)	1.60	(0.063)	2.77	(0.109)
0.91	(0.036)	1.98	(0.078)	3.18	(0.125)
0.99	(0.039)	1.60	(0.063)	2.77	(0.109)
0.99	(0.039)	2.00	(0.079)	3.00	(0.118)

Figure 5.2
Example of baffle overlap



5.8.3 Openings in enclosure tops

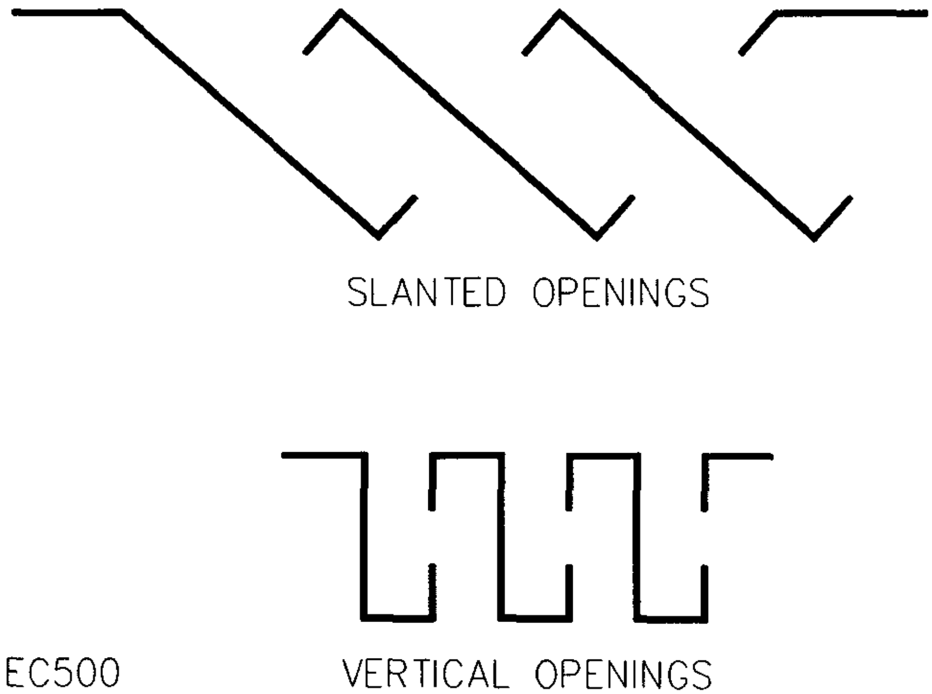
5.8.3.1 Openings in the top of an enclosure shall be located and sized to protect against the entry of foreign objects. Openings directly over uninsulated live parts:

a) Shall not exceed 4.7 mm (0.187 inch) in any dimension,

b) Be configured as illustrated in Figure 5.3, or

c) Be constructed to provide equivalent protection against the entry of foreign objects.

Figure 5.3
Cross sections of top-cover design



5.8.4 Openings in enclosure sides

5.8.4.1 A louver shall not be more than 305 mm (12 inches) long.

5.8.4.2 The area of an opening covered by louvers, perforated sheet steel, or by expanded-metal mesh that is thinner than the enclosure shall not exceed 0.129 m^2(200 square inches).

5.8.5 Expanded metal mesh and screens

5.8.5.1 The thickness of perforated sheet steel and sheet steel employed for expanded-metal mesh used to cover an opening in the enclosure shall comply with of Table 5.7.

Exception: Thicknesses less than specified in Table 5.7, and not less than specified in Table 5.8 meet the intent of the requirement where:

a) The indentation of the material does not adversely affect performance or reduce spacings to live parts below the minimum values specified in Spacings, Section 24, or Alternate Spacings-Clearances and Creepage Distances, Section 25, and

b) The opening has an area of not more than 464.5 cm^2 (72 in^2) and no dimension greater than 304.8 mm (12 inches), or

c) The width of the opening is not greater than 88.9 mm (3-1/2 inches).

Table 5.7
Minimum thickness of expanded metal mesh

Opening area	Uncoated, mm	(inch)	Zinc coated, mm (inch) mm	(inch)
Maximum 323 mm^2 (0.5 in^2) or less	1.07	(0.042)	1.14	(0.045)
More than 323 mm^2 (0.5 in^2)	2.03	(0.080)	2.13	(0.084)

Table 5.8
Minimum thickness of expanded metal mesh

Uncoated, mm	(inch)	Zinc coated, mm	(inch)
0.51	(0.020)	0.61	(0.024)

5.8.5.2 The diameter of the wires of a screen shall not be less than 1.30 mm (0.051 inch) where the screen openings are 323 mm^2 (0.5 in^2) or less in area, and not less than 2.06 mm (0.081 inch) for larger screen openings.

5.8.6 Barriers used with ventilation openings

5.8.6.1 Unless a ventilation opening is located at least 305 mm (12 inches) from an arcing part, such as a switch, fuse, circuit breaker or a similar source, a barrier shall be placed between the ventilation opening and the source of arcing.

5.8.6.2 The barrier shall be of such dimensions and so located that any straight line drawn from an arcing part past the edge of the barrier intersects a point in the ventilation opening plane that is at least 6.4 mm (0.25 inch) outside of the edge of the ventilation opening.

5.8.6.3 A sheet-metal barrier shall not be less than 1.35 mm (0.053 inch) thick when uncoated steel, 1.42 mm (0.056 inch) thick when zinc-coated, or 1.19 mm (0.075 inch) thick when aluminum.

Exception: A metal barrier of thinner material meets the intent of the requirement when its strength and rigidity are not less than that of flat sheet steel having the same dimensions of the barrier and having the specified thickness.

5.9 Environmental rated enclosures

5.9.1 An enclosure shall comply with the construction requirements applicable to an enclosure of the Type number or numbers with which it is marked.

5.9.1 effective November 7, 2000

5.9.2 An environmental type connection, such as a watertight connection at a conduit entrance, shall be a conduit hub or the equivalent, such as a knockout or fitting, located so that when conduit is connected and the enclosure is mounted in the intended manner, the enclosure complies with the tests specified in the Enclosure Types Table, in the Standard for Enclosures for Electrical Equipment, UL 50.

5.9.2 effective November 7, 2000

5.9.3 Type 3, 3R, and 3S enclosures shall comply with the Rain and Sprinkler Tests, Section 61.

5.9.3 effective November 7, 2000

5.9.4 A Type 2 enclosure shall have provision for drainage of water and shall have a threaded conduit hub or the equivalent for the connection of conduit in the top or sidewalls.

Exception No. 1: A threaded conduit hub or the equivalent is not required where the conduit connection opening is wholly below the lowest terminal lug or other live part within the enclosure. See 63.32.

Exception No. 2: A conduit hub or fitting is not required when information is provided in accordance with 63.30.

5.9.4 effective November 7, 2000

5.9.5 A Type 3 enclosure shall have:

a) A threaded conduit hub or the equivalent for a watertight connection at conduit entrances – see 5.9.2,

b) A mounting means external to the equipment cavity, and

c) Provision for locking a door, when a door is provided.

Exception: A conduit hub or fitting is not required when information is provided in accordance with 63.30.

5.9.5 effective November 7, 2000

5.9.6 A Type 3R enclosure shall have:

a) A threaded conduit hub or the equivalent for a watertight connection at conduit entrances – see 5.9.2,

b) Provision for drainage of water, and

c) Provision for locking a door, when a door is provided.

Exception No. 1: A threaded conduit hub or the equivalent is not required where the conduit connection opening is wholly below the lowest terminal lug or other live part intended for use within the enclosure. See 63.32.

Exception No. 2: A conduit hub or fitting is not required when information is provided in accordance with 63.30.

5.9.6 effective November 7, 2000

5.9.7 A Type 3S enclosure shall have:

a) A threaded conduit hub or the equivalent for a watertight connection at conduit entrances – see 5.9.2,

b) A mounting means external to the equipment cavity,

c) Provision for locking a door, when a door is provided, and

d) Operating mechanisms that support the additional weight of ice and that withstand the removal of ice by means of a hand tool used to gain access to the interior of the enclosure when ice is present. Auxiliary means are able to be provided to break the ice and to enable operation of external mechanisms.

Exception: A conduit hub or fitting is not required when information is provided in accordance with 63.30.

5.9.7 effective November 7, 2000

5.9.8 A Type 4, 4X, 6, 6P, or 11 enclosure shall have a conduit hub or the equivalent mounted in place to provide a watertight connection at conduit entrances and shall have mounting means external to the equipment cavity – see 5.9.2.

Exception No. 1: The watertight conduit connection is not required to be mounted in place when information is provided in accordance with 65.2.4.

Exception No. 2: A hub or a fitting is not required to be provided or installed on a Type 4 or 4X enclosure when instructions are provided as specified in 65.2.6.

5.9.8 revised January 17, 2001

5.9.9 A Type 12 enclosure shall have no conduit knockout or conduit opening and no hole through the enclosure other than a hole for a Type 12 mechanism, or the equivalent. A gasket, when provided, shall be oil resistant.

Exception: A Type 12 enclosure is able to employ a conduit opening when the enclosure is marked in accordance with 63.34.

5.9.9 effective November 7, 2000

5.9.10 A Type 12K enclosure is to be as specified in 5.9.9, unless it has knockouts located in the top or bottom walls, or both.

5.9.10 effective November 7, 2000

5.9.11 A Type 13 enclosure shall have oil-resistant gaskets and, when intended for wall or machine mounting, shall have a mounting means external to the equipment cavity. There shall be no conduit knockout or unsealed opening providing access to the equipment cavity. All conduit openings shall have provisions for oiltight connections.

5.9.11 effective November 7, 2000

5.9.12 A gasket of an elastomeric or thermoplastic material or a composition gasket utilizing an elastomeric material employed to comply with the requirements for a Type 2, 3, 3R, 3S, 4, 4X, 6, 6P, 11, 12, 12K, or 13 enclosure shall comply with the Gasket Tests, Section 43, in the Standard for Enclosures for Electrical Equipment, UL 50.

5.9.12 effective November 7, 2000

5.9.13 When a component, such as a pilot light, a disconnect, a pushbutton, or similar component, intended for use with a Type designated environmental enclosure is used with a specific Type enclosure, it shall meet the following:

a) The component has been evaluated for its intended use installed on a representative enclosure.

b) All hardware, gaskets, or other parts required to complete the installation are provided with the component.

Exception: Hardware, gaskets, or other parts are not required to be provided with the component when they are available from the component manufacturer in the form of a kit and are marked or rated for the application.

c) Installation instructions including such information as mounting hole location, opening configuration, and similar information, are provided on the component, in the component package, or on a stuffer sheet.

d) The component, its carton, or accompanying instruction sheet shall be marked or rated for use on a flat surface of the specific type enclosure in the construction.

5.9.13 effective November 7, 2000

5.9.14 A drain hole shall be provided on all units to prevent the accumulation of water above a level that results in the wetting of an electrical part or opening for the connection of conduit or for an auxiliary part under all mounting orientations specified by the installation instructions. The hole shall be as specified in Table 5.9.

Exception: A unit that has been subjected to the Rain and Sprinkler Tests, Section 61, is not required to be provided with a drain hole where no water enters the fixture.

5.9.14 effective November 7, 2000

Table 5.9
Size of drain holes
Table 5.9 effective November 7, 2000

Opening shape	Minimum dimension		Minimum area		Maximum dimension		Maximum area	
	mm	(inch)	mm^2	($inch^2$)	mm	(inch)	cm^2	($inches^2$)
Slot	3.2 (width)	(1/8)	7.74	(0.012)	9.6 (width)	(3/8)	9.68	(1-1/2)
Square	3.2 (side)	(1/8)	–		12.7 (side)	(1/2)	–	
Round	3.2 (diameter)	(1/8)	–		12.7 (diameter)	(1/2)	–	
Irregular	–		7.74	(0.012)	–		9.68	(1-1/2)

6 Protection Against Corrosion

Section 6 effective November 7, 2000

6.1 Iron and steel parts shall be protected against corrosion by enameling, galvanizing, plating, or other equivalent means. This applies to all springs and other parts which are relied upon for the intended mechanical operation.

Exception No. 1: Parts such as bearings and thermal elements for which such protection is impracticable.

Exception No. 2: Small minor parts of iron or steel such as washers, screws, or bolts that are not current-carrying and are not in the equipment grounding conductor path, when corrosion of such unprotected parts does not result in a risk of fire, electric shock, or injury to persons.

Exception No. 3: Parts made of stainless steel.

7 Mechanical Assembly

Section 7 effective November 7, 2000

7.1 A unit shall be assembled so that it is not adversely affected by the vibration of normal operation.

7.2 A switch, a fuseholder, or a lampholder shall be securely mounted and shall be prevented from turning or shifting in its mounting panel.

Exception: The requirement that a switch be prevented from turning or shifting does not apply where:

a) The switch is a plunger, slide, or other type that does not rotate when operated. A toggle switch is subjected to forces that tend to turn the switch during normal operation of the switch,

b) Means for mounting the switch prevents the switch from loosening during operation,

c) Spacings are not reduced below the minimum specified in Spacings, Section 24, or Alternate Spacings-Clearances and Creepage Distances, Section 25, when the switch rotates, and

d) Normal operation of the switch is by mechanical means rather than by direct contact by persons.

7.3 With reference to 7.2, friction between surfaces shall not be the sole means to prevent shifting or turning of live parts for a device having a single-hole mounting means. An additional means such as a lock washer applied as intended shall be used.

8 Mounting

Section 8 effective November 7, 2000

8.1 Provision shall be made for securely mounting a unit in position. Bolts, screws, or other parts used for mounting a unit shall be independent of those used for securing components to the frame, base, or panel.

Exception: A provision for mounting is not required for a floor supported or freestanding unit. See Stability, Section 58.

8.2 A keyhole slot for a mounting screw shall be provided with at least one round hole for accommodation of a permanent mounting screw. A keyhole slot shall be arranged so that a wall-mounting screw does not project into a compartment containing electrical parts and reduce spacings to less than those specified in Spacings, Section 24, or Alternate Spacings – Clearances and Creepage Distances, Section 25.

8.3 A unit shall not be provided with casters unless the casters are used solely for transporting the unit and the unit is provided with four leveling feet that are intended to be lowered after the unit is installed or the unit is provided with an equivalent means for securing the unit in position.

9 Protection of Users – Accessibility of Uninsulated Live Parts

Section 9 effective November 7, 2000

9.1 The requirements in this Section apply to a part that is accessible to the user. For protection of service personnel, see Protection of Service Personnel, Section 10.

9.2 To reduce the potential for unintentional contact that involves a risk of electric shock from an uninsulated live part or film-coated wire; electrical energy - high current levels; or injury to persons from a moving part; an opening in an enclosure shall comply with (a) or (b):

a) For an opening that has a minor dimension (see 9.5) less than 25.4 mm (1 inch), the part or wire shall not be contacted by the probe illustrated in Figure 9.1.

b) For an opening that has a minor dimension of 25.4 mm (1 inch) or more, the part or wire shall be spaced from the opening as specified in Table 9.1.

Figure 9.1
Accessibility probe

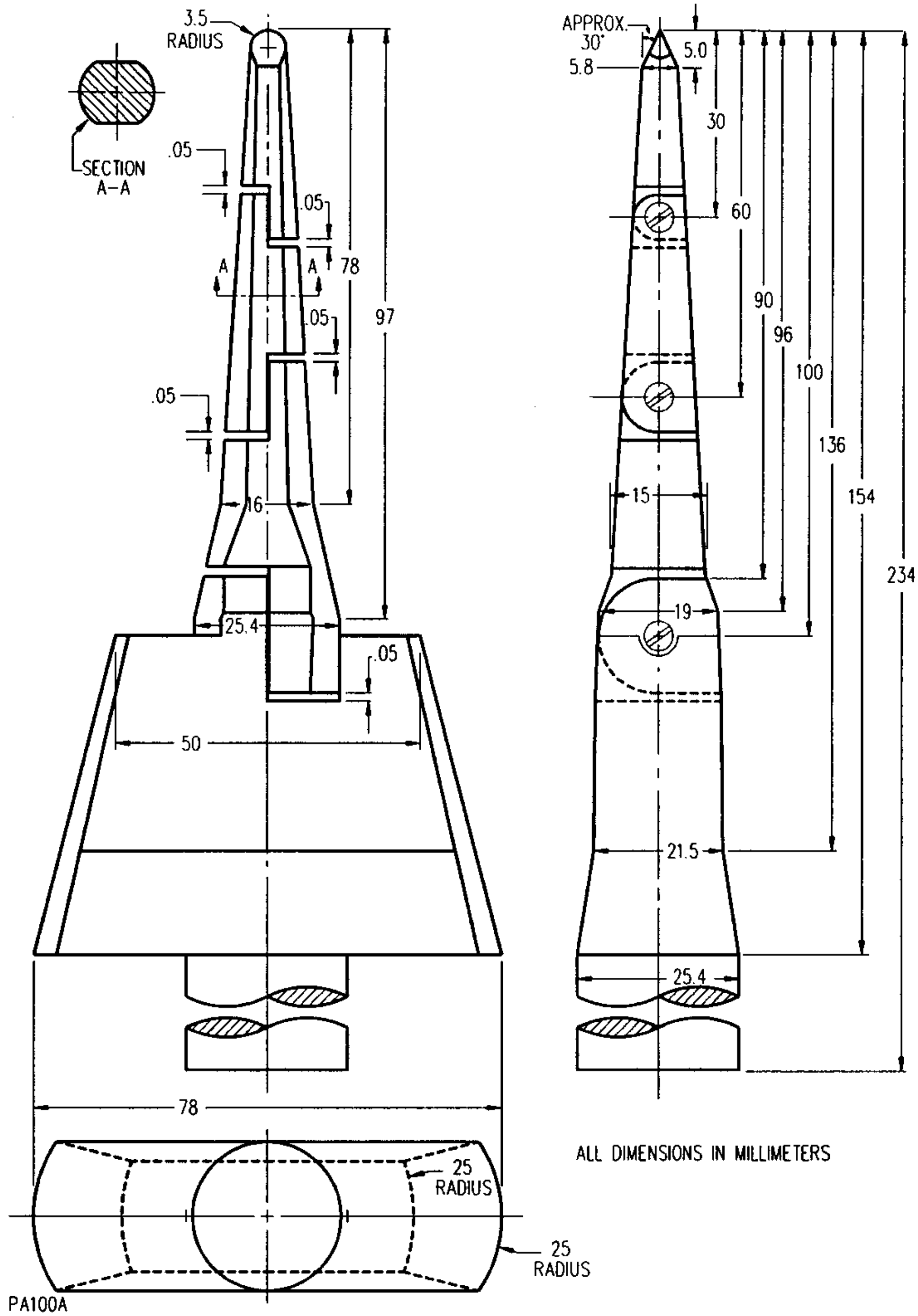


Table 9.1
Minimum distance from an opening to a part that involves a risk of electric shock, electrical energy-high current levels, or injury to persons

Minor dimension of opening[a,b]		Minimum Distance from opening to Part[b]	
mm	(inch)	mm	(inch)
25.4	(1)	165.0	(6-1/2)
31.8	(1-1/4)	190.0	(7-1/2)
38.1	(1-1/2)	318.0	(12-1/2)
47.6	(1-7/8)	394.0	(15-1/2)
54.0	(2-1/2)	444.0	(17-1/2)
(c)		762.0	(30)

[a] See 9.5.
[b] Between 25.4 and 54.0 mm, interpolation is to be used to determine a value between values specified in the table.
[c] More than 54.0 mm, and not more than 152.0 mm (5.98 in).

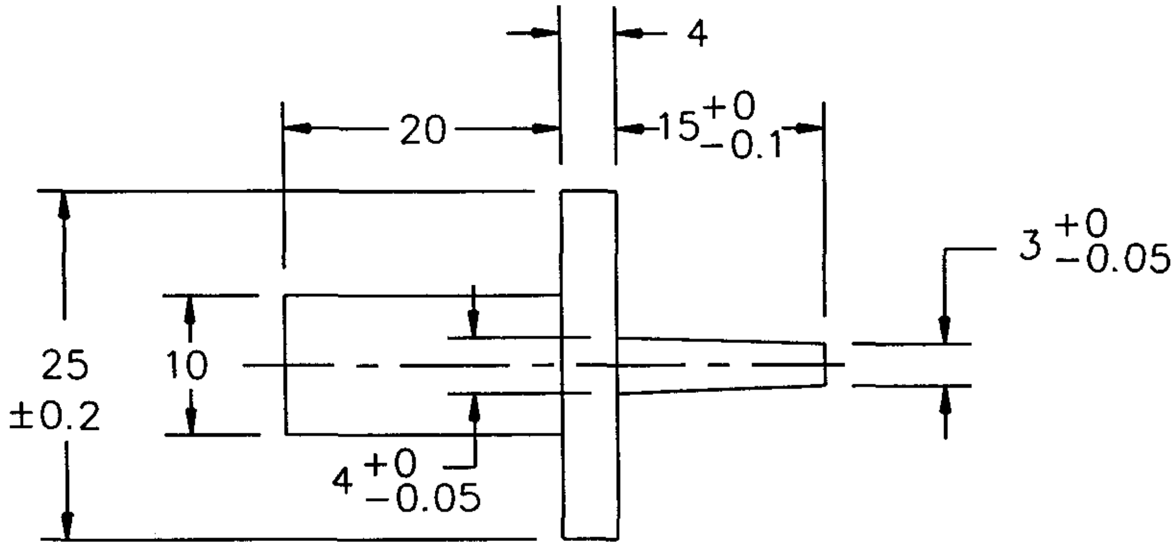
9.3 The probe illustrated in Figure 9.1 shall be applied to any depth that the opening accommodates; and shall be rotated or angled before, during, and after insertion through the opening to any position that is required to examine the enclosure. The probe shall be applied in any possible configuration; and, when required, the configuration shall be changed after insertion through the opening.

9.4 The probe specified in 9.3 shall be used as a measuring instrument to investigate the accessibility provided by an opening, and not as an instrument to investigate the strength of a material; it shall be applied with a maximum force of 4.4 N (1 pound).

9.5 With reference to 9.2, the minor dimension of an opening is equal to the diameter of the largest cylindrical probe that is able to be inserted through the opening.

9.6 The test pin illustrated in Figure 9.2, when inserted as specified in 9.3 through an opening in an enclosure, shall not touch any uninsulated live part that involves a risk of electric shock.

Figure 9.2
Test pin



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Dimensions in millimeters

9.7 The probe shown in Figure 9.1 and the test pin shown in Figure 9.2 are to be inserted as specified in 9.3 into all openings, including those in the bottom of the unit. The unit is to be positioned so that the entire bottom is accessible for insertion of the probe.

Exception: For openings in the bottom of a floor-standing unit, the probe and test pin are only to be inserted into openings that are accessible without tipping, turning over, or otherwise moving the unit from its intended installed position.

9.8 During the examination of a unit to determine compliance with 9.2 through 9.7, a part of the enclosure that is able to be opened or removed by the user without using a tool (to attach an accessory, to make an operating adjustment, to give access to a fuse or other overload protective device as described in 5.2.1, or for other reasons) is to be opened or removed. A fastener, such as a slotted-head thumb screw, that is able to be turned by hand, does not require the use of a tool.

10 Protection of Service Personnel

Section 10 effective November 7, 2000

10.1 The requirements in this Section apply to the protection of service personnel who reach over, under, across, or around uninsulated electrical parts or moving parts to make adjustments or measurements while the unit is energized. For requirements covering protection of users, see Protection of Users – Accessibility of Uninsulated Live Parts, Section 9.

10.2 Live parts shall be arranged and covers located to reduce the risk of electric shock or electrical energy-high current levels while covers are being removed and replaced.

10.3 An uninsulated live part involving a risk of electric shock or electrical energy-high current levels and a moving part that involves a risk of injury to persons shall be located, guarded, or enclosed to protect against unintentional contact by service personnel adjusting or resetting controls, or similar actions, or *performing mechanical service functions that are performed with the equipment energized*, such as lubricating a motor, adjusting the setting of a control with or without marked dial settings, resetting a trip mechanism, or operating a manual switch.

10.4 Live parts involving a risk of electric shock or electrical energy-high current levels and located on the back side of a door shall be guarded or insulated to protect against unintentional contact with live parts by service personnel.

10.5 A component that requires examination, resetting, adjustment, servicing, or maintenance while energized shall be located and mounted with respect to other components and with respect to grounded metal parts so that it is accessible for electrical service functions without subjecting service personnel to a risk of electric shock, electrical energy-high current levels, or injury to persons by adjacent moving parts. Access to a component shall not be impeded by other components or by wiring.

10.6 For an adjustment that is to be made with a screwdriver or similar tool when the unit is energized, protection shall be provided against inadvertent contact with adjacent uninsulated live parts involving a risk of electric shock. Misalignment of the tool with the adjustment means when an adjustment is attempted is to be taken into account. This protection is able to be provided by:

a) Location of the adjustment means away from uninsulated live parts involving a risk of electric shock, or

b) A guard to reduce the potential for the tool contacting uninsulated live parts.

10.7 A live heat sink for a solid-state component, a live relay frame, and similar components, involving a risk of electrical shock or electrical energy-high current levels, which is mistakable for dead metal, shall be guarded to protect against unintentional contact by service personnel or shall be marked in accordance with 64.4.

Exception: This requirement does not apply to a heat sink mounted on a printed wiring board.

10.8 A moving part that involves a risk of injury to persons and that must be in motion during service operations not involving the moving part shall be located or protected against unintentional contact with the moving parts.

10.9 Reduction of the risk of electric shock and injury to persons is able to be accomplished by mounting control components so that unimpeded access to each component is provided by an access cover or panel in the outer cabinet.

11 Electric Shock

Section 11 effective November 7, 2000

11.1 Voltage

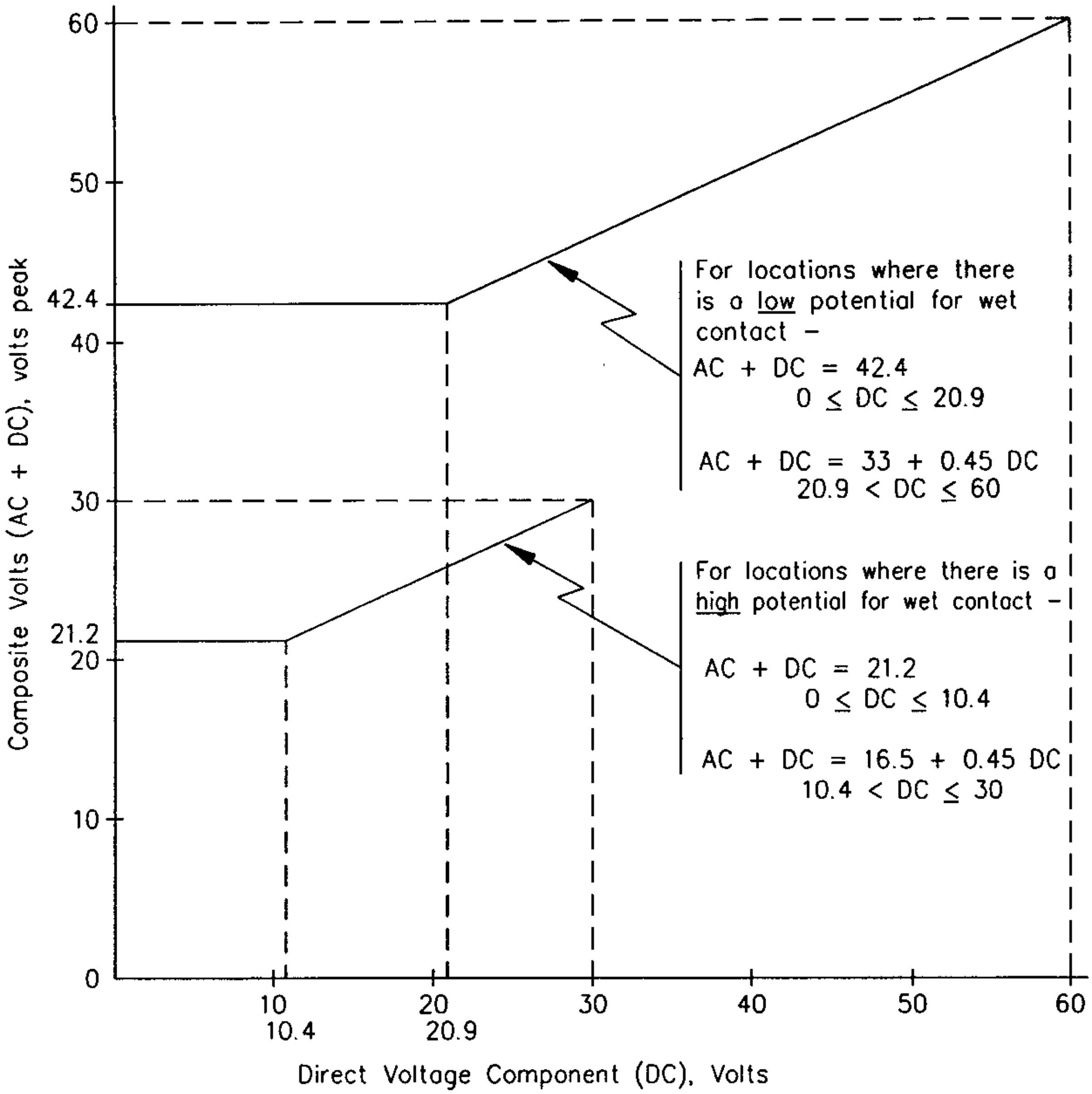
11.1.1 The requirements described in 11.1.2 – 11.2.2 are to be used to determine whether or not the voltage of an accessible live part involves a risk of electric shock.

11.1.2 A live part does not involve a risk of electric shock where the voltage of the part does not exceed the values specified in Table 11.1.

Table 11.1
Risk of electric shock – maximum voltage

	Voltage type	Indoor-use units (low potential for wet contact)	Outdoor-use units (high potential for wet contact – immersion not included)
1.	Sinusoidal ac	30 V rms	15 V rms
2.	Nonsinusoidal ac	42.4 V peak	21.2 V peak
3.	Pure dc	60 V	30 V
4.	DC interrupted at a rate of 10 to 200 Hz	24.8 V peak	12.4 V peak
5.	Combinations of dc and sinusoidal ac at frequencies not greater than 100 Hz	See Figure 11.1	See Figure 11.1

Figure 11.1
Maximum voltage



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11.2 Stored energy

11.2.1 The capacitance between capacitor terminals that are accessible as determined in accordance with Protection of Users – Accessibility of Uninsulated Live Parts, Section 9, and Protection of Service Personnel, Section 10, shall satisfy the following expressions:

$V < 40{,}000$	where $C < 0.00328$
$V < 729\ C^{-0.7}$	where $0.00328 \leq C < 2.67$
$V < 367$	where $2.67 \leq C < 13.9$
$V < 2314\ C^{-0.7}$	where $13.9 \leq C < 184.5$ in a DRY environment
$V < 60$	where $C \geq 184.5$ in a DRY environment
$V < 2314\ C^{-0.7}$	where $13.9 \leq C < 497$ in a WET environment
$V < 30$	where $C \geq 497$ in a WET environment

in which:

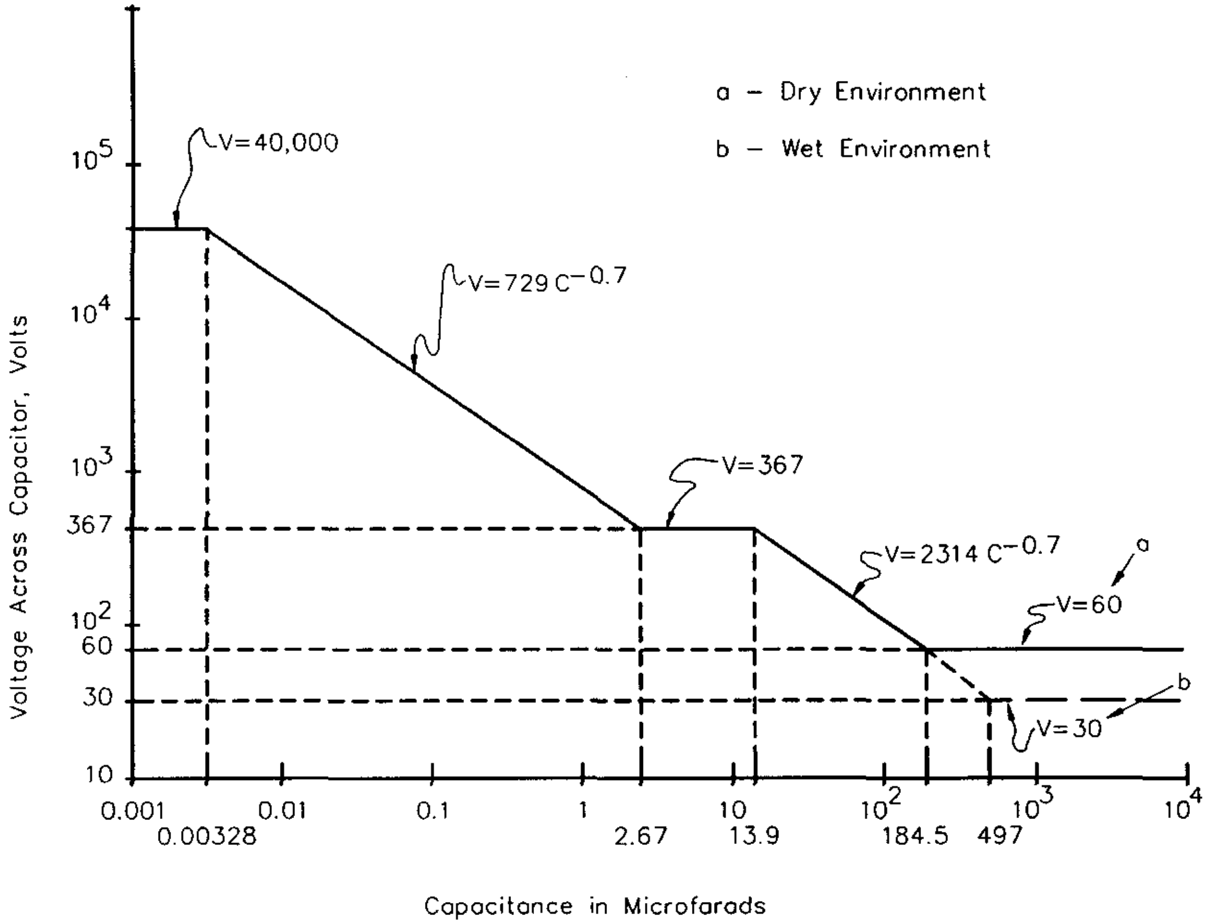
C is the capacitance of the capacitor in microfarads, and

V is the voltage across the capacitor. The voltage is to be measured in accordance with 57.1. Typical calculated values are specified in Table 11.2, and the equation is shown graphically in Figure 11.2.

Table 11.2
Risk of electric shock – stored energy current

Environment	Capacitance in microfarads	Maximum voltage across the capacitor, in volts peak
Wet or Dry	0.00328 or less	40,000
	0.005	29,749
	0.01	18,313
	0.02	11,273
	0.05	5,936
	0.1	3,654
	0.2	2,249
	0.5	1,184
	1.0	729
	2.0	449
	2.0	449
	2.67 to 13.9	367
	20.0	284
	50.0	150
	100.0	92.1
	184.5	60.0
Dry only	184.5 or more	60.0
Wet	200	56.7
	497 or more	30.0

Figure 11.2
Voltage limits across capacitors



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11.2.2 With reference to 11.2.1, a part involving a potential of more than 40 kilovolts peak shall be investigated to determine whether or not it involves a risk of electric shock.

11.2.3 A means such as a bleeder resistor shall be provided to drain the charge stored in a capacitor so that it does not provide a risk of electric shock or a risk of electrical energy-high current level. A risk of electric shock exists when the voltage across the capacitor, determined in accordance with Capacitor Voltage Determination Test, Section 57, exceeds the limits specified in 11.1.2. A risk of electrical energy-high current level exists when the stored energy exceeds 20 joules as determined by the following equation:

$$J = 5 \times 10^{-7}\ CV^2$$

in which:

J is the stored energy in Joules,

C is the capacitance in microfarads, and

V is the voltage determined in accordance with Capacitor Voltage Determination Test, Section 57.

Exception No. 1: The requirement does not apply where:

a) A tool is required to remove a panel to reach the capacitor or accessible uninsulated portions of the associated circuit,

b) The time required to discharge the capacitor is within the limitations specified in 11.2.1 and is less than 5 minutes, and

c) The unit is marked as specified in 64.11.

Exception No. 2: The requirement does not apply where:

a) The unit is marked in accordance with 64.12, and

b) The unit is provided with a built-in, insulated circuit that discharges the capacitor or capacitor bank by the actuation of a switch or by plugging in a connector. When a connector or a non-momentary type switch is used, the circuit assembly shall be constructed and evaluated for continuous operation. When a momentary type switch is used, the capacitor or capacitor bank shall be discharged to levels in accordance with Table 11.2 within 1 minute.

Exception No. 3: The requirement does not apply where:

a) The capacitor terminals and all parts connected to these terminals are insulated to protect against contact with these terminals and parts by the serviceman, and *b) A cautionary marking in accordance with 64.13 is provided.*

12 Switches and Controls

Section 12 effective November 7, 2000

12.1 An ac or dc switch or similar control device shall have current and voltage ratings not less than those of the circuit that it controls when the unit is operated in its intended manner.

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12.2 A primary-circuit switch that controls an inductive load having a power factor less than 75 percent, and that does not have an inductive rating, shall:

a) Be rated not less than twice the maximum load current under normal operating conditions, or

b) Be investigated for the application.

12.3 A switch used to connect a load to various sources or potentials shall be rated for such use. This includes a switch used for switching a voltmeter, frequency meter, or power factor meter between various phases.

12.4 A switch or other device controlling a relay coil, solenoid coil, or similar coil load shall have a pilot-duty rating.

Exception: A device as described in 12.5 is not required to have a pilot duty-rating.

12.5 A device that is rated for across-the-line motor starting of an alternating current motor is usable for alternating current pilot-duty without further tests when the power factor is 0.5 or less and the overload current is at least 150 percent of the pilot-duty inrush current at the same voltage. Switching devices rated in accordance with Table 12.1 are in compliance with this requirement.

Table 12.1
Horsepower rating versus pilot duty rating

Horsepower rating 1-phase (120 – 600 volts)	AC pilot-duty rating
1/10	125 VA (light duty)
1/2	360 VA (standard duty)
1	720 VA (heavy duty)

12.6 Each pole of a snap switch rated as a 2-circuit, 3-circuit, or multi-circuit switch is not prohibited from controlling a separate load at the full voltage rating of the switch. Each pole of a snap switch rated as a 240-volt, 2-pole switch is not prohibited from controlling a separate 120-volt load, and both poles are not prohibited from controlling both legs of a single 240-volt load. Each pole of a snap switch rated as a 240-volt, 3-pole switch is not prohibited from controlling a separate load not exceeding 139 volts and the three poles are not prohibited from controlling the three legs of a 3-phase, 240-volt load.

12.7 A 240-volt or 250-volt snap switch used in a circuit involving more than 120 volts to ground shall be rated for such use.

12.8 A switch shall not disconnect the grounded conductor of a circuit.

Exception No. 1: The grounded conductor is able to be disconnected by a switch that simultaneously disconnects all conductors of the circuit.

Exception No. 2: The grounded conductor is able to be disconnected by a switch that is so arranged that the grounded conductor is not disconnected until the ungrounded conductors of the circuit have been disconnected.

12.9 A bypass switch or maintenance bypass used to connect the load directly to the bypass source shall comply with the Standard for Automatic Transfer Switches, UL 1008.

Exception: A bypass switch or maintenance bypass complying with Load Transfer Test, Section 47.7, is not required to comply with UL 1008. See 12.10.

12.10 With reference to the Exception to 12.9, a solid-state switch shall comply with the requirements in this Standard. A mechanical or electromechanical switch shall comply with the applicable requirements for switches in the Standard for General-Use Snap Switches, UL 20, and the Standard for Industrial Control Equipment, UL 508.

12.11 Where a unit switch or circuit breaker is mounted such that movement of the operating handle between the on position and off position results in one position being above the other position, the upper position shall be the on position.

Exception: This requirement does not apply to:

a) A switching device having more than one on position (such as a bypass switch),

b) A double throw switch,

c) A rotationally-operated switch, or

d) A rocker switch.

13 Disconnect Devices

Section 13 effective November 7, 2000

13.1 A disconnect device shall:

a) Open all ungrounded conductors of the circuit to which it is connected,

b) Consist of a manually operated switch or a circuit breaker,

c) Employ an operating handle that is accessible from outside of the enclosure or located behind a hinged cover not requiring a tool for opening, and

d) Be marked in accordance with 63.26.

13.2 Where the operating handle of a disconnect device is operated vertically rather than rotationally or horizontally, the up position of the handle shall be the on position.

13.3 For a unit investigated in combination with a remote battery supply intended to be used with the unit, only one disconnect device is required to be provided for the battery supply circuit.

14 AC Output Connections

Section 14 effective November 7, 2000

14.1 Stand-alone inverters

14.1.1 The ac output of a stand-alone inverter shall be provided with (a) or (b), or both:

a) Receptacles which comply with 14.1.2.

b) Provision for connection of a fixed wiring system in accordance with Supply Connections, Section 16.

14.1.2 An inverter provided with an ac output receptacle shall comply with the following:

a) The receptacle shall be of the grounding type,

b) The ac output conductor that is connected to the white or silver terminal of the receptacle shall be bonded to ground in accordance with 19.1, 19.3, and 19.5,

c) An equipment-grounding connection as described in Equipment Grounding, Section 18, shall be provided. Grounding of the receptacle shall not rely on mounting means only. The ground terminal provided as part of the receptacle shall be employed, and

d) Receptacles installed in raised covers shall not be secured solely by a single screw.

14.1.3 A ground-fault circuit-interrupter shall comply with the Standard for Ground-Fault Circuit-Interrupters, UL 943.

14.2 Utility-interactive inverters

14.2.1 A utility-interactive inverter shall have provision for connection of a wiring system complying with Supply Connections, Section 16.

14.2.2 A general-use ac output receptacle shall not be provided on a utility-interactive inverter unless it is internal to the unit and accessible for service personnel use only.

14.2.3 An inverter with an ac output shall comply with the following:

a) The installation instructions shall comply with 65.2, and

b) The output circuit shall not be bonded to the enclosure. See also 19.2.

15 Receptacles

15.1 A general-use receptacle in an inverter shall be of the grounding type.

15.1 effective November 7, 2000

15.2 A receptacle supplied from the output ac circuit of an inverter shall comply with the following:

a) The white or silver terminal of the receptacle shall be grounded, see AC Output Circuit Grounded Conductor, Section 19,

b) The equipment-grounding terminal of the receptacle shall be conductively connected to the equipment-grounding means in accordance with Internal Bonding for Grounding, Section 20, and

c) A receptacle installed in a raised cover shall be in accordance with Section 410.56(i) of the National Electrical Code, ANSI/NFPA 70.

15.2 revised January 17, 2001

16 Supply Connections

16.1 General

16.1.1 A unit shall have provision for connection of a wiring system consisting of:

a) Wiring terminals as specified in 16.1.3 – 16.2.10 or wiring leads as specified in 16.1.3 and 16.3.1 – 16.3.6, and

b) A means for connection of cable or conduit as specified in 16.5.1.

Exception No. 1: The requirements described in 16.1.3 – 16.4.3 do not apply to the means for connection to isolated accessible signal circuits complying with the requirements specified in Isolated Accessible Signal Circuits, Section 28.

Exception No. 2: This requirement does not apply to ac output power circuit of an inverter consisting of receptacles complying with the requirements specified in Receptacles, Section 15.

16.1.1 effective November 7, 2000

16.1.2 The requirement in 16.1.1 applies to the wiring connection means for ac and dc input and output power circuits of a unit intended to be made in the field when the unit is installed.

16.1.2 effective November 7, 2000

16.1.3 A wiring terminal or lead shall be rated and sized for connection to a field wiring conductor having an ampacity based on Table 310.16 of the National Electrical Code, ANSI/NFPA 70, of no less than 125 percent of the RMS or dc current that the circuit carries during rated conditions. For determining the appropriate column in Table 310.16, see 66.4 (L) and (M).

16.1.3 revised January 17, 2001

16.2 Wiring terminals

Section 16.2 effective November 7, 2000

16.2.1 A wiring terminal shall comply with the requirement in 16.1.3 for a wire of each metal for which it is marked. See 63.11.

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16.2.2 A wiring terminal shall be provided with a factory-installed pressure terminal connector that is securely fastened in place – for example, firmly bolted or held by a screw.

Exception No. 1: A field-installed pressure terminal connector in accordance with 16.2.4 meets the intent of this requirement.

Exception No. 2: A wire-binding screw employed at a wiring terminal intended for connection of a No. 10 AWG (5.3 mm^2) or smaller conductor and having upturned lugs, a cupped washer, or the equivalent to hold the wire in position meets the intent of this requirement.

16.2.3 A wiring terminal shall be secured in position, by a means other than friction between surfaces, so that it does not turn or shift. This is able to be accomplished by two screws or rivets; by square shoulders or mortises; by a dowel pin, lug, or offset; by a connecting strap or clip fitted into an adjacent part; or by an equivalent method.

Exception: A pressure terminal connector used in accordance with 16.2.4 is able to turn when the spacing complies with Spacings, Section 24, when the connector is oriented in the position resulting in the least spacing between adjacent terminals and also between terminals and dead metal parts.

16.2.4 With reference to Exception No. 1 to 16.2.2, a pressure terminal connector is not required to be factory installed when the conditions in (a) – (e) are met:

a) One or more component terminal assemblies shall be available from the unit manufacturer or others and specified in the instruction manual. See 66.4(B) and (C).

b) The fastening hardware such as a stud, nut, bolt, spring, or flat washer, and similar hardware, as required for an effective installation, shall be:

1) Provided as part of the terminal assembly,

2) Mounted on or separately packaged with the unit, or

3) Specified in the instruction manual.

c) The installation of the terminal assembly shall not involve the loosening or disassembly of parts other than a cover or other part giving access to the terminal location. The means for securing the terminal connector shall be readily accessible for tightening before and after installation of conductors.

d) When the pressure terminal connector provided in a terminal assembly requires the use of other than a common tool for securing the conductor, identification of the tool and any additional instructions shall be included in the assembly package or with the unit. See 66.4(D).

e) Installation of the pressure terminal connector in the intended manner shall result in a unit complying with the requirements of this Standard.

16.2.5 A terminal block or insulating base for support of a pressure terminal connector shall comply with the Standard for Terminal Blocks, UL 1059.

16.2.6 A wire-binding screw at a field-wiring terminal shall not be smaller than No. 10 (4.8 mm diameter).

Exception No. 1: A No. 8 (4.2 mm diameter) screw is usable at a terminal intended only for the connection of:

a) No. 14 AWG (2.1 mm^2) conductor, or

b) No. 16 or 18 AWG (1.3 or 0.82 mm^2) control-circuit conductor.

Exception No. 2: A No. 6 (3.5 mm diameter) screw is usable for the connection of a No. 16 or 18 AWG (1.3 or 0.82 mm^2) control-circuit conductor.

16.2.7 A wire-binding screw shall thread into metal.

16.2.8 A terminal plate tapped for a wire-binding screw shall be of metal not less than 1.27 mm (0.050 inch) thick.

Exception: A terminal plate of metal less than 1.27 mm (0.050 inch) thick complies where used in a low-voltage, limited-energy (LVLE) circuit or limited energy (LE) circuit (see 2.23 and 2.25) and the tapped threads are capable of withstanding the tightening torque specified in Table 16.1 without stripping.

Table 16.1
Tightening torque for wire-binding screws

Size of terminal screw,		Wire sizes to be tested,	Tightening torque	
No.	(diameter, mm)	AWG (mm^2)	Newton meters	(Pound-inch)
6	(3.5)	Stranded 16 – 18 (1.3 – 0.82)	1.4	(12)
8	(4.2)	Solid 14 (2.1) and Stranded 16 – 18	1.8	(16)
10	(4.8)	Solid 10 – 14 (4.8 – 2.1) and Stranded 16 – 18	2.3	(20)

16.2.9 There shall be two or more full threads in the metal of a terminal plate. The metal is to be extruded at the tapped hole to provide at least two full threads.

Exception: Two full threads are not required for a terminal in a low-voltage, limited-energy (LVLE) circuit or limited-energy (LE) circuit, see 2.23 and 2.25, when a lesser number of threads results in a secure connection in which the threads do not strip when subjected to the tightening torque specified in Table 16.1.

16.2.10 A terminal for connection of a grounded conductor of an ac circuit shall be identified as described in 63.15.

16.3 Wiring leads

Section 16.3 effective November 7, 2000

16.3.1 A field-wiring lead shall not be more than two wire sizes smaller than the copper conductor to which it is to be connected, and shall not be smaller than No. 18 AWG (0.82 mm^2). For example, a No. 10 AWG (5.3 mm^2) or larger field-wiring lead is required for connection to a No. 6 AWG (13.3 mm^2) field-provided conductor. A field-wiring lead shall not be less than 152.4 mm (6 inches) long.

Exception: A lead is able to be more than two wire sizes smaller than the field-provided copper conductor to which it is to be connected, and be not smaller than No. 18 AWG (0.82 mm^2), when more than one factory-provided copper lead is intended for connection to the same field-provided lead, and the construction complies with the following:

a) A wire connector for connection of the field-provided wire is factory-installed as part of the unit or remote-control assembly, and the wire connector is rated for the combination of wires that are to be spliced,

b) The factory-provided leads are bunched or otherwise arranged so that stress does not result on an individual lead, and

c) Instructions are provided in accordance with 66.4(E).

16.3.2 A field-wiring lead shall consist of general building wire, or of other wiring having an insulation of:

a) At least 0.8-mm (1/32-inch) thick thermoplastic material,

b) At least 0.4-mm (1/64-inch) thick rubber plus a braid cover for applications of 300 volts or less, or

c) At least 0.8-mm thick rubber plus a braid cover for applications between 301 and 600 volts.

16.3.3 A field-wiring lead shall comply with Strain Relief Test, Section 50.

16.3.4 A field-wiring lead provided for connection to an external line-voltage circuit shall not be connected to a wire-binding screw or pressure terminal connector located in the same compartment as the free end of the wiring lead unless the screw or connector is rendered unusable for field-wiring connection or:

a) The lead is insulated at the unconnected end, and

b) A marking is provided on the unit in accordance with 63.23.

16.3.5 The free end of a field-wiring lead that is not used in every installation, such as a lead for a tap of a multivoltage transformer, shall be insulated. For an equipment-grounding lead, see 18.1.7.

16.3.6 A field-wiring lead for connection of a grounded conductor of an ac circuit shall be identified as described in 63.15.

16.4 Wiring compartments

Section 16.4 effective November 7, 2000

16.4.1 A wiring compartment for a unit shall be located so that wire connections therein are accessible for inspection, without disturbing factory or field connected wiring, after the unit is installed in the intended manner.

16.4.2 A wiring compartment, raceway, or similar device, for routing and stowage of conductors connected in the field shall not contain rough, sharp, or moving parts that are capable of damaging conductor insulation.

16.4.3 A wiring compartment shall not have a volume less than specified in Table 16.2. The volume is to be determined in accordance with the Standard for Metallic Outlet Boxes, UL 514A, or the Standard for Nonmetallic Outlet Boxes, Flush-Device Boxes and Covers, UL 514C, as applicable. No compartment enclosure dimension shall be less than 19.1 mm (3/4 inch).

Table 16.2
Wiring compartment volume

Size of conductor,		Free space for each conductor	
AWG	(mm^2)	Cubic centimeter	(Cubic inches)
18	(0.82)	24.60	(1.50)
16	(1.3)	28.70	(1.75)
14	(2.1)	32.80	(2.00)
12	(3.3)	36.90	(2.25)
10	(5.3)	40.00	(2.50)
8	(8.4)	49.20	(3.00)
6	(13.3)	82.00	(5.00)

16.5 Openings for conduit or cable connection

Section 16.5 effective November 7, 2000

16.5.1 For a fixed unit, an opening or knockout complying with the requirements specified in 5.7.1 – 5.7.7 shall be provided for connection of conduit or a cable wiring system.

Exception: A unit complying with 5.7.6 is not required to be provided with an opening or a knockout.

16.6 Openings for class 2 circuit conductors

Section 16.6 effective November 7, 2000

16.6.1 An opening for the entry of a conductor or conductors of a Class 2 circuit, such as a control or sensor circuit, shall be supplied with an insulating bushing. The bushing shall be factory-installed in the opening or shall be supplied within the enclosure so that it is available for installation when the unit is installed.

Exception: A bushing is not required where:

a) The opening is sized and intended for armored cable or conduit, and

b) The installation instructions indicate that Class 1 wiring methods are to be used as indicated in 66.4 (N).

16.6.2 For Type 1 enclosures only, a bushing of rubber or rubber type material provided in accordance with 16.6.1 shall not be less than 3.2 mm (1/8 inch) thick; however, it shall not be less than 1.2 mm (3/64 inch) thick when the metal around the hole is eyeletted or similarly treated to provide smooth edges. A bushing shall be located so that it is not exposed to oil, grease, oily vapors, or other substances having a deleterious effect on the material of the bushing. A hole in which such a hinge is mounted shall be free from sharp edges, burrs, or projections capable of damaging the bushing.

17 Wire-Bending Space

17.1 A permanently connected unit employing pressure terminal connectors for field connection of circuits described in 16.1.2 shall be provided with wire-bending space within the enclosure for the installation of conductors (including grounding conductors) that are to be employed in the installation as specified in 16.1.2 – 16.2.4.

17.1 effective November 7, 2000

17.2 The conductor size used to determine compliance with 17.1 is to be based on the use of a conductor sized in accordance with 16.1.3.

Exception No. 1: Where a unit is marked with a maximum wire size for a field-installed conductor in accordance with 63.27, the marked maximum size is to be used.

Exception No. 2: The requirements in 16.4.3 are to be used to investigate the wire-bending space in a wiring compartment.

17.2 effective November 7, 2000

17.3 Wire-bending space for field installed conductors shall be provided opposite any:

a) Pressure wire connector as specified in 17.4 or 17.5, and

b) Opening or knockout for a conduit or wireway in a gutter as specified in 17.9.

17.3 effective November 7, 2000

17.4 Where a conductor is able to be installed such that it enters or leaves the enclosure surface opposite its wire-terminal, the wire-bending space shall be as specified in Table 17.1. A wire is able to enter or leave a top, back, bottom, or side surface when there is an opening or knockout for a wireway or conduit.

17.4 effective November 7, 2000

Table 17.1
Minimum wire-bending space for conductors through a wall opposite terminals in mm (inch)

Table 17.1 effective November 7, 2000

Wire size, AWG or		Wires per terminal (pole)[a]											
		1			2			3			4 or More		
kcmil	(mm^2)	mm		(inch)	mm		(inch)	mm		(inch)	mm		(inch)
14 – 10	(2.1 – 5.3)	Not specified				–			–			–	
8	(8.4)	38.1		(1-1/2)		–			–			–	
6	(13.3)	50.8		(2)		–			–			–	
4	(21.1)	76.2		(3)		–			–			–	
3	(26.7)	76.2		(3)		–			–			–	
2	(33.6)	88.9		(3-1/2)		–			–			–	
1	(42.4)	114		(4-1/2)		–			–			–	
0	(53.5)	140		(5-1/2)	140		(5-1/2)	179		(7)		–	
2/0	(67.4)	152		(6)	152		(6)	191		(7-1/2)		–	
3/0	(85.0)	165	[12.7]	(6-1/2)	165	[12.7]	(6-1/2)	203		(8)		–	
4/0	(107)	179	[25.4]	(7)	191	[38.1]	(7-1/2)	216	[12.7]	(8-1/2)		–	
250	(127)	216	[50.8]	(8-1/2)	216	[50.8]	(8-1/2)	229	[25.4]	(9)	254		(10)
300	(152)	254	[76.2]	(10)	254	[50.8]	(10)	279	[25.4]	(11)	305		(12)
350	(177)	305	[76.2]	(12)	305	[76.2]	(12)	330	[76.2]	(13)	355	[50.8]	(14)
400	(203)	330	[76.2]	(13)	330	[76.2]	(13)	355	[76.2]	(14)	381	[76.2]	(15)
500	(253)	355	[76.2]	(14)	355	[76.2]	(14)	381	[76.2]	(15)	406	[76.2]	(16)
600	(304)	381	[76.2]	(15)	406	[76.2]	(16)	457	[76.2]	(18)	483	[76.2]	(19)
700	(355)	40	[76.2]	(16)	457	[76.2]	(18)	508	[76.2]	(20)	559	[76.2]	(22)
750	(380)	432	[76.2]	(17)	483	[76.2]	(19)	559	[76.2]	(22)	610	[76.2]	(24)
800	(405)	457		(18)	508		(20)	559		(22)	610		(24)
900	(456)	483		(19)	559		(22)	610		(24)	610		(24)
1000	(507)	508		(20)		–			–			–	
1250	(633)	559		(22)		–			–			–	
1500	(760)	610		(24)		–			–			–	
1750	(886)	610		(24)		–			–			–	
2000	1013	610		(24)		–			–			–	

Note– This table includes only those multiple-conductor combinations that are commonly used. Combinations not specified shall be further investigated.

[a] Compliance with the following conditions reduces the wire-bending space by the number of mm's shown in brackets:

1) Only removable or lay-in wire connectors receiving one wire each are used (sometimes there is more than one removable wire connector per terminal) and

2) A removable wire connector is able to be removed from its intended location and reinstalled with the conuductor in place without disturbing structural or electrical parts other than a cover.

17.5 Where a conductor is intended to enter or leave the enclosure surface adjacent (not opposite) to its wire terminal, the wire-bending space shall be as specified in Table 17.2 where:

a) A barrier is provided between the connector and the opening, or

b) Drawings are provided specifying that the conductor is not to enter or leave the enclosure directly opposite the wire connector. See Illustrations A, B, and C of Figure 17.1.

17.5 effective November 7, 2000

Table 17.2
Minimum wire-bending space and width of gutter for conductors through a wall not opposite terminals in mm (inches)

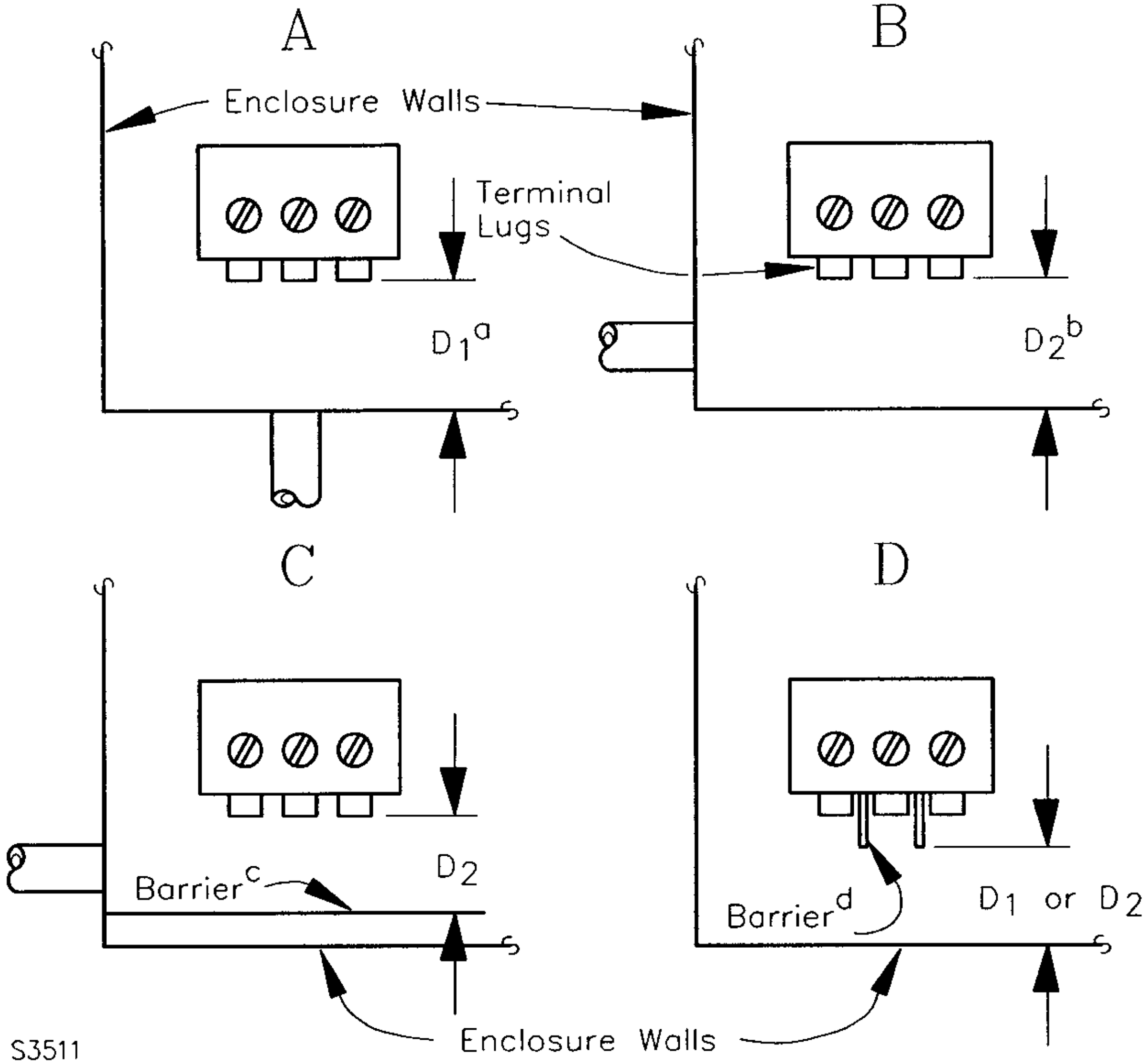
Table 17.2 revised January 17, 2001

Size of wire, AWG or kcmil (mm^2)		Wires per terminal (pole)									
		1		2		3		4		5	
		mm	(inch)	mm	(inch)	mm	(inch)	mm	(inch)	mm	(inch)
14 – 10	(2.1 – 5.3)	Not specified	–	–		–		–		–	
8 – 6	(8.4 – 13.3)	38.1	(1-1/2)	–		–		–		–	
4 – 3	(21.1 – 26.7)	50.8	(2)	–		–		–		–	
2	(33.6)	63.5	(2-1/2)	–		–		–		–	
1	(42.4)	76.2	(3)	–		–		–		–	
1/0 – 2/0	(53.5 – 7.4)	88.9	(3-1/2)	127	(5)	178	(7)	–		–	
3/0 – 4/0	(85.0 – 107)	102	(4)	152	(6)	203	(8)	–		–	
250	(127)	114	(4-1/2)	152	(6)	203	(8)	254	(10)	–	
300 – 350	(152 – 177)	127	(5)	203	(8)	254	(10)	305	(12)	–	
400 – 500	(203 – 253)	152	(6)	203	(8)	254	(10)	305	(12)	356	(14)
600 – 700	(304 – 355)	203	(8)	254	(10)	305	(12)	356	(14)	406	(16)
750 – 900	(380 – 456)	8	(203)	305	(12)	356	(14)	406	(14)	457	(18)
1000 – 1250	(507 – 633)	254	(10)	–		–		–		–	
1500 – 2000	(760 – 1010)	305	(12)	–		–		–		–	

Note – This table includes only those multiple-conductor combinations that are commonly used. Combinations not specified shall be further investigated.

Figure 17.1
Wire-bending space

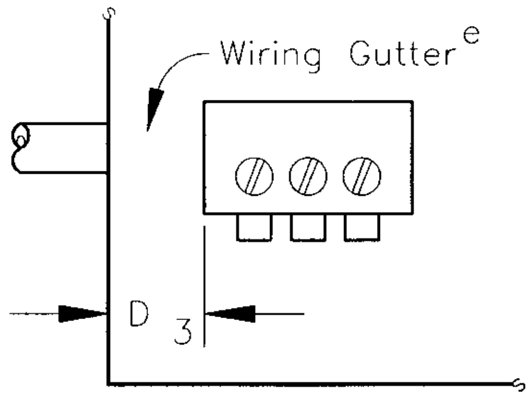
Figure 17.1 effective November 7, 2000



(Continued)

Figure 17.1 (cont'd)
Wire-bending space

E



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NOTES –

D_1 is the distance between a wire connector or an adjacent barrier and the opposite wall that conductors pass through.

D_2 is the distance between a wire connector or an adjacent barrier and the opposite wall or barrier that conductors do not pass through.

D_3 is the width of a wiring gutter having a side through which conductors pass through.

[a] A conduit opening or knockout is provided in the wall opposite the terminal lugs. D_1 shall not be less than the minimum wire-bending space specified in Table 17.1.

[b] A conduit opening or knockout is provided in the wall at a right angle to the wall opposite the terminal lugs. The wall opposite the terminal lugs:

1) Is not provided with a knockout or conduit opening, or

2) A marking is provided indicating that the conduit opening or knockout is not to be used. D_2 shall not be less than the minimum wire-bending space specified in Table 17.2.

[c] A conduit opening or knockout is provided in the wall at a right angle to the wall opposite the terminal lugs. In addition, a conduit opening or knockout is provided in the wall opposite the terminal lugs; however, a barrier preventing the use of the opening is provided. D_2 shall not be less than the minimum wire-bending space specified in Table 17.2.

[d] Where a barrier or other means restricts bending of the conductor, the distance D_1 or D_2, as appropriate – see notes D_1 – D_3 – is to be measured from the end of the barrier.

[e] A conduit opening or knockout is provided in a wiring gutter. The width of the gutter, D_3, shall not be less than the minimum wire-bending space specified in Table 17.2.

17.6 Where a conductor is restricted by a barrier or other means from being bent where it leaves the connector, the distance is to be measured from the end of the barrier. See illustration D of Figure 17.1.

17.6 effective November 7, 2000

17.7 For a unit not provided from the factory with a conduit opening or knockout, see 5.7.6, the minimum wiring-bending space specified in 17.4 – 17.6 shall be based on:

a) Any enclosure wall used for installation of the conduit, or

b) Only specific walls that are to be used as specified by a marking, drawing, or template furnished with the unit.

17.7 effective November 7, 2000

17.8 The distance specified in 17.3 – 17.5 is to be measured in a straight line from the edge of the wire terminal closest to the wall in a direction perpendicular to the box wall or barrier. See illustrations A – C of Figure 17.1. The wire terminal is to be turned so that the axis of the wire opening in the connector is as close to perpendicular to the wall of the enclosure as possible without defeating any means provided to prevent turning, such as a boss, shoulder, walls of a recess, multiple bolts securing the connector, or a similar means. A barrier, shoulder, or similar component is to be disregarded when the measurement is being made where it does not reduce the radius to which the wire must be bent. Where a terminal is provided with one or more connectors for the connection of conductors in multiple, the distance is to be measured from the wire opening closest to the wall of the enclosure.

Exception: See 17.6.

17.8 effective November 7, 2000

17.9 The width of a wiring gutter in which one or more knockouts are provided shall be large enough to accommodate (with respect to wire-bending space) conductors of the maximum size usable at that knockout. The width of a wiring gutter is given in Table 17.2. See illustration E of Figure 17.1.

Exception: The wiring space is able to be narrower when:

a) Knockouts are provided elsewhere that are in compliance with these requirements,

b) The wire-bending space at such other point or points is of a width that accommodates the conductors in question, and

c) The knockout or knockouts at such other points are able to be conveniently used in the intended wiring of the unit.

17.9 effective November 7, 2000

18 Equipment Grounding

18.1 General

18.1.1 There shall be means for grounding all dead metal parts of a unit.

18.1.1 effective November 7, 2000

18.1.2 The means for equipment grounding specified in 18.1.1 shall be provided for each wiring system to be connected to the unit for the following circuits:

a) Each dc input circuit,

b) Each ac input circuit,

c) Each ac output circuit, and

d) Each battery circuit.

Exception: An isolated accessible signal circuit complying with Isolated Accessible Signal Circuits, Section 28, is not required to have means for equipment grounding.

18.1.2 effective November 7, 2000

18.1.3 The equipment-grounding means for a fixed unit shall consist of an equipment-grounding terminal or lead.

18.1.3 effective November 7, 2000

18.1.4 An equipment-grounding terminal or lead shall be connected to the frame or enclosure by a positive means, such as by a bolted or screwed connection. The head of a screw or bolt, other than a double-nut secured bolt or screw, used to secure a terminal or lead, shall not be accessible from outside of the enclosure.

18.1.4 effective November 7, 2000

18.1.5 An equipment-grounding connection shall penetrate a nonconductive coating, such as paint or vitreous enamel.

18.1.5 effective November 7, 2000

18.1.6 An equipment-grounding means shall be located so that the means is not subject to inadvertent removal during servicing.

18.1.6 effective November 7, 2000

18.1.7 A free end of an equipment-grounding lead shall be insulated (for example, the end is to be folded back and taped to the lead) unless the lead is located so that the lead is not capable of contacting live parts in the event that the lead is not used in the field.

18.1.7 effective November 7, 2000

18.1.8 Equipment grounding leads or equipment grounding terminals shall be provided for each input and each output circuit. Any supplied lead shall have a free length of not less than 152 mm (6 inches) and the surface of the insulation shall be green with or without one or more yellow stripes. Where equipment ground leads are used, no other lead in a field-wiring compartment or that is visible to the installer shall be so identified. Equipment-grounding terminals shall be marked as described in 63.12. An equipment-grounding lead or equipment-grounding terminal shall have a minimum size or be rated to carry the required current in accordance with the following:

a) For a dc input from a photovoltaic source or output circuit, 1.25 times the rated short-circuit input current for that input, see Table 62.1.

b) For any ac input or output circuit or dc (non-PV) input or output circuit, Column 2 of Table 18.1 based on the size of the overcurrent device protecting that circuit.

Exception: The color coding requirement does not apply to Class 2 circuits where the leads are:

a) Located remote from the line-voltage connections and the segregation complies with the requirements in Separation of Circuits, Section 23, or

b) Marked in accordance with 63.24.

18.1.8 revised November 7, 2005

Table 18.1
Size of equipment-grounding and grounding electrode conductors

Table 18.1 effective November 7, 2000

Column 1	Column 2				Column 3			
	Minimum size of equipment-grounding or bonding conductor AWG or kcmil (mm²)				Minimum size of grounding electrode conductor, AWG or kcmil (mm²)			
Maximum current rating,[a] amperes	Copper		Aluminum or copper-clad aluminum		Copper		Aluminum or copper-clad aluminum	
15	14	(2.1)	12	(3.3)	8	(8.4)	6	(13.3)
20	12	(3.3)	10	(5.3)	8	(8.4)	6	(13.3)
30	10	(5.3)	8	(8.4)	8	(8.4)	6	(13.3)
40	10	(5.3)	8	(8.4)	8	(8.4)	6	(13.3)
60	10	(5.3)	8	(8.4)	8	(8.4)	6	(13.3)
90	8	(8.4)	6	(13.3)	8	(8.4)	6	(13.3)
100	8	(8.4)	6	(13.3)	6	(13.3)	6	(13.3)
150	6	(13.3)	4	(21.2)	6	(13.3)	4	(21.2)
200	6	(13.3)	4	(21.2)	4	(21.2)	2	(33.6)
300	4	(21.2)	2	(33.6)	2	(33.6)	1/0	(53.5)
400	3	(26.7)	1	(42.4)	1/0	(53.5)	3/0	(85.0)
500	2	(33.6)	1/0	(53.5)	2/0	(67.4)	4/0	(107.2)
600	1	(42.4)	2/0	(67.4)	2/0	(67.4)	4/0	(107.2)
800	1/0	(53.5)	3/0	(85.0)	3/0	(85.0)	250	(127)
1000	2/0	(67.4)	4/0	(107.2)	3/0	(85.0)	250	(127)
1200	3/0	(85.0)	250	(127)	3/0	(85.0)	250	(127)
1600	4/0	(107.2)	350	(127)	3/0	(85.0)	250	(127)
2000	250	(127)	400	(203)	3/0	(85.0)	250	(127)
2500	350	(177)	600	(304)	3/0	(85.0)	250	(127)
3000	400	(203)	600	(304)	3/0	(85.0)	250	(127)
4000	500	(253)	800	(405)	3/0	(85.0)	250	(127)
5000	700	(355)	1200	(608)	3/0	(85.0)	250	(127)
6000	800	(405)	1200	(608)	3/0	(85.0)	250	(127)

Note – See Table 19.2 for equivalent area of bus.

[a] Maximum ampere rating of the input circuit dc overcurrent protective device described in 47.1.5 or the ac output circuit overcurrent protective device described in 30.3.1 – 30.4.3, whichever is larger.

18.1.9 An equipment-grounding conductor shall not be spliced internal to the equipment.

18.1.9 effective November 7, 2000

18.1.10 An equipment-grounding connection, equipment-grounding conductor, enclosure, frame, component mounting panel, or other part connected to earth ground shall not carry current unless an electrical malfunction occurs. See 20.12.

Exception: This requirement does not apply to a line bypass capacitive impedance circuit for a radio frequency signal circuit or a transient voltage surge suppressor.

18.1.10 effective November 7, 2000

18.1.11 A soldering lug, a connection means that depends on solder, a screwless (push-in) connector, a quick-connect connector, or other friction-fit connector shall not be used as an equipment-grounding means.

18.1.11 effective November 7, 2000

18.1.12 An equipment-grounding terminal shall be rated for securing a conductor of a size based on the size of the overcurrent protection device to be employed in accordance with Columns 1 and 2 of Table 18.1 and shall be constructed in accordance with 16.2.1 – 16.2.9.

18.1.12 effective November 7, 2000

18.1.13 A wire-binding screw intended for the connection of a field-installed equipment-grounding conductor shall have a green colored head that is hexagonal, slotted, or both. A pressure wire connector or a stud-and-nut type terminal intended for connection of such a conductor shall be marked as described in 63.12.

18.1.13 revised January 17, 2001

18.2 Grounding electrode terminal

18.2.1 Equipment intended to be installed as service entrance equipment or equipment containing the main dc or ac bonding connection shall be provided with a grounding electrode terminal. The terminal shall:

a) Be capable of securing a conductor size based on the maximum current rating of the highest current circuit connected to the unit, as specified in Column 3 of Table 18.1,

b) Comply with 16.2.1 – 16.2.10 for construction, and

c) Be marked as described in 63.16.

18.2.1 revised November 7, 2005

18.2.2 A grounding-electrode terminal shall be connected to the main bonding point (ac or dc) in the equipment by a positive means, such as by a bolted or screwed connection. For grounding electrode connections that are internal to a product, the head of a screw or bolt, other than a double-nut secured bolt or screw, used to secure a terminal shall not be accessible from outside of the enclosure.

18.2.2 added November 7, 2005

19 AC Output Circuit Grounded Conductor

Section 19 effective November 7, 2000

19.1 The requirements for circuit grounding specified in 19.3 – 19.5 apply to the ac output circuit of a stand-alone inverter.

19.2 An inverter intended to be utility-interactive shall not have a direct/solid electrical connection between any output ac conductor and the enclosure.

19.3 Other than as specified in 19.2, each ac output circuit shall have a grounded conductor. The ac output circuit conductor to be grounded shall be as follows:

a) Single-phase, 2-wire – one conductor.

b) Single-phase, 3-wire – the neutral conductor.

c) Multiphase system having one wire common to all phases – the common conductor.

d) Multiphase system in which one phase is used as in item (b) – the neutral conductor.

19.4 The conductor specified in 19.3 is to be connected by a bonding jumper connected between the grounded conductor and:

a) The enclosure of a metal-enclosed unit, or

b) For a nonmetallic enclosed unit, the metal chassis that is bonded to the equipment-grounding conductor or terminal. See 18.2.1.

19.5 The size of the bonding jumper specified in 19.4 shall not be less than specified in Table 19.1.

Table 19.1
Minimum size of bonding jumper

Maximum circuit current rating, amperes	Copper, AWG or Kcmil (mm^2)		Aluminum or copper-clad aluminum, AWG or kcmil (mm^2)	
15	8	(8.4)	6	(13.3)
20	8	(8.4)	6	(13.6)
30	8	(8.4)	6	(13.3)
40	8	(8.4)	6	(13.3)
60	8	(8.4)	6	(13.3)
90	8	(8.4)	6	(13.3)
100	6	(13.3)	4	(21.2)
150	6	(13.3)	4	(21.2)
200	4	(21.2)	2	(33.6)
300	2	(33.6)	1/0	(53.5)
400	1/0	(53.5)	3/0	(85.0)
500	1/0	(53.5)	3/0	(85.0)
600	2/0	(67.4)	4/0	(107.2)
800	2/0	(67.4)	4/0	(107.2)
1000	3/0	(85.0)	250	(127)
1200	250	(127)	250	(127)
1600	300	(152)	400	(203)

Table 19.1 Continued on Next Page

Table 19.1 Continued

Maximum circuit current rating, amperes	Copper, AWG or Kcmil (mm^2)		Aluminum or copper-clad aluminum, AWG or kcmil (mm^2)	
2000	400	(203)	500	(253)
2500	500	(253)	700	(355)
3000	600	(304)	750	(380)
4000	700	(380)	1000	(508)
500	900	(456)	1250	(635)
6000	1200	(608)	1500	(759)
Note – See Table 19.2 for equivalent area of bus.				

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Table 19.2
Equivalent cross-sectional areas of wires and buses

Wire size, AWG or kcmil (mm^2)		Minimum cross section of bus mm^2	($inch^2$)
8	(8.4)	8.39	(0.013)
6	(13.3)	13.55	(0.021)
4	(21.1)	21.29	(0.033)
3	(26.7)	26.45	(0.041)
2	(33.6)	33.55	(0.052)
1	(42.4)	42.58	(0.066)
0	(53.5)	53.55	(0.083)
2/0	(7.4)	67.74	(0.105)
3/0	(85.0)	85.16	(0.132)
4/0	(107)	107.10	(0.166)
250	(127)	236.45	(0.196)
300	(152)	152.26	(0.236)
350	(177)	177.42	(0.275)
400	(203)	202.58	(0.314)
500	(253)	253.55	(0.393)
600	(304)	303.87	(0.471)
700	(355)	364.84	(0.550)
750	(380)	380.00	(0.589)
800	(405)	405.16	(0.628)
1000	(507)	506.45	(0.785)
1200	(608)	607.73	(0.942)
1250	(633)	632.90	(0.981)
1500	(760)	760.00	(1.178)

20 Internal Bonding for Grounding

Section 20 effective November 7, 2000

20.1 All exposed dead metal parts, which in the event of an electrical malfunction, involve a risk of electric shock or electrical energy-high current levels, shall be conductively connected to the equipment-grounding means specified in Equipment Grounding, Section 18.

20.2 In a unit having means for grounding, all uninsulated metal parts of the enclosure, motor frames and mounting brackets, component mounting brackets, capacitors, and other electrical components that involve a risk of electric shock or electrical energy-high current levels shall be bonded for grounding where they are accessible for contact by the user or inadvertent contact by a serviceman.

Exception: A metal part as described in (a) – (g) is not required to be bonded for grounding:

a) An adhesive-attached metal foil marking, a screw, a handle, or similar metal part, that is located on the outside of an enclosure or cabinet and isolated from electrical components or wiring by grounded metal parts so that they do not become energized.

b) An isolated metal part, such as a magnet frame and an armature, a small assembly screw, or similar part, that is positively separated from wiring and uninsulated live parts.

c) A panel or cover that does not enclose uninsulated live parts; and wiring is positively separated from the panel or cover so that it is unable to become energized.

d) A panel or cover that is secured in place and that is insulated from electrical components and wiring by an insulating barrier of vulcanized fiber, varnished cloth, phenolic composition, or similar material not less than 0.8 mm (1/32 inch) thick.

e) An isolated metal part that is mounted on a printed wiring board – such as transformer and choke cores and heat sinks.

f) An isolated metal part that is marked in accordance with 64.12.

g) A capacitor sleeved with insulating tubing complying with 24.2.2.

20.3 A metal-to-metal piano-type hinge is usable as a means for bonding a door for grounding.

20.4 Where the continuity of the grounding system relies on the dimensional integrity of a nonmetallic material, the material shall be in accordance with the requirements for creep in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. See also 20.9.

20.5 A conductor or strap used for bonding shall be of copper, a copper alloy, or an equivalent material. A conductor or strap:

a) Shall be protected from mechanical damage or be located within the outer enclosure or frame,

b) Shall not be secured by a removable fastener used for any purpose other than bonding for grounding, unless there is a low risk of the bonding conductor being omitted after removal and replacement of the fastener, and

c) Shall not be spliced.

20.6 A connection in the bonding path shall be by a positive means, such as by a clamp, a rivet, a bolted or screwed connection, or by welding, soldering, or brazing with materials having a softening or melting point greater than 455°C (850°F). The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel. Ferrous metal parts in the grounding path shall be protected against corrosion by painting, galvanizing, plating, or equivalent means. Bonding around a resilient mount shall not depend on the clamping action of rubber or similar material.

20.7 A bolted or screwed connection that incorporates a star washer under the screwhead shall penetrate nonconductive coatings and shall comply with Grounding Impedance Test, Section 48.

20.8 Where the bonding connection depends on screw threads in metal, two or more screws or two full threads of a single screw engaging two full threads in the metal shall be used.

20.9 A connection that depends on the clamping action exerted by rubber or similar material shall comply with Bonding Conductor Test, Section 52, when installed as intended. The material shall be rated for the condition of use, such as oil, grease, moisture, and thermal degradation that potentially occur in service. Before testing, the clamping device is to be disassembled as it is for maintenance purposes and then reassembled.

20.10 A bonding conductor or strap:

a) Shall not be smaller than the size specified in Column 2 of Table 18.1, see 20.11,

b) Shall not be smaller than the conductor supplying the component, or

c) Shall comply with Grounding Impedance Test, Section 48.

Exception: A smaller conductor or strap is usable when it complies with Bonding Conductor Test, Section 52.

20.11 With reference to Column 2 of Table 18.1, where more than one size branch-circuit overcurrent device is involved, the size of the bonding conductor or strap is to be based on the rating of the overcurrent device intended to provide ground-fault protection for the component bonded by the conductor.

20.12 The bonding connection, the enclosure, the frame, or a component mounting panel shall not carry current other than current resulting from an electrical malfunction.

Exception: An enclosure, frame, chassis, or panel, having bolted joints, is not restricted from carrying the current of a low-voltage, limited-energy (LVLE) circuit. Current shall not normally be carried through the field-equipment grounding means, the metallic raceway or other inverter grounding means, or the earth ground.

21 Internal Wiring

Section 21 effective November 7, 2000

21.1 General

21.1.1 The internal wiring of a unit shall consist of general-use building wire or appliance wiring material rated for the temperature, voltage, and conditions of service to which the wiring is subjected. The insulation of appliance wiring material shall comply with Table 21.1.

Exception: Appliance wiring material having an insulation thickness other than specified in Table 21.1 complies when the insulation ratings are equivalent to that specified with respect to temperature, voltage, and conditions of service.

Table 21.1
Appliance-wiring material

Type of insulation	Thickness of insulation, mm (inch)[a]	
	600-volt applications	300-volt applications
Thermoplastic	0.8 (1/32)	0.8 (1/32)[b,c]
Rubber	0.8 (1/32) plus an impregnated braid cover	0.4 (1/64) plus impregnated braid cover 0.8 (1/32) without a braid cover
Neoprene	0.2 (3/64)	0.4 (1/64) plus an impregnated braid cover 0.8 (1/32) without a braid cover
Silicone rubber	0.8 (1/32) plus an impregnated braid cover 0.8 (1/32) without a braid cover[d]	0.4 (1/64) plus an impregnated braid cover 0.8 (1/32) without a braid cover[d]
Cross-linked synthetic polymer	0.4 (1/64)	0.4 (1/64)

[a] The minimum thickness is 0.71 mm (0.028 inch) for 0.8 mm-thick insulation; the minimum thickness is 0.33 mm (0.013 inch) for 0.4 mm-thick insulation

[b] Shall not be less than 0.33 mm (0.013 inch) for short, moving pigtails or coil leads in a small device, where such leads make no more than casual contact with parts of opposite polarity or ungrounded parts.

[c] Shall not be less than 0.18 mm (0.007 inch) where routed away from live parts of opposite polarity and protected from mechanical damage during installation of field wiring and while the equipment is in operation.

[d] Applies only when routed away from live parts of opposite polarity and protected from mechanical damage during installation of field wiring and while the equipment is in operation.

21.1.2 Insulating tubing or sleeving shall not be used as insulation other than for a short length of insulated conductor, for example, a short coil lead, or similar component. Where so used:

a) The tubing or sleeving shall not be subjected to compression, repeated flexure, or sharp bends,

b) The conductor covered with the tubing or sleeving shall be well rounded and free from sharp edges,

c) A shrinkable tubing shall be used in accordance with the tubing manufacturer's instructions, and

d) The tubing or sleeving shall not be subjected to a temperature or voltage higher than that for which the tubing or sleeving is rated.

21.1.3 Where wiring extends to a hinged door or other part that is subject to movement in use, stranded conductors shall be employed, and the arrangement shall preclude twisting or stressing of conductors as a result of the movement. The wiring shall be routed or protected against damage to the insulation. The conductors shall be secured so that stress is not transmitted to terminals or splices.

21.2 Protection of wiring

21.2.1 Internal wiring shall not be accessible from outside the enclosure in accordance with 9.1.

21.2.2 Wires within an enclosure, compartment, raceway, or similar housing, shall be located or protected against contact with any sharp edge, burr, fin, moving part, or similar part, that is able to damage the conductor insulation.

21.2.3 Mounting screws and nuts shall be constructed or located so that sharp edges do not damage wiring. A screw shall have a flat or blunt end. The end of the screw shall not have burrs, fins, or sharp edges that are able to abrade wire insulation, and the end shall not project more than 4.8 mm (3/16 inch) into a wireway.

21.2.4 A hole through which insulated wires pass in a sheet metal wall internal to the overall enclosure of a unit shall be provided with smooth, rounded surfaces upon which the wires bear, to protect against abrasion of the insulation.

21.3 Electrical connections

21.3.1 A splice or connection shall be mechanically secure and shall make reliable electrical contact.

21.3.2 A soldered connection shall be made mechanically secure before being soldered.

Exception: A connection is not required to be mechanically secured before soldering when:

> *a) A soldering or brazing material having a softening or melting point greater than 454°C (849°F) is used,*
>
> *b) A hand-soldered lead is passed through a hole in a printed wiring board and bent 90 degrees to the board to make contact with the conductor before soldering,*
>
> *c) Soldering on a printed wiring board is done by a machine process in which the soldering time and solder temperature are automatically controlled – bending over of leads is not required, or*
>
> *d) The lead wire is strapped in place, or the equivalent, adjacent to the soldered connection to hold the lead end in place.*

21.3.3 A stranded internal wiring connection shall be such that it reduces the potential for loose strands of wire contacting dead metal parts or other live parts not always of the same potential. This is able to be accomplished by the use of a pressure terminal connector, a soldering lug, a crimped eyelet, soldering of all strands together, or an equivalent means.

21.3.4 An open-end spade lug secured by a screw or nut shall be secured by additional means, such as upturned ends on the lug, or bosses or shoulders on the terminal, to hold the lug in place in the event the screw or nut loosens.

21.3.5 A nominal 0.110-, 0.125-, 0.187-, 0.205-, or 0.250-inch wide quick-connect terminal shall comply with the Standard for Electrical Quick-Connect Terminals, UL 310. Other sizes of quick-connect terminals shall be investigated with respect to crimp pull-out, engagement-disengagement forces of the connector and tab, and temperature rises in accordance with UL 310.

21.3.6 Aluminum conductors, insulated or uninsulated, used as internal wiring, such as for interconnection between current-carrying parts or in a component winding, shall be terminated at each end by a terminal that is rated for the combination of metals involved at the connection points. A wire-binding screw or a pressure wire connector used as a terminating device shall be rated for use with aluminum under the conditions involved – for example, temperature, heat cycling, vibration, and other similar conditions.

21.3.7 A splice shall be provided with insulation equivalent to that of the wires involved unless permanent spacings are maintained between the splice and other metal parts.

a) Splicing devices such as pressure wire connectors insulated for the voltage and temperature to which they are subjected are in compliance with this requirement.

b) Insulating tubing or sleeving used to cover a splice shall comply with 21.1.2.

c) Two layers of thermoplastic tape, or two layers of friction tape, or one layer of friction tape and one layer of rubber tape, are able to be used on a splice when the voltage involved is less than 250 volts. The use of thermoplastic tape wrapped over a sharp edge is not in compliance with the requirement.

22 Live Parts

Section 22 effective November 7, 2000

22.1 A current-carrying part shall be of silver, copper, copper alloy, aluminum, or the equivalent.

22.2 Uninsulated live parts and components that have uninsulated live parts shall be secured so they do not turn or shift in position where such displacement results in a reduction of spacings below the minimum values specified in Spacings, Section 24, or Alternate Spacings – Clearances and Creepage Distances, Section 25.

23 Separation of Circuits

23.1 Factory wiring

Section 23.1 effective November 7, 2000

23.1.1 Insulated conductors of different circuits– see 23.1.2 – within a unit, including wires in a terminal box or compartment, shall be separated by barriers or segregated and shall also be so separated or segregated from uninsulated live parts connected to different circuits.

Exception: For insulated conductors of different circuits, where each conductor is provided with insulation rated for the highest of the circuit voltages, no barriers or segregation are required.

23.1.2 For the purpose of determining compliance with 23.1.1, different circuits include:

a) Circuits connected to the primary and secondary windings of an isolation transformer,

b) Circuits connected to different isolated secondary windings of a multi-secondary transformer,

c) Circuits connected to secondary windings of different transformers,

d) Input and output circuits of an optical isolator,

e) Isolated circuits, and

f) AC power and dc power circuits.

Exception: Power circuits that are derived from the taps of an autotransformer or similar component – that does not provide isolation – are not different circuits.

23.1.3 Segregation of insulated conductors shall be by means of clamping, routing, or an equivalent means that maintains permanent separation from insulated and uninsulated live parts and from conductors of a different circuit.

23.2 Field wiring

Section 23.2 effective November 7, 2000

23.2.1 A unit shall be constructed so that a field-installed conductor of a circuit is separated as specified in 23.2.2 or separated by barriers as specified in 23.3.1 and 23.3.2 from:

a) Factory-installed conductors connected to any other circuit, unless the conductors of both circuits are insulated for the maximum voltage of one of the circuits.

b) An uninsulated live part of another circuit or from an uninsulated live part where a short circuit between the conductors involves a risk of fire, electric shock, electrical energy-high current levels, or injury to persons.

c) Field-installed conductors connected to any other circuit unless:

1) Both circuits are Class 2 or Class 3 or both circuits are other than Class 2 or Class 3, and

2) Both circuits are insulated for the maximum voltage of one of the circuits.

Exception: A field-installed conductor is not required to be separated from a field wiring terminal of a different circuit where the field wiring is intended to be insulated for the maximum voltage of one of the circuits, and both circuits are Class 2 or Class 3 or both circuits are other than Class 2 or Class 3.

23.2.2 Separation of a field-installed conductor from another field-installed conductor and from an uninsulated live part connected to another circuit is able to be accomplished by locating an opening in the enclosure for the conductor opposite to the conductor terminal so that, when the installation is complete, the conductors and parts of different circuits are separated by a minimum of 6.4 mm (1/4 inch). In determining whether a unit having such openings complies with this requirement, it is to be wired as in service including 152.4 mm (6 inches) of slack in each conductor within the enclosure. No more than average care is to be exercised in routing the wiring and stowing the conductor slack into the wiring compartment.

23.2.3 With reference to 23.2.2, when the number of openings in the enclosure does not exceed the minimum required for the intended wiring of the unit, and where each opening is located opposite a set of terminals, it is to be assumed that a conductor entering an opening is to be connected to the terminal opposite that opening. When more than the minimum number of openings are provided, the possibility of a conductor entering an opening other than the one opposite the terminal to which it is intended to be connected and the potential for it to contact insulated conductors or uninsulated current-carrying parts connected to a different circuit is to be investigated.

23.3 Separation barriers

23.3.1 A barrier used for separation between the wiring of different circuits shall be:

a) Grounded metal or 0.71 mm (0.028 inch) minimum thick insulating material, and

b) Supported so that it is unable to be readily deformed or displaced to defeat its purpose.

23.3.1 revised January 17, 2001

23.3.2 A barrier used for separation between field wiring of one circuit and field or factory wiring or uninsulated live parts of another circuit shall not be spaced more than 1.6 mm (1/16 inch) from the surface that serves to provide separated compartments.

23.3.2 effective November 7, 2000

24 Spacings

Section 24 effective November 7, 2000

24.1 General

24.1.1 The spacings in a unit shall not be less than specified in Table 24.1.

Exception No. 1: Where liners and barriers are employed, 24.2.1 shall be used to determine the spacings.

Exception No. 2: As an alternative to Table 24.1, the spacings are able to be investigated in accordance with Alternate Spacings – Clearances and Creepage Distances, Section 25.

Exception No. 3: The inherent spacings of a component shall comply with the spacing requirements for the component.

Exception No. 4: The spacings specified in Table 24.1 do not apply within a circuit that complies with Isolated Accessible Signal Circuits, Section 28, or Control Circuits, Section 29. The spacing between these circuits and other circuits shall comply with Table 24.1.

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Exception No. 5: Spacings between adjacent foils on a printed wiring board with a conformal coating complying with the requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluation, UL 746C, are not required to comply with Table 24.1.

Exception No. 6: On printed wiring boards having a flammability classification of V-0 and constructed from a base material having a minimum Comparative Tracking Index (CTI) rating of 175 volts, spacings (other than spacings to ground, between primary and secondary circuits, between the battery supply circuit and other circuits and at field wiring terminal) are not specified between traces of different potential connected in the same circuit where:

a) The spacing complies with Reduced Spacings on Printed Wiring Boards Tests, Section 51, or

b) An analysis of the circuit indicates that no more than 12.5 milliamperes of current is able to flow between short-circuited traces having reduced spacings.

Exception No. 7: For multilayer printed wiring boards, the minimum spacing between adjacent internal foils of opposite polarity and between an internal foil and a plated through-hole shall not be less than 0.8 mm (1/32 inch).

Exception No. 8: Spacing requirements do not apply between adjacent terminals of a power switching semiconductor device, including the connection points of the terminals of the device.

Table 24.1
Spacings

Potential involved, volts rms (peak)	Minimum spacings, mm (inch)					
	Between an uninsulated live part and an uninsulated live part of opposite polarity, uninsulated grounded part other than the enclosure, or exposed metal part[a]				Between an uninsulated live part and the walls of a metal enclosure including a fitting for conduit or armored cable[b]	
	Through air		Over surface		Shortest distance	
0 – 50 (0 – 70.7)	1,6[c,d]	(1/16)	1.6[c,d]	(1/16)	1.6[c]	(1/16)
Greater than 50 to 150 (70.7 to 212.1)	3.2[c,d]	(1/8)	6.4[d]	(1/4)	6.4	(1/4)
Greater than 150 to 300 (212.1 to 424.2)	6.4	(1/4)	9.5	(3/8)	12.7	(1/2)
Greater than 300 to 600 (424.2 to 848.4)	9.5	(3/8)	12.7	(1/2)	12.7	(1/2)

[a] For printed wiring boards, see Exceptions Nos. 2 – 7 to 24.1.1.

[b] A metal piece attached to the enclosure shall be invstigated as a part of the enclosure where deformation of the enclosure reduces spacings between the metal piece and uninsulated live parts.

[c] The spacing between field-wiring terminals of opposite polarity and the spacing between a field-wiring terminal and a grounded dead metal part shall not be less than 6.4 mm (1/4 inch).

[d] At closed-in points only, such as a screw and washer construction of a insulated stud mounted in metal, the spacing shall not be less than 1.2 mm (3/64 inch).

24.1.2 Uninsulated live parts connected to different circuits shall be investigated as though they are parts of opposite polarity and on the basis of the highest voltage involved. See Maximum-Voltage Measurements, Section 42.

24.1.3 The spacing at a field wiring terminal is to be measured with wires representative of field wiring in place and connected to the terminals as in actual service.

24.1.4 In a multi-component unit, the spacings from one component to another, from any component to the enclosure, and to another uninsulated dead metal part (excluding the component mounting surface), are to be based on the maximum voltage rating of the complete unit and not on the individual component ratings. The inherent spacings of an individual component is to be investigated on the basis of the voltage used and controlled by the individual component. Spacings between metal oxide varistors, capacitors, and other components shall comply with Table 24.1.

Exception: Components that comply with the requirements in the Standard for Across-the-Line, Antenna Coupling, and Line-By-Pass Capacitors for Radio- and Television-Type Appliances, UL 1414, are not required to comply with Table 24.1.

24.1.5 Spacings for a fuse and fuseholder are to be measured with a fuse in place that has the maximum standard dimension for the rating, and such spacings shall not to be less than those specified in Table 24.1.

24.1.6 Where an uninsulated live part is not rigidly secured in position by means other than friction between surfaces, or where a movable dead metal part is in proximity to an uninsulated live part, the construction shall be such that for any position resulting from turning or other movement of the parts in question, at least the minimum required spacings shall be maintained.

24.1.7 With reference to 24.1.6, a lock washer is one means of rigidly securing a part.

24.1.8 Spacings to film coated wire are to be investigated as though the wire is an uninsulated live part.

24.1.9 Spacings within the circuits described in (a), (b), or (c) that are not safety circuits shall be such that the circuit complies with Dielectric Voltage-Withstand, Section 44. Spacings between these circuits and the enclosure, grounded dead metal, and other circuits shall comply with the applicable spacing requirements of this Standard.

a) Secondary circuits supplied by a transformer winding rated less than 200 volt-amperes or at a potential of 100 volts or less,

b) Battery circuits at a potential of 100 volts or less, or

c) A circuit derived from a battery rated over 100 volts in which the voltage within the circuit is limited to 100 volts or less by a regulating network complying with the requirement in 29.11.

24.2 Insulating liners and barriers

24.2.1 With reference to Exception No. 1 to 24.1.1, an insulating liner or barrier of material such as vulcanized fiber is able to be used when it is:

a) Not the sole support for uninsulated live parts involving a risk of fire, electric shock, or electrical energy-high current levels,

b) Not less than 0.71 mm (0.028 inch) thick, and

c) Located so that it is not adversely affected by arcing.

Other insulating materials used as a barrier or as direct or indirect support of uninsulated live parts involving a risk of fire, electric shock, or electrical energy-high current levels shall comply with the requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

Exception No. 1: Vulcanized fiber not less than 0.33 mm (0.013 inch) thick is usable when:

a) In conjunction with an air spacing of not less than 50 percent of the minimum through air spacing as specified in Table 24.1, and

b) Between a heat sink and a metal mounting surface, including the enclosure, of an isolated secondary circuit rated 50 volts rms or less.

Exception No. 2: Mica shall be not less than 0.165 mm (0.006 inch) thick when used as insulation between a heat sink and a live case of a semiconductor device.

24.2.2 Insulating tubing complying with the requirements in the Standard for Extruded Insulating Tubing, UL 224, is usable for insulating a conductor including a bus bar in lieu of the minimum specified spacings and insulating a capacitor case in lieu of bonding the case for grounding, when the following conditions are met:

a) The conductor is not subjected to compression, repeated flexing, or sharp bends,

b) The conductor or case covered with the tubing is well rounded and free from sharp edges,

c) The tubing is used in accordance with the manufacturer's instructions, and

d) The conductor or case is not subjected to a temperature or voltage higher than that for which the tubing is rated.

24.2.3 A wrap of thermoplastic tape, complying with the requirements in the Standard for Polyvinyl Chloride, Polyethylene, and Rubber Insulating Tape, UL 510, is usable when all of the following conditions are met:

a) The wrap is no less than 0.33 mm (0.013 inch) thick, is applied in two or more layers, and is used in conjunction with not less than one-half the required through-air spacing.

b) The wrap is not less than 0.72 mm (0.028 inch) thick where used in conjunction with less than one-half the required through-air spacing.

c) The temperature rating of the tape is not less than the maximum temperature observed during the temperature test.

d) The tape is not subject to compression.

e) The tape is not wrapped over a sharp edge.

25 Alternate Spacings – Clearances and Creepage Distances

Section 25 effective November 7, 2000

25.1 Other than specified in 25.2 and 25.3, as an alternative approach to the spacing requirements specified in Spacings, Section 24, clearances and creepage distances are able to be investigated in accordance with the requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, as described in 25.4. See Maximum-Voltage Measurements, Section 42.

25.2 The clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable, shall be as specified in Table 24.1. The clearances are to be determined by physical measurement.

25.3 The clearances and creepage distances at field wiring terminals shall comply with Spacings, Section 24.

25.4 In conducting investigations in accordance with the requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, the following shall be used:

a) Unless specified elsewhere in this Standard, the pollution degree 3 applies,

b) An inverter shall comply with the requirements for Overvoltage Category IV,

c) Pollution degree 2 applies on a printed wiring board between adjacent conductive material which is covered by any coating which provides an uninterrupted covering over at least one side and the complete distance up to the other side of conductive material,

d) All printed wiring boards shall be identified as having a minimum Comparative Tracking Index (CTI) of 100 without further investigation.

e) The use of a coating which complies with the requirements for conformal coatings in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C is in compliance with the requirements of UL 840 to achieve pollution degree 1,

f) Pollution degree 1 is achievable at a specific printed wiring board location by application of at least a 0.79 mm (1/32 inch) thick layer of silicone rubber or for a group of printed wiring boards through potting, without air bubbles, in epoxy or potting material,

g) The Phase-to-Ground Rated System Voltage used in the determination of Clearances shall be the equipment rated supply voltage rounded to the next higher value (in the table for determining clearances for equipment) for all points on the supply side of an isolating transformer or the entire product when no isolating transformer is provided. The System Voltage used in the evaluation of secondary circuitry is able to be interpolated across the table for the Rated Impulse Withstand Voltage Peak and Clearance, and

h) Determination of the dimensions of clearance and creepage distances shall be conducted in accordance with the requirements for Measurement of Clearance and Creepage Distances of UL 840.

26 Insulating Materials

Section 26 effective November 7, 2000

26.1 General

26.1.1 A polymeric material on which uninsulated live parts is mounted shall be Classed V-0, V-1, or V-2 in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The use of a material Classed V-2 requires the use of an enclosure without ventilation openings. Drain holes are not prohibited regardless of the material Class.

Exception: This requirement does not apply to a material supporting only live parts connected in low-voltage, limited-energy (LVLE) circuits where deterioration of the material does not involve a risk of fire or electric shock.

26.1.2 Vulcanized fiber shall not be used as the sole support of an uninsulated live part where shrinkage, current leakage, or warpage introduces a risk of fire or electric shock. Electrical grade vulcanized fiber is able to be used for an insulating bushing, a washer, a separator, or a barrier.

26.1.3 A polymeric material used to support an uninsulated live part or parts, shall comply with the requirements for mechanical strength and rigidity, resistance to heat, resistance to flame propagation, and dielectric strength in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A; Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B; and the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

26.2 Barriers

26.2.1 An insulating barrier of vulcanized fiber, thermoplastic, or other material used in lieu of required spacings shall not be less than 0.71 mm (0.028 inch) thick and shall be so located or of such material that it is not adversely affected by arcing.

Exception: Vulcanized fiber not less than 0.33 mm (0.013 inch) thick is usable:

a) In conjunction with an air spacing of not less than 50 percent of the minimum through-air spacing as specified in Table 24.1, and

b) Between a heat sink and a metal mounting surface, including the enclosure, or an isolated secondary circuit rated 50 volts rms or less.

26.2.2 Insulation used in lieu of required spacings between a magnet-coil winding and other uninsulated live parts or grounded dead metal parts, shall comply with 26.2.1.

27 Capacitors

Section 27 effective November 7, 2000

27.1 A capacitor used for electromagnetic interference elimination or power-factor correction that is oil filled shall comply with the Standard for Capacitors, UL 810.

Exception: The container of the capacitor is able to be of thinner sheet metal or be of material other than metal, where the capacitor is mounted inside a unit having an enclosure that complies with the requirements in 5.1.1 – 5.5.1 without Exceptions.

27.2 A capacitor connected across an input/output ac circuit that is connected to a utility shall comply with the requirements for across-the-line capacitors in the Standard for Across-the-Line, Antenna-Coupling, and Line-By-Pass Capacitors for Radio- and Television-Type Appliances, UL 1414.

28 Isolated Accessible Signal Circuits

28.1 An isolated accessible signal circuit having means for external connections, such as a RS232 communication port and similar connections, shall comply with 28.2 and 28.3.

28.1 effective November 7, 2000

28.2 A signal circuit that extends outside of a unit shall be an isolated circuit and shall be isolated from internal circuits having a voltage involving a risk of electric shock, as determined in accordance with Electric Shock, Section 11, by one of the following:

a) An optical isolator, complying with the Standard for Optical Isolators, UL 1577, having an isolation voltage rating of not less than the test potential required in 44.1.1,

b) An isolation transformer complying with the Standard for Class 2 and Class 3 Transformers, UL 1585, or an isolation transformer as defined in 2.21 – autotransformers are excluded,

c) A capacitor complying with the Standard for Capacitors and Suppressors for Radio- and Television-Type Appliances, UL 1414,

d) An electro-mechanical relay complying with the requirements in the Standard for Industrial Control Equipment, UL 508, or

e) A voltage regulating network where:

1) The voltage being isolated is not directly derived from the ac circuit, and

2) The network does not involve a risk of electric shock at the external connection as determined in accordance with Electric Shock, Section 11, or as indicated by a failure mode and effect analysis in accordance with the method described in the Standard for Tests for Safety Related Controls Employing Solid-State Devices, UL 991.

28.2 revised January 17, 2001

28.3 The maximum power voltage and current available from an isolated accessible signal circuit shall comply with 29.4 – 29.11.

28.3 revised January 17, 2001

28.4 The maximum power available from an isolated accessible signal circuit that employs an overcurrent protection device to limit the current as described in the Exception to 29.4 shall not exceed the values specified in Table 28.1.

28.4 effective November 7, 2000

Table 28.1
Maximum power of isolated accessible signal circuits

Table 28.1 effective November 7, 2000

Circuit voltage, volts rms	Maximum power, volt-amperes
15 or less	350
More than 15 and not greater than 60	250

29 Control Circuits

Section 29 effective November 7, 2000

29.1 A control circuit that is a low-voltage, limited-energy (LVLE) circuit or a limited-energy (LE) circuit is able to be connected to a single-point reference ground.

29.2 Other than for safety circuits, as indicated in 29.3, a low-voltage, limited-energy (LVLE) circuit is not required to be investigated. Printed-wiring boards and insulated wire used in such circuits shall comply with 21.1.1 and 32.1.

29.3 A control circuit that is a safety circuit shall be investigated in accordance with the requirements for primary circuits.

29.4 A control circuit, including associated electronic components on printed wiring boards, that does not extend out of the unit is not required to be investigated where the maximum voltage and current are limited as specified in (a) and (b). Printed wiring boards and insulated wires used in such circuits shall comply with 21.1.1 and 32.1.

a) The voltage shall not exceed the limits specified in Table 11.1, and

b) The current shall not exceed:

1) Eight amperes for 0 – 42.4 volts peak ac, or 0 – 30 volts dc, or

2) Amperes equal to 150 divided by the maximum voltage for 30 – 60 volts dc. See 29.5.

Exception: The maximum current specified is able to be exceeded where the circuit includes an overcurrent protective device as described in 29.8 and 29.9.

29.5 With reference to 29.4(b), the maximum current is to be measured under any condition of loading including short circuit using a resistor that is to be continuously readjusted during the 1-minute period to maintain maximum load current; however, the value indicated in (b) is not to be exceeded.

29.6 With reference to 29.4(a), measurement is to be made with the unit connected to the voltage specified in 44.1 and with all loading circuits disconnected. When a tapped transformer winding is used to supply a full-wave rectifier, voltage measurement is to be made from either end of the winding to the tap.

29.7 When the control circuit specified in 29.4 is not limited as to available short-circuit current by the construction of a transformer, and the circuit includes one or more resistors, a fuse, a nonadjustable manual-reset protective device, or a regulating network – see 29.11 – the circuits in which the current is limited in accordance with 29.8, 29.9, or 29.10 are not required to be investigated.

29.8 A fuse or circuit-protective device used to limit the current in accordance with 29.7 shall be rated or set at not more than the values specified in Table 29.1.

Table 29.1
Rating for secondary fuse or circuit protector

Circuit voltage, V rms	Maximum overcurrent protection, amperes
20 or less	5
More than 20 and not greater than 60	100/V[a]

[a] V is the maximum output voltage, regardless of load, with the primary energized in accordance with 44.1.

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29.9 A fuse or circuit-protective device connected to the primary of a transformer to limit the current in accordance with 29.7 shall be equivalent to that specified in 29.8 as determined by conducting the Overcurrent Protection Calibration Test, Section 49.

Exception: The Overcurrent Protection Calibration Test, Section 49, does not apply when the combination of a fuse or overcurrent protective device and a transformer complies with the Standard for Class 2 and Class 3 Transformers, UL 1585.

29.10 A regulating network or one or more resistors used to limit the current in accordance with 29.7 shall be such that the current under any condition of load, including short circuit, does not exceed the values indicated in 29.4(b).

29.11 Where a regulating network is used to limit the voltage or current in accordance with 29.4 – 29.10, and the performance is affected by malfunction (short circuit or open circuit) of any single component – excluding short-circuiting a resistor – the network:

a) Shall comply with the tests specified in 29.13, and

b) Critical components identified by the failure mode and effect analysis in accordance with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, shall be derated in accordance with the Electronic Reliability Design Handbook, Military Handbook Number 338-1988.

29.12 In a circuit of the type described in 29.7, the secondary winding of the transformer, the fuse or circuit protective device, or the regulating network, and all wiring up to the point at which the current and voltage are limited shall be investigated in accordance with the applicable requirements in this Standard.

29.13 With reference to 29.11 (a), the regulating network shall comply with the following tests in accordance with the method described in the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991. See 29.14.

a) Transient Overvoltage Test,

b) Ramp Voltage Test,

c) Electromagnetic Susceptibility Tests,

d) Electrostatic Discharge Test,

e) Thermal Cycling Test,

f) Humidity Test, and

g) Effects of Shipping and Storage Test.

29.14 The following test parameters are to be used in the investigation of a regulating network covered by 29.13.

a) Electrical supervision of critical components applies,

b) Audibility is usable as a trouble indicator for an electrical supervision circuit,

c) A field strength of 3 volts per meter is to be used for the Radiated EMI Test, and

d) Exposure Class H5 is to be used for the Humidity Test.

30 Overcurrent Protection

30.1 General

30.1.1 An overcurrent protective device, the intended functioning of which requires renewal, replacement, or resetting, shall be accessible:

a) From outside of the enclosure, or

b) Behind a hinged cover – see 5.2.1.

Exception No. 1: A protective device that is normally unknown to the user because of its location and omission of reference to the device in the operating instructions provided with the unit is not required to be accessible.

Exception No. 2: A control-circuit fuse does not require renewal as an intended function when the fuse and the load are contained within the same enclosure.

30.1.1 effective November 7, 2000

30.1.2 The screw shell of a plug-type fuseholder and the contacts, including associated live parts that are able to be contacted by the probe illustrated in Figure 9.1, of an extractor-type fuseholder shall be connected toward the load.

30.1.2 effective November 7, 2000

30.1.3 The type of fuseholder described in 30.1.2 shall not be used in circuits where boths ends of the fuse are live, such as between an inverter and the utility or between a charge controller and a battery.

30.1.3 effective November 7, 2000

30.1.4 A fuse and a fuseholder shall have voltage and current ratings not less than the circuit in which they are connected. A plug fuse shall not be used in a circuit exceeding 125 volts or in a 125/250 volts, 3-wire, circuit.

30.1.4 effective November 7, 2000

30.1.5 A fuseholder shall be of the cartridge, plug, or extractor type.

Exception: A fuse intended to be replaced only by service personnel– see Protection of Service Personnel, Section 10 – that is bolted in place meets the intent of this requirement.

30.1.5 effective November 7, 2000

30.1.6 A plug-type fuseholder shall be of the Type S construction.

30.1.6 effective November 7, 2000

30.1.7 An appliance protector used in the output circuit of an inverter in lieu of a branch-circuit rated fuse or circuit breaker shall have a short-circuit interrupting rating not less than the maximum fault current available from the inverter and shall comply with the requirements in the Standard for Supplementary Protectors for Use in Electrical Equipment, UL 1077.

30.1.7 effective November 7, 2000

30.1.8 A circuit breaker in the input or output circuit shall open all ungrounded conductors of the circuit. A multipole circuit breaker shall be a common trip type.

Exception: Single-pole circuit breakers with handle ties, the combination of which complies with the applicable requirements in the Standard for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures, UL 489, are usable as the protection for each ungrounded conductor supplying line-to-line connected loads of equipment rated for connection to one of the following circuits of a grounded system, where no conductor involves a potential to ground in excess of 150 volts (see 64.9):

a) In a single-phase circuit,

b) In a 3-wire dc circuit, or

c) In a circuit that is connected to a 4-wire, 3-phase; or 5-wire, 2-phase, system with a grounded neutral.

30.1.8 effective November 7, 2000

30.1.9 A unit shall be marked in accordance with 64.6 when it is provided with overcurrent protection consisting of an interchangeable fuse and when the fuse is:

a) Accessible to the user, or

b) Used to comply with the requirements in this Standard.

30.1.9 effective November 7, 2000

30.1.10 An overcurrent protective device shall not be connected in the grounded (neutral, in an ac circuit) side of the supply circuit unless the protective device simultaneously disconnects the grounded and ungrounded conductors of the supply circuit.

30.1.10 effective November 7, 2000

30.1.11 Temperature or current-sensitive devices such as temperature limiting thermostats, thermal cutoffs, appliance protectors, fuses, circuit breakers, or similar devices that are relied upon to comply with the Abnormal Tests, Section 47, shall comply with the requirements applicable to the particular component. See Components, Section 30.

30.1.11 effective November 7, 2000

30.1.12 Overcurrent protection employing solid-state component circuitry used for protection of control circuits in accordance with 30.2.1 – 30.2.5 shall comply with the calibration and interrupt requirements in the Standard for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures, UL 489. The interrupt test is to be based on the maximum rated short circuit current available from the inverter.

Exception: These requirements do not apply to overcurrent protection whose performance is not affected by malfunction of any single component that is short-circuited or open-circuited.

30.1.12 revised January 17, 2001

30.1.13 Units having overcurrent protective devices connected directly to input or output terminals or having overcurrent device terminals serving as inputs or outputs shall have labels or markings near those input or output terminals showing conductor temperature limitations for field installed conductors in accordance with Section 110.14 of the National Electrical Code, ANSI/NFPA 70.

Added 30.1.13 effective May 7, 2007

30.2 Control circuit overcurrent protection

30.2.1 A control circuit that extends from the unit to a remote control panel, status panel, or a similar component shall be protected in accordance with 30.2.2– 30.3.2.

Exception: An external control circuit derived from a Class 2 transformer is not required to be provided with overcurrent protection.

30.2.1 effective November 7, 2000

30.2.2 The overcurrent protective device specified in 30.2.1 shall be a circuit breaker or fuse that is:

a) Rated for branch-circuit overcurrent protection, or

b) In compliance with 30.1.6.

When the protective device is a fuse, the unit shall be marked in accordance with 64.6.

30.2.2 effective November 7, 2000

30.2.3 A Class 1 power-limited circuit, in accordance with the National Electrical Code, ANSI/NFPA 70, used to supply an external control circuit shall be supplied from a source having a rated output of no more than 30 volts and 1000 volt-amperes. When the source is other than a transformer, the circuit shall be protected by an overcurrent protection device rated no more than 167 percent of the volt-ampere rating divided by the rated voltage. The overcurrent device shall not be interchangeable with overcurrent devices of higher ratings.

30.2.3 revised January 17, 2001

30.2.4 An external control circuit derived from the secondary of a transformer other than that described in 30.2.3 and the Exception to 30.2.1 shall be provided with overcurrent protection in accordance with 30.2.5. For a transformer not having a rating, the rated primary or secondary current specified in 30.2.5 is to consist of the maximum current during normal operation of the unit.

30.2.4 revised January 17, 2001

30.2.5 A transformer used to supply a control circuit shall be provided with overcurrent protection in the primary circuit rated as indicated in Table 30.1.

Exception No. 1: Where the rated primary current of the transformer is 9 amperes or more and 125 percent of this current does not correspond to a Standard rating of fuse or circuit breaker, the next higher Standard rating of protective device shall be used. Standard ratings of protective devices are specified in Section 240.6 of the National Electrical Code, ANSI/NFPA 70.

Exception No. 2: Where the rated secondary current of the transformer is less than 9 amperes, the overcurrent protection in the secondary circuit is able to be rated or set at no more than 167 percent of the rated secondary current.

Exception No. 3: Where a control circuit is derived from the secondary of a transformer that is provided with primary circuit overcurrent protection rated at no more than 250 percent of the rated primary current of the transformer, additional overcurrent protection is not required in the primary circuit where the secondary circuit is protected at no more than 125 percent of the rated secondary current of the transformer.

30.2.5 revised January 17, 2001

No Text on This Page

Table 30.1
Primary overcurrent protection for control circuit transformers

Table 30.1 effective November 7, 2000

Rated primary current, amperes	Maximum rating of overcurrent device, percent of transformer primary current rating
Less than 2	300
2 or more and less than 9	167
9 or more	125

30.3 Output ac power circuit overcurrent protection

Section 30.3 effective November 7, 2000

30.3.1 An ac output power circuit shall be provided with overcurrent protection for all ungrounded conductors as described in 30.3.2 and 30.3.3. The voltage rating of the overcurrent protection shall not be less than the rating of the circuit with which it is used. The voltage rating for a 3-phase circuit shall be based on the phase-to-phase voltage. The overcurrent protection device shall be a circuit breaker or a fuse rated for use as branch circuit protection.

Exception: Overcurrent protection is not required to be provided with a unit having provision for permanent wiring connection of the output circuit and the instruction manual indicates that the overcurrent protection is to be provided by others. See 66.4(Q).

30.3.2 For a unit having provision for permanent wiring connection of the ac output power circuit, the rating of the overcurrent protection shall not exceed the ampacity of the conductors intended to be connected to the unit as determined in accordance with 16.1.3.

30.3.3 Where a unit includes one or more attachment-plug receptacles for connections to the ac output circuit, overcurrent protection shall be provided for each receptacle. A single overcurrent protection device, whose rating does not exceed the ampere rating of any receptacle connected to it, is usable when all receptacles are connected in parallel.

Exception: Two or more 15 ampere rated receptacles in a unit with 12 AWG (3.3 mm^2) minimum internal wiring are able to be protected by a 20 ampere overcurrent protection device.

30.4 Battery circuits

30.4.1 A unit intended for connection to a battery circuit shall be provided with overcurrent protection complying with the requirements described in 30.4.2– 30.4.4.

Exception: Overcurrent protection is not required to be provided when the instruction manual contains the statement indicated in 66.4(Q).

30.4.1 effective November 7, 2000

30.4.2 The overcurrent protective device shall be dc rated and shall be for branch-circuit protection in accordance with the National Electrical Code, NFPA 70.

30.4.2 revised January 17, 2001

30.4.3 The protective device shall be located adjacent to the battery connecting means ahead of any component which is able to malfunction under short-circuit conditions such as capacitors, solid-state devices, or similar components.

30.4.3 effective November 7, 2000

30.4.4 The rating of the overcurrent protective device shall be based on the ampacity of the conductors intended to be connected between the unit and battery as determined from the requirement described in 16.1.3 *under inverter mode operating conditions.*

30.4.4 effective November 7, 2000

31 DC Ground Fault Detector/Interrupter

31.1 Inverters or charge controllers with direct photovoltaic inputs from a grounded photovoltaic array or arrays shall be provided with a ground-fault detector/interrupter (GFDI). The GFDI shall be capable of detecting a ground fault, providing an indication of the fault, interrupting the flow of fault current, and either isolating the faulted array section or disabling the inverter to cease the export of power. The GFDI shall comply with 31.2 – 31.6 and Sections 53 – 56.

Exception No. 1: AC modules are not required to be provided with a GFDI.

Exception No. 2: Inverters or charge controllers without GFDI devices may be used when the unit includes markings in accordance with 66.4(S).

Revised 31.1 effective May 7, 2007

31.2 The ground-fault detector/interrupter (GFDI) shall sense a ground fault, interrupt the ground-fault current path and provide an indication of the fault when the ground-fault currents exceed the limits shown in Table 31.1.

Revised 31.2 effective May 7, 2007

Table 31.1
Maximum allowable ground current detection settings

Added Table 31.1 effective May 7, 2007

Device dc rating (kW)	Maximum ground-fault current detecting setting (Amperes)
0 – 25	1
25 – 50	2
50 – 100	3
100 – 250	4
> 250	5

31.3 A ground fault detector/interrupter that has tripped in accordance with 31.2 shall not be capable of automatic reclosure.

31.3 effective November 7, 2000

31.4 When a ground fault detector/interrupter trips as a result of utility loss of power in accordance with Utility Disconnect, Section 39, it shall be capable of automatic reclosure when power is restored.

31.4 effective November 7, 2000

31.5 When the ground fault detector/interrupter incorporates solid-state components, the ground fault detector/interrupter circuit shall be analyzed to determine the effect of malfunction of any component excluding the short circuiting of a resistor. Critical components identified by the failure mode and effect analysis in accordance with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, shall be derated in accordance with the Electronic Reliability Design Handbook, Military Hand Book Number 338-1988.

31.5 effective November 7, 2000

31.6 When the analysis specified in 31.5 indicates that the malfunction of one or more components renders the ground fault detector/interrupter inoperative, the components shall comply with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991. See 31.7 and 31.8.

31.6 effective November 7, 2000

31.7 With reference to 31.6, the components are to be subjected to the following test in accordance with the methods described in the Standard for Test for Safety-Related Controls Employing Solid-State Devices, UL 991:

a) Transient Overvoltage Test,

b) Ramp Voltage Test,

c) Electromagnetic Susceptibility Tests,

d) Electrostatic Discharge Test,

e) Thermally Cycling Tests,

f) Humidity Test, and

g) Effects of Shipping and Storage Test.

31.7 effective November 7, 2000

31.8 For the tests specified in 31.7:

a) Electrical supervision of critical components applies,

b) Audibility is usable as a trouble indicator for an electrical supervision circuit,

c) A field strength of 3 volts per meter is to be used for the Radiated EMI Test, and

d) Exposure class H5 is to be used for the Humidity Test.

31.8 effective November 7, 2000

31.9 An integral ground-fault detector/interrupter (GFDI) or a separate device shall not be linked to any main photovoltaic disconnect (internal or external to the unit) and operation of the main photovoltaic disconnect shall not affect the normal grounding of the system.

Added 31.9 effective May 7, 2007

31.10 An integral ground-fault detector/interrupter (GFDI) or a photovoltaic inverter intended for operation with a separate GFDI shall be marked in accordance with 64.16.

Added 31.10 effective May 7, 2007

32 Printed-Wiring Boards

32.1 A printed-wiring board in a unit shall comply with the Standard for Printed-Wiring Boards, UL 796. For a unit with miscellaneous or ventilation openings in the enclosure, the board shall be classed V-0 or V-1 in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The use of a material Classed V-2 requires the use of an enclosure without openings. Drain holes are not prohibited regardless of the material Class.

Exception: This requirement does not apply to a printed wiring board connected only in low-voltage, limited-energy (LVLE) circuits and where deterioration or breakage of the bond between a conductor and the base material does not result in a risk of fire or electric shock.

32.1 revised January 17, 2001

32A External Transformers

Added 32A effective May 7, 2007

32A.1 A manufacturer-specified external isolation transformer, see 2.25A, shall comply with the Standard for Dry-Type General Purpose and Power Transformers, UL 1561, or the Standard for Transformers, Distribution, Dry-Type B Over 600 Volts, UL 1562, whichever applies.

Added 32A.1 effective May 7, 2007

32A.2 A product that measures the utility voltage and frequency through a manufacturer-specified external isolation transformer that is also used to export power to the EPS shall be provided with that manufacturer-specified external isolation transformer.

Added 32A.2 effective May 7, 2007

32A.3 A product, not covered by 32A.2, that uses a manufacturer-specified external isolation transformer shall be provided with instructions in accordance with 65.2.8.

Added 32A.3 effective May 7, 2007

PROTECTION AGAINST RISKS OF INJURY TO PERSONS

33 General

Section 33 effective November 7, 2000

33.1 When operation, maintenance, or foreseeable misuse of a unit involves a risk of injury to persons, protection shall be provided to reduce the risk.

33.2 Among the factors to be regarded in judging exposed moving parts are:

a) Degree of exposure required to perform its intended function,

b) Sharpness of the moving part,

c) Potential for unintentional contact,

d) Speed of the moving part, and

e) Potential for a part of the body to be endangered or for clothing to be entangled by the moving part.

These factors are to be regarded with respect to both intended operation of the unit and foreseeable misuse.

33.3 Whether a guard, a release, an interlock, or similar device is required and whether such a device functions as intended shall be determined from a study of the complete unit, its operating characteristics, and the potential for a risk of injury to persons. The investigation is to include evaluation of the results of a breakdown or malfunction of any one component; however, not more than one component is to be investigated at a time, unless one event contributes to another. When the study shows that malfunction of a component is able to result in a risk of injury to persons, that component is to be investigated for reliability.

34 Enclosures and Guards

Section 34 effective November 7, 2000

34.1 A part capable of resulting in a risk of injury to persons shall be enclosed.

34.2 An opening in a guard or enclosure around a moving part that is able to involve a risk of injury to persons shall have a minor dimension less than 25.4 mm (1 inch), and shall not accommodate the probe illustrated in Figure 9.1 to contact the part when the probe is inserted through the opening to its maximum depth in a straight or articulated position.

34.3 An enclosure, an opening, a frame, a guard, a knob, a handle, or similar component, shall not be sharp enough to constitute a risk of injury to persons in normal maintenance or use.

34.4 A guard or portion of an enclosure acting as a guard for a part that involves a risk of injury to persons shall be:

a) Mounted to the assembly so that the part is unable to be operated with the guard or portion of the enclosure removed,

b) Secured to the assembly using fasteners requiring a tool for removal, or

c) Provided with an interlock to reduce the risk of contacting the part.

35 Moving Parts

Section 35 effective November 7, 2000

35.1 A rotating member, such as a fan blade, breakage of which results in a risk of injury to persons, shall be enclosed or guarded to reduce the risk of injury to persons.

35.2 A rotating or moving part that involves a risk of injury to persons when it becomes disengaged shall be provided with a positive means to retain it in place under conditions of use.

36 Switches and Controls

Section 36 effective November 7, 2000

36.1 When unintentional operation of a switch involves a risk of injury to persons, the actuator of the switch shall be located or guarded so that such operation is unforeseeable.

36.2 When required in accordance with 36.1, the actuator of a switch shall be guarded by recessing ribs, barriers, or similar component.

37 Mounting

Section 37 effective November 7, 2000

37.1 When mounting instructions furnished with a unit specify mounting hardware that is not readily available commercially, the manufacturer shall provide the hardware with the unit.

OUTPUT POWER CHARACTERISTICS AND UTILITY COMPATIBILITY

38 General

Section 38 effective November 7, 2000

38.1 A stand-alone inverter shall comply with 45.2.1 and with the harmonic voltage distortion requirements in 45.4.1.

38.2 A utility-interactive inverter shall comply with the applicable tests in Utility Interaction, Section 39.

Revised 38.2 effective May 7, 2007

39 Utility Interaction

39.1 A utility-interactive inverter or interconnection system equipment (ISE) shall comply with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1, excluding the requirements for Interconnection Installation Evaluation, Commissioning Tests, and Periodic Interconnection Tests.

Revised 39.1 effective May 7, 2007

39.2 In order to cease exporting power automatically in accordance with specific utility requirements, utility-interactive inverters and interconnection system equipment (ISE) shall be provided with field adjustable trip limits and trip times for voltage and frequency.

Exception: Units used in systems with an ac output rating of 30 kW or less may be provided with fixed set points as specified by theStandard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547, when the instruction manual notes this limitation in accordance with 63.4.

Revised 39.2 effective May 7, 2007

39.3 For a utility-interactive inverter or interconnection system equipment (ISE) with field adjustable trip limits and trip times, the controls shall be accessible to service personnel only.

Revised 39.3 effective May 7, 2007

39.4 For units with field adjustable trip points, the installation manual shall describe the trip limit and time adjustment ranges in addition to the default factory settings, see 65.2.1(g).

Revised 39.4 effective May 7, 2007

39.4A Units with field adjustable trip points shall be provided with a means to display or indicate the programmed trip limits, trip times and reconnect time delay.

Exception No. 1: A unit with provisions for signal injection testing of trip limits, trip times and reconnect time delay complies with this requirement.

Exception No. 2: A unit that interfaces with a companion tool for the display of the programmed trip limits, trip times and reconnect time delay complies with this requirement.

Added 39.4A effective May 7, 2007

39.5 Deleted effective May 7, 2007

39.6 Each combination of microprocessor model, manufacturer and firmware/software version used in the production of a utility-interactive inverter or interconnection system equipment (ISE) shall be evaluated in accordance with 39.1.

Exception: For units with firmware/software that is in compliance with the Standard for Software in Programmable Components, UL 1998, subsequent firmware/software revisions may be entitled to a limited revaluation in accordance with 39.1 as determined by the subsequent UL 1998 evaluation of the revised firmware or software. The scope of the 39.1 re-evaluation shall be defined by the potential impact of the firmware or software revisions.

Added 39.6 effective May 7, 2007

40 DC Isolation From the Utility

Section 40 deleted effective May 7, 2007

PERFORMANCE

41 General

41.1 Inverters and converters shall be subjected to the tests described in Sections 43 – 57.

41.1 revised November 7, 2005

41.2 Unless otherwise specified, the unit is to be energized from a supply that simulates the current-voltage characteristics and time response of the input source. The tests are to be performed at the maximum and minimum rated input voltages. The output of a utility-interactive inverter or converter is to be connected to a supply voltage as specified in 41.3 and Table 41.1.

41.2 revised November 7, 2005

Table 41.1
Output voltages for tests

Table 41.1 effective November 7, 2000

Rated ac output voltage	AC test voltage
110 – 120	120
121 – 219	Rated voltage
220 – 240	240
241 – 253	Rated voltage
254 – 277	277
278 – 439	Rated voltage
440 – 480	480
481 – 525	Rated voltage
550 – 600	600

41.3 When a simulated utility source is required for a test, the impedance of the simulated utility source for a utility-interactive inverter shall be less than 5 percent of the inverter output impedance where the inverter output impedance is equal to the inverter rated output voltage divided by the inverter rated output current.

41.3 effective November 7, 2000

41.3A When a simulated utility source is required for a test, the actual utility is able to be used for the simulated utility.

41.3A added January 17, 2001

41.4 Input and output overcurrent protection is to be installed in accordance with the manufacturer's instructions.

41.4 revised November 7, 2005

41.5 The equipment under test provided with, or intended for use with, specific defined input sources that cannot provide the input power range described in the test shall be tested within the limitations of the specified or supplied input source. Under these circumstances, the test may be performed with the actual utility source or a simulated source. Test results shall only be applicable to the combination of the equipment under test and the specified source, and this limitation is to be noted.

41.5 added November 7, 2005

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42 Maximum-Voltage Measurements

Section 42 effective November 7, 2000

42.1 The maximum voltage determined in accordance with 42.2 and 42.3 is to be used as a basis for the:

a) Calculation of the dielectric voltage-withstand test potentials specified in 44.1.1, and

b) Determination of the minimum spacings specified in Spacings, Section 24, or Alternate Spacings – Clearances and Creepage Distances, Section 25.

42.2 A connector or comparable part that is expected to be disconnected during intended operation is to be both connected and disconnected during the test to obtain maximum voltage.

42.3 When a complex voltage is present, the peak value of the voltage is to be measured and this value is to be used for calculation of the dielectric voltage-withstand potential and determination of the minimum spacings. For a sinusoidal or a direct current voltage, the rms or average values respectively is to be measured.

43 Temperature

43.1 A unit shall not attain a temperature at any point so as to result in a risk of fire, to damage any material used, to result in the operation of a protective device, or to exceed the maximum temperatures specified in 43.2 and Tables 43.1 and 43.2:

a) When the unit is delivering maximum rated output power in an ambient temperature as specified in 43.3, and

b) For a unit marked for operation at a higher ambient at reduced output power, the test is to also be performed at the specified higher ambient and the associated reduced output power.

43.1 revised January 17, 2001

Table 43.1
Maximum temperature

Table 43.1 revised January 17, 2001

Materials and Components	Degrees °C	Degrees °F
1. Capacitors:		
a. Electrolytic types	65[b]	149[b]
b. Other than electrolytic	90[b]	194[b]
2. Field wiring terminals	75[c]	167[c]
3. Vulcanized fiber employed as electric insulation	90	194
4. Relays, solenoids, and similar components		
a. Class 105 (Class A) coil insulation systems:		
Thermocouple method	90[a]	194[a]
Resistance method	110	230

Table 43.1 Continued on Next Page

Table 43.1 Continued

Materials and Components			Degrees °C	Degrees °F
	b.	Class 130 (Class B) coil insulation systems:		
		Thermocouple method	110[a]	230[a]
		Resistance method	120	248
5.	Transformer insulation systems:			
	a.	Class 105 (Class A):		
		Thermocouple method	90[a]	194[a]
		Resistance method	95	203
	b.	Class 130 (Class B):		
		Thermocouple method	110[a]	230[a]
		Resistance method	120	248
	c.	Class 155 (Class F):		
		Thermocouple method	135[a]	275[a]
		Resistance method	140	284
	d.	Class 180 (Class H):		
		Thermocouple method	150[a]	302[a]
		Resistance method	160	320
	e.	Class 200 (Class N):		
		Thermocouple method	165[a]	329[a]
		Resistance method	175	347
	f.	Class 220 (Class R):		
		Thermocouple method	180[a]	356[a]
		Resistance method	190	374
6.	Phenolic composition employed as electrical insulation or as a part the deterioration of which results in a risk of fire or electric shock		150[d]	302[d]
7.	Wood and other combustible material		90	194
8.	Rubber- or thermoplastic-insulated wire and cord		60[d,e]	140[d,e]
9.	Other types of insulated wire		f	f
10.	A surface upon which a stationary unit is mounted and surfaces that are adjacent to the unit when so mounted		90	194
11.	Any point on or within a terminal box or wiring compartment of a fixed unit which field-installed conductors are able to contact		60[c]	140[c]
12.	Thermoplastic sealing compound		g	g
13.	Selenium rectifier		75[h,d]	167[h,d]

Table 43.1 Continued on Next Page

Table 43.1 Continued

Materials and Components		Degrees	
		°C	°F
14.	Power semiconductor	i	i
15.	Printed-wiring board	j	j

[a] At a point on the surface of a coil where the temperature is affected by an external source of heat, the temperature measured by a thermocouple is able to be 5°C (9°F) higher than that specified when the temperature of the coil as measured by the resistance method is not more than that specified.

[b] A capacitor that operates at a temperature of more than 65°C (149°F) for electrolytic or more than 90°C (194°F) for other types that are rated for a higher temperature shall not exceed its marked temperature limit.

[c] The temperature observed on the terminals and at points within a terminal box or wiring component of a unit is able to exceed the values specified and shall not attain a temperature higher than the temperature marking required 63.11 and 66.4 (L) and (M).

[d] The temperature limitation on phenolic composition and on rubber and thermoplastic insulation do not apply to a compound that has heat-resistant properties in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

[e] For a short length of rubber- or thermoplastic-insulated cord inside the unit, a temperature greater than 60° C (140°F) where each individual conductor has supplementary insulation rated for the measured temperature and has dielectric properties in accordance with the Standard for Polymeric Materials– Short Term Property Evaluations, UL 746A, and the Standard for Polymeric Materials– Long Term Property Evaluations, UL 746B.

[f] Other than specified in (e), the maximum temperature shall not to exceed the temperature rating of the wire.

[g] The sealing compound temperature limit is 15°C (27°F) less than the softening point of the compound as determined in accordance with the test method for Vicat Softening Temperature of Plastics, ASTM D1525-91.

[h] A maximum temperature of 85°C (185°F) applies where the stack assembly is insulated with phenolic composition or other insulating material rated for a temperature of 150°C (302°F) or more.

[i] For a power-switching semiconductor and similar devices, the maximum temperature limit on the case shall not exceed the maximum case temperature specified by the semiconductor manufacturer.

[j] For a printed-wiring board, the maximum temperature shall not exceed the temperature rating of the board.

43.2 The temperature of a surface that is subject to contact shall not be more than specified in Table 43.2.

Exception: The temperature maximums specified for casual contact in Table 43.2 do not apply when:

a) The unit is a fixed unit that is typically not subject to contact by persons;

b) The unit is marked as required by 64.8; and

c) The unit is provided with instructions as specified in 66.4(H).

43.2 effective November 7, 2000

Table 43.2
Maximum surface temperatures

Table 43.2 effective November 7, 2000

Location	Composition of surface[a]			
	Metal		Nonmetallic	
Handles or knobs that are grasped for lifting, carrying, or holding	50°C	(122°F)	60°C	(140°F)
Handles or knobs that are contacted that do not involve lifting, carrying, or holding; and other surfaces subject to contact and user maintenance	60°C	(140°F)	85°C	(185°F)
Surfaces subject to casual contact[b]	70°C	(158°F)	95°C	(203°F)

[a] A handle, knob, or similar component made of a material other than metal that is plated or clad with metal having a thickness of 0.127 mm (0.005 inch) or less is to be judged as a nonmetallic part.

[b] See Exception to 43.2.

43.3 The temperature maximums in Tables 43.1 and 43.2 are based on an ambient temperature of 25°C (77°F). Tests are to be performed in the ambient temperature specified in Table 43.3 and corrected in accordance with Table 43.3.

43.3 effective November 7, 2000

Table 43.3
Temperature measurement correction

Table 43.3 effective November 7, 2000

Ambient temperature rating of unit	Test ambient temperature	Correction of observed temperature
1. 25°C (77°F)	Range of 10 – 40°C (50 – 104°F)	a
2. Range of 25 – 40°C (77 – 104°F)	Range of 20 – 40°C (68 – 104°F)	b
3. Above 40°C (104°F)	Rated ambient [c]	d

[a] The measured temperature is to be corrected by addition [when the test ambient temperature is lower than 25°C (77°F)] or by subtraction [when the test ambient is higher than 25°C (77°F)] of the difference between 25°C (77°F) and the test ambient temperature.

[b] The measured temperature is to be corrected by addition (when the test ambient temperature is lower than the rated ambient temperature) or by subtraction (when the test ambient temperature is higher than the rated ambient temperature) of the difference between the rated ambient temperature and the test ambient temperature.

[c] Tolerances are:

Minus – not less than 5°C (9°F) below rated ambient.

Plus – not specified.

[d] When the test ambient temperature equals rated ambient, no correction is to be made, and the measured temperature shall not exceed the maximum temperature limit specified in Table 43.1. When the test ambient temperature is other than rated ambient, correction is to be made as described in b.

43.4 Temperatures used to determine compliance are to be stable. A temperature is stable when three successive readings taken at intervals of 10 percent of the previously elapsed duration of the test, and not less than 15 minutes apart, indicate no further increase in temperature.

43.4 effective November 7, 2000

43.5 During the temperature test, the unit is to be connected as specified in 41.2 and mounted as in normal service to provide for normal convection cooling.

43.5 effective November 7, 2000

43.6 A unit intended for mounting or support in more than one position or in a confined location is to be tested in a manner representing the most severe conditions. An adjacent mounting or supporting surface shall consist of 25.4-mm (1-inch) thick soft-pine boards.

43.6 effective November 7, 2000

43.7 Thermocouples are to consist of wires not larger than No. 24 AWG and not smaller than No. 30 AWG. When thermocouples are used in determining temperatures, it is common practice to employ thermocouples consisting of No. 30 AWG iron and constantan wire and a potentiometer type instrument. Such equipment is to be used whenever referee temperature measurements by thermocouples are required. The thermocouples and related instruments are to be accurate and calibrated in accordance with laboratory practice. The thermocouple wire is to conform with the requirements specified in the Initial Calibration Tolerances for Thermocouples table in Temperature Measurement Thermocouples, ANSI/ISA MC96.1.

43.7 revised January 17, 2001

43.8 A thermocouple junction is to be held securely in intimate thermal contact with the surface of the material being tested. Thermocouples are to be secured to surfaces by welding, brazing, soldering, fuller's earth and sodium silicate (waterglass), adhesive rated for the surface and temperatures involved, or an equivalent method. Tape is not to be used as a means of securing the thermocouple junction. The thermocouple lead is to be secured so that strain on the lead does not affect the adhered thermocouple junction. Tape is usable as a means of strain relief for the thermocouple junction.

43.8 effective November 7, 2000

43.9 Coil and winding temperatures are to be measured by thermocouples located on exposed surfaces.

Exception: The change-of-resistance method is to be used for a coil that is inaccessible for attachment of thermocouples, such as a coil:

a) Immersed in sealing compound,

b) Wrapped with thermal insulation, or

c) Wrapped with more than two layers of material, such as cotton, paper, or rayon, more than 0.8 mm (1/32 inch) thick.

43.9 effective November 7, 2000

43.10 The temperature of a winding by the change-of-resistance method is to be determined using the following formula:

$$T = \frac{R}{r}(k + t) - k$$

in which:

T is the temperature of the winding in degrees C;

R is the resistance of the winding at the end of the test in ohms;

r is the resistance of the winding at the beginning of the test in ohms;

t is the ambient temperature in degrees C at the beginning of the test; and

k is 234.5 for copper, 225.0 for electrical conductor grade (EC) aluminum. Values of the constant for other conductor materials are to be determined.

43.10 effective November 7, 2000

43.11 Localized component heating is able to occur in products that reduce their output power with an increase in temperature. For example, heat generating components, such as Transformers, Inductors, Capacitors, Semiconductors and other similar components, which quickly increase in temperature, independent of the temperature sensing device, are able to attain thermal peaks prior to the first or subsequent power reductions. This is more prevalent in a lower ambient. In such instances, the measured peak temperature results is to be taken as the component operating temperature and shall comply with 43.1, or the results shall be investigated to the requirements for Temperature Excursions Beyond the Maximum Use Temperature in the Standard for Polymeric Material – Electrical Equipment Evaluations, UL 746C.

43.11 effective November 7, 2000

44 Dielectric Voltage-Withstand Test

Section 44 effective November 7, 2000

44.1 General

44.1.1 Immediately following the temperature test or with the unit at normal operating temperature, a unit shall withstand for 1 minute without breakdown the application of an ac rms test potential of:

a) One thousand volts plus twice the maximum voltage (see 42.1) between:

(1) the input circuit and dead metal parts,

(2) the output circuit and dead metal parts, and

(3) the input and output circuits.

Exception: A test between input and output circuits is not required for an inverter not provided with a transformer or capacitor network isolating the input from the output circuit.

b) Five hundred volts between a secondary circuit operating at 50 volts or less and dead metal parts; 1000 volts plus twice the maximum secondary circuit voltage between a secondary circuit operating at more than 50 volts and dead metal parts.

c) One thousand volts plus twice the voltage between the terminals of a capacitor used across the ac or dc power circuit for electromagnetic interference elimination or power factor correction; and between the terminals of a capacitor connected between an ac or dc power circuit and the enclosure.

Exception: This test potential does not apply to capacitors that comply with either the Standard for Capacitors, UL 810, the Standard for Across-the-Line, Antenna-Coupling, and Line-By-Pass Capacitors for Radio- and Television-Type Appliances, UL 1414, or the Standard for Electromagnetic Interference Filters, UL 1283.

Exception: As an alternative to the ac rms test potential specified, use of a dc test potential of 1.414 times the ac rms value is not prohibited.

44.1.2 To determine whether a unit complies with the requirements in 44.1.1, the unit is to be tested using a 500 volt-ampere or larger capacity transformer, the output voltage of which is variable. The applied potential is to be increased from zero until the required test level is reached, and is to be held at that level for 1 minute. The increase in applied potential is to be at a substantially uniform rate as rapid as is consistent with correct indication of its value by a voltmeter.

Exception: When a voltmeter is connected across the output circuit to directly indicate the test potential, the transformer is not required to be rated 500 or more volt-amperes.

44.1.3 A low-voltage control circuit or a sensor circuit is not required to be connected during the test. Any circuit which is connected from input to output circuit shall remain connected during the test and provide proper isolation in accordance with 2.20.

45 Output Power Characteristics

45.1 General

45.1 effective November 7, 2000

45.1.1 When a utility-interactive inverter or ac module is required to be connected to a simulated utility source by Sections 45.2 – 45.4, the simulated utility source shall be in accordance with 41.3.

Revised 45.1.1 effective May 7, 2007

45.2 Output ratings

45.2 effective November 7, 2000

45.2.1 For a stand-alone inverter or converter, the output voltage shall be within ±10 percent of its rated output voltage range when it is connected to its rated input supply and loaded over its full range of rated output current. The output frequency shall be within±1 Hz of rated output frequency.

45.2.1 revised November 7, 2005

45.2.2 Deleted effective May 7, 2007

45.2.3 A utility-interactive inverter or converter shall be capable of operating at rated output current ±10 percent when loaded and connected to the rated input and to a simulated utility source. The input source shall be capable of delivering twice the unit's rated input current rating of the inverter.

45.2.3 revised November 7, 2005

45.2.4 When connected to a simulated utility source, an ac module shall be within ±10 percent of its rated output power and current when run with a dc input voltage and current set at the photovoltaic module *maximum power point, rated voltage* (V_R), *and current* (I_R).

45.2.5 For units marked with lower output ratings at higher ambient temperatures, the ratings shall be verified in accordance with 45.2.1 – 45.2.3 at the higher ambient.

45.3 Input range

45.3 revised November 7, 2005

45.3.1 A utility-interactive inverter or converter shall operate as intended when the input is varied within the unit's marked input range. During the test, the utility-interactive inverter or converter is to be loaded to its rated load with the minimum and maximum input voltage supplied to the unit. The load for a stand-alone inverter or converter is to include both resistance and inductance with a power factor of 0.5.

Exception: This test does not apply to an ac module inverter that is provided integral to a photovoltaic panel.

45.3.1 revised November 7, 2005

45.4 Harmonic distortion

45.4.1 For a stand-alone inverter, the total rms of the harmonic voltages, excluding the fundamental delivered, shall not exceed 30 percent of the fundamental rms output voltage rating. The rms voltage in any single harmonic shall not exceed 15 percent of the nominal fundamental rms output voltage rating. The measurements are to be made with the inverter delivering 100 percent of its rating to a resistive load.

Exception: A unit having total rms harmonic voltages exceeding 30 percent of the fundamental rms output voltage rating meets the intent of the requirement when the inverter is marked in accordance with 63.28.

45.4.1 effective November 7, 2000

45.4.2 Deleted effective May 7, 2007

Table 45.1
RMS current distortion limits for individual odd harmonics

Table 45.1 deleted effective May 7, 2007

Table 45.2
RMS current distortion limits for individual even harmonics

Table 45.2 deleted effective May 7, 2007

45.4.3 Deleted effective May 7, 2007

45.5 DC injection

Section 45.5 deleted effective May 7, 2007

46 Utility Compatibility

46.1 General

46.1.1 A utility-interactive inverter and interconnection system equipment (ISE) shall comply with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1, excluding the requirements for Interconnection Installation Evaluation, Commissioning Tests, and Periodic Interconnection Tests.

Revised 46.1.1 effective May 7, 2007

46.2 Utility voltage and frequency variation test

Section 46.2 deleted effective May 7, 2007

46.3 Anti-Islanding test

Section 46.3 deleted effective May 7, 2007

46.4 Loss of Control Circuit

Section 46.4 revised and relocated as 47.8 effective May 7, 2007

47 Abnormal Tests

47.1 General

47.1.1 A unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons – see 47.1.3 – when subjected to the tests specified in 47.1.2 – 47.7.3. Separate units are usable for these tests.

47.1.1 effective November 7, 2000

47.1.2 Following each test, the unit shall comply with Dielectric Voltage-Withstand Test, Section 44. The potential is to be applied across the points indicated in Table 47.1.

Exception No. 1: More than one abnormal test is able to be conducted on a unit, and the dielectric voltage-withstand test is able to be conducted after completion of all abnormal tests.

Exception No. 2: This test is not required following the DC Input Miswiring Test, Section 47.4.

47.1.2 effective November 7, 2000

Table 47.1
Dielectric voltage-withstand test following abnormal tests

Table 47.1 effective November 7, 2000

Test No.	Circuit parts
1	ac power circuits to dc power circuits
2	ac and dc power circuits to accessible dead metal parts
3[a]	primary to secondary winding of isolating transformer

[a] Perform only after Short-Circuit Test, Section 47.3.

47.1.3 A risk of fire, electric shock, or injury to persons exists when there is:

a) Emission of flame, molten metal, glowing or flaming particles through any openings (pre-existing or created as a result of the test) in the product,

b) Charring, glowing, or flaming of the supporting surface, tissue paper, or cheesecloth,

c) Ignition of the enclosure,

d) Creation of any openings in the enclosure that results in accessibility of live parts, as determined in accordance with Accessibility of Uninsulated Live Parts, Section 9, or

e) Opening of the 3-ampere fuse connected to ground. See 47.1.6.

47.1.3 effective November 7, 2000

47.1.4 During these tests, the unit is to be placed on a softwood surface covered with white tissue paper. A single layer of cheesecloth is to be draped loosely over the entire enclosure. The cheesecloth is to be untreated cotton cloth running 28 – 30 m^2/kg (14 – 15 yards per pound), and having, for any square inch, a count of 32 threads in one direction and 28 in the other direction.

Exception No. 1: A unit not having bottom openings is not required to be placed on a softwood surface covered with tissue paper.

Exception No. 2: When it is inappropriate to drape the entire unit, cheesecloth is able to be placed only over all ventilation openings.

47.1.4 effective November 7, 2000

47.1.5 The input and output circuits of the unit are to be connected as specified in 41.2 – 41.4 during these tests. Fusing for the input and output circuits shall be connected in accordance with the instructions provided with the unit and in accordance with the markings on the unit.

47.1.5 revised January 17, 2001

47.1.6 The enclosure of the unit is to be connected to ground through a 3-ampere fast acting fuse.

47.1.6 effective November 7, 2000

47.1.7 Each test is to be continued until ultimate results and there is no further change as a result of the test condition. When an automatically reset protector functions during a test, the test is to be continued for 7 hours. When a manual reset protector functions during a test, the test is to be continued until the protector is operated for 10 cycles using the minimum resetting time, and not at a faster rate than 10 cycles of operation per minute. The following defines the termination of the test:

a) Opening or shorting of one or more components such as capacitors, diodes, resistors, solid-state devices, printed wiring board traces, or similar components.

b) Opening of an internal fuse.

Exception No. 1: When the manually reset protector is a circuit breaker that complies with the Standard for Molded-Case Circuit Breakers and Circuit-Breaker Enclosures, UL 489, it is to be operated for 3 cycles using the minimum resetting time not exceeding 10 cycles of operation per minute.

Exception No. 2: A manual reset protector that becomes inoperative in the open condition is able to be operated fewer than 10 cycles, and not less than 3 cycles.

47.1.7 effective November 7, 2000

47.2 Output overload test

Section 47.2 effective November 7, 2000

47.2.1 After thermal stabilization is reached during the conditions described in Temperature, Section 43, the following tests are to be performed:

a) A stand-alone inverter is to be subjected to the overload test described in 47.2.3, while delivering maximum rated output power to an adjustable resistive load connected to the output ac circuit, and

b) A utility-interactive inverter is to be subjected to the overload test described in 47.2.4.

As a result of the tests, a unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons, see 47.1.3.

47.2.2 Firmware or Software controlling the temperature limits of an inverter shall be disabled for the tests described in 47.2, or evaluated for reliability in accordance with the Standard for Software in Programmable Components, UL 1998.

47.2.2 revised November 7, 2005

47.2.3 For units that charge batteries, the dc output is to be connected to a simulated battery load in accordance with 71.4. The load is to be increased in increments of 10 percent of the maximum output rating of the unit and held for 1/2 hour at each increment until:

a) There is no further change as a result of the test condition, or

b) The unit shuts down.

Exception: Thermal stabilization is obtainable with a load adjusted to result in maximum obtainable output power without resulting in operation of overcurrent protective devices, followed by increased incremental loading as described in 47.2.3.

47.2.4 For a utility-interactive inverter, the input is to be connected to a source that delivers a minimum of twice the rated input current. The utility voltage is to be adjusted to provide for the maximum output current. The utility is not to be adjusted less than the utility trip voltage rating. The inverter is to remain in the loaded condition until it shuts down, reaches thermal stabilization, or has been operated for seven hours, whichever occurs first.

47.3 Short-circuit test

Section 47.3 effective November 7, 2000

47.3.1 The dc battery circuit and the ac output circuit of a unit are to be shorted separately. The shorting is to be from line to neutral (when applicable) and from line to line.

47.3.2 When shorting the unit, the source (input or output/utility) is to be disconnected by a relay or similar device.

47.3.2 revised November 7, 2005

47.3.3 With reference to Table 62.1, Item (m), the maximum inverter output fault current (peak and RMS) and short circuit current duration are to be measured immediately after the short is applied.

47.3.3 revised November 7, 2005

47.3.4 The short-circuit test is to be performed a total of four times so the short occurs in different portions of the line cycle.

47.3.5 For a unit with a 3-phase output, the test is to be performed with shorts applied from phase to phase and from phase to neutral or ground.

47.3.6 For a unit intended for use with external isolation transformers, the short is to be applied before and after the external transformer.

47.3.7 The location of the applied short in the test circuit shall not direct the output short-circuit test current through the 3-ampere ground fuse described in 47.1.6.

47.4 DC input miswiring test

47.4.1 The dc input of a unit is to be connected in accordance with Table 47.2. As a result of the tests, a unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons, see 47.1.3.

47.4.1 effective November 7, 2000

47.4.2 When a simulated input source is used for the test, the source is to be adjusted to maximum rated input voltage and the current is to be limited to 1.5 times the rated input current.

47.4.2 revised November 7, 2005

Table 47.2
DC input miswiring test

Table 47.2 revised January 17, 2001

Input terminal polarity	DC source polarity
Positive	Negative
Negative	Positive

47.5 Ventilation test

47.5.1 A unit having forced ventilation, using fan motors that have been investigated for the locked-rotor condition, is to be operated at full load with the power to the forced ventilation disconnected.

47.5.1 effective November 7, 2000

47.5.2 A unit having forced ventilation, using fan motors that have not been investigated for the locked-rotor condition or when the heating of the locked fan motor adds to the heating of the enclosure, is to be operated with the rotor of a fan motor locked. For a unit having more than one fan motor, the test is to be performed with the rotor of each fan motor locked, one at a time.

Exception: Simultaneously locking all fan motors in a unit having more than one fan motor is not prohibited.

47.5.2 effective November 7, 2000

47.5.3 A unit having filters, guards, or screens over input ventilation openings that are able to be clogged is to be operated with the openings blocked to represent clogging. The test is to be performed initially with the input ventilation openings blocked 50 percent and then repeated under a fully blocked condition. For a unit having multiple input ventilation openings, the test is to be performed with all of the input ventilation openings blocked 50 percent and then repeated with all of the input ventilation openings fully blocked.

47.5.3 revised January 17, 2001

47.6 Component short- and open-circuit

Section 47.6 effective November 7, 2000

47.6.1 Components, such as capacitors, diodes, solid-state devices, and similar components, are to be short- or open-circuited, any two terminals, one pair at a time. Short circuiting a resistor is excluded.

Exception: This test is not required:

a) Where circuit analysis indicates that no other component or portion of the circuit is able to be overloaded.

b) For components in low-voltage, limited-energy (LVLE) circuits, or other circuits that are not required to be investigated in accordance with this Standard.

47.6.2 In addition to compliance with 47.1.3, during the test described in 47.6.1 for a utility-interactive inverter or converter, the maximum backfeed current that flows from the simulated utility source, see 41.3, into the input source as a result of a faulted component shall not exceed the marked maximum input source backfeed current. See Table 62.1, Item (e).

47.6.2 revised November 7, 2005

47.7 Load transfer test

Section 47.7 effective November 7, 2000

47.7.1 With reference to the Exception to 12.9, a bypass switch shall continue to operate normally after completion of the test described in 47.7.2 and 47.7.3.

47.7.2 The bypass ac source is to be displaced 120 electrical degrees from the ac output of the inverter for a 3-phase supply or 180 electrical degrees for a single phase supply. The transfer switch is to be subjected to one operation of switching the load from the ac output of the inverter to a bypass ac source. The load is to be adjusted to draw maximum rated ac power.

47.7.3 For an inverter employing a bypass switch having a control preventing switching between two ac sources out of synchronization, the test specified in 47.7.2 is to be conducted under the condition of a component malfunction – see 47.6.1 – when such a condition results in an out-of-phase transfer between the two ac sources of supply.

47.8 Loss of Control Circuit

Section 46.4 revised and relocated as Section 47.8 effective May 7, 2007

47.8.1 A utility-interactive inverter or interconnection system equipment (ISE) shall cease the export of power to the EPS upon the loss of control circuit power when tested in accordance with 47.8.2.

46.4.1 revised and relocated as 47.8.1 effective May 7, 2007

47.8.2 The inverter, converter, or interconnection system equipment (ISE) is to be connected to its rated input supply and simulated utility source. A single fault is to be placed such that it disables the power to the control circuit.

Exception No. 1: When the control circuit is unable to be disabled under any single fault condition, this test is not required to be performed.

Exception No. 2: The unit may continue to export power if it continues to meet 39.1 with the single fault specified in 47.8.2 in place.

46.4.2 revised and relocated as 47.8.2 effective May 7, 2007

48 Grounding Impedance Test

Section 48 effective November 7, 2000

48.1 The impedance at 60 hertz between the point of connection of the equipment-grounding means and any other metal part that is required to be grounded (see 20.10) shall not be more than 0.1 ohm when measured in accordance with 48.2.

48.2 Compliance with 48.1 is determined by measuring the voltage when a current of 25 amperes derived from a 60-hertz source with a no-load voltage not exceeding 6 volts is passed between the grounding connection and the metal part in question.

49 Overcurrent Protection Calibration Test

Section 49 effective November 7, 2000

49.1 With reference to 29.9, a fuse or circuit protective device connected to the primary of a transformer for protection of the secondary circuit shall operate to open the circuit in not more than the time indicated in Table 49.1 when the transformer is delivering the specified secondary current.

Table 49.1
Maximum time to open

Maximum transformer open circuit secondary voltage (V^{max}), volts	Secondary test current, amperes	Maximum time for overcurrent protective device to open, minutes
20 or less	10	2
20 or less	6.75	60
Over 20	$200/V_{max}$	2
Over 20	$135/V_{max}$	60

49.2 To determine whether a fuse or circuit protective device complies with the requirement in 49.1, the transformer is to deliver the test current to a resistance load with the primary connected to a circuit as described in 41.1. During the 2-minute test, the load is to be adjusted continuously to maintain the required test current. During the 60-minute test, the load is to be adjusted once after 15 minutes of operation and the test is to be continued without further adjustment.

49.3 Where the fuse or circuit protective device is used to protect more than one secondary winding or taps, each winding or partial winding is to be tested as indicated in 49.1 and 49.2 with the remaining windings delivering rated load.

50 Strain Relief Test

Section 50 effective November 7, 2000

50.1 A wiring lead intended for field-wiring connection – see 16.3.1 and 16.3.3 – shall withstand without damage or displacement a direct pull of:

a) 89 N (20 lbf) for 1 minute applied to a lead extending from the enclosure (such as through a knockout), and

b) 44.5 N (10 lbf) for 1 minute applied to a lead within a wiring compartment.

50.2 An input or output cord shall withstand a 155.7 N (35 lbf) pull for one minute in the most severe direction without damage or displacement. All internal connections are to be severed during the test.

51 Reduced Spacings on Printed Wiring Boards Tests

Section 51 effective November 7, 2000

51.1 General

51.1.1 With reference to Exception No. 6(a) to 24.1.1, printed wiring board traces of different potential having reduced spacings shall comply with:

a) Dielectric Voltage-Withstand Test, Section 51.2, or

b) Shorted Trace Test, Section 51.3.

51.2 Dielectric voltage-withstand test

51.2.1 A printed wiring board as specified in 51.1.1 shall withstand for 1 minute without breakdown the application of a potential between the traces having reduced spacings in accordance with 44.1.1, as appropriate.

51.2.2 Power-dissipating component parts, electronic devices, and capacitors connected between traces having reduced spacings are to be removed or disconnected so that the spacings and insulations, rather than these component parts, are subjected to the full test potential.

51.3 Shorted trace test

51.3.1 The printed wiring board traces described in 51.1.1 shall be short-circuited, one location at a time, and the test shall be performed as described in 47.1.1 – 47.1.7. As a result of the test:

a) The overcurrent protection associated with the branch circuit to the unit shall not open, and

b) A wire or a printed wiring board trace shall not open. When the circuit is interrupted by opening of a component, the test is to be repeated two additional times using new components, as required. Opening of an internal overcurrent protective device is a result that is in compliance with the requirement and the test is not required to be repeated.

52 Bonding Conductor Test

Section 52 effective November 7, 2000

52.1 With reference to the Exception to 20.10, a bonding circuit, including the conductor, terminations and portions of the unit intended to be bonded, shall be subjected to the following tests using a separate bonding circuit for each test:

a) The conductor is to carry currents equal to 135 and 200 percent of the rating or setting of the intended branch-circuit overcurrent-protective device for the times specified in Table 52.1, and

b) Three specimens are to be subjected to a limited-short-circuit test using a test current as specified in Table 52.2 while connected in series with a nonrenewable fuse having a rating equal to the intended branch-circuit overcurrent-protective device.

Exception: When a fuse smaller than that indicated in (a) and (b) is employed in the unit for protection of the circuit to which the bonding conductor is connected, the magnitude of the test current and size of fuse used during the test is to be based on the rating of the smaller fuse.

Table 52.1
Duration of overcurrent test

Rating or setting of branch-circuit overcurrent protective device, amperes	Test time, minutes	
	135 percent of current	200 percent of current
0 – 30	60	2
31 – 60	60	4
61 – 100	120	6
101 – 200	120	8

Table 52.2
Circuit capacity for bonding conductor short-circuit test

Rating of unit, volt-ampere		Volts	Capacity of test circuit, amperes
Single phase	3-Phase		
0 – 1176	0 – 832	0 – 250	200
0 – 1176	0 – 832	251 – 600	1000
1177 – 1920	833 – 1496	0 – 600	1000
1921 – 4080	1497 – 3990	0 – 250	2000
4081 – 9600	3991 – 9145	0 – 250	3500
9601 or more	9146 or more	0 – 250	5000
1921 or more	1497 or more	251 – 600	5000

52.2 The test circuit described in 52.1(b) is to have a power factor of 0.9 – 1.0 and a closed-circuit test voltage as specified in Table 41.1. The open-circuit voltage is to be 100 – 105 percent of the closed-circuit voltage. The test is to be performed on each of the three specimens.

52.3 After the bonding circuits are subjected to the tests in 52.1, the circuits shall comply with Grounding Impedance Test, Section 48.

53 Voltage Surge Test

Section 53 effective November 7, 2000

53.1 A unit provided with a ground fault detector/interrupter is to be preconditioned at a relative humidity of 93 ±2 percent at a temperature of 32.0 ±2.0°C (89.6 ±3.6°F). The inverter is to be exposed to ambient air at a temperature of at least 30°C (89.6°F) until thermal equilibrium is attained before being placed in the test chamber. An outdoor rated unit is to be kept in the chamber for 168 hours. Other units are to be kept in the chamber for 48 hours.

53.2 After conditioning the unit is to be subjected to the following surge voltage impulses in the order given:

a) Ten applications of a 6 kV surge impulse at 60 second intervals. Tripping of the interrupter is in compliance with the requirement when it does not result in a risk of fire or electric shock.

b) Ten applications of a 3 kV surge impulse at 60 second intervals. The ground-fault detector shall not trip.

A typical surge generator and dc control relay are shown in the Standard for Ground-Fault Circuit-Interrupters, UL 943.

53.3 The unit is to be connected to a supply of rated voltage. Utility-interactive inverters shall also be supplied from a simulated utility. The grounding lead or terminal of the unit is to be connected to the supply conductor serving as the neutral. The unit is to be in the "on" condition with no load connected. For each application, the voltage is to have the specified initial peak amplitude of 6 or 3 kV when applied to the supply to the unit under test. Each of the ten applications is to be random with respect to the phase of the 60 Hz supply voltage when applied on the ac circuits or at the peak voltage of the dc circuits. When three controlled applications are employed for the ac circuits, one application is to be at the zero crossing of the supply voltage wave, one at the positive peak, and one at the negative peak.

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53.4 The surge generator is to have a surge impedance of 50 ohms. When there is no load on the generator, the waveform of the surge is to be as followed:

a) Initial rise time, 0.5 microseconds between 10 percent and 90 percent of peak amplitude,

b) The period of the following oscillatory wave, 10 microsecond, and

c) Each successive peak, 60 percent of the preceding peak.

53.5 After the voltage surge test is performed, the unit shall comply with the requirements of Calibration Test, Section 54, under the condition described in 54.1(a).

54 Calibration Test

54.1 The operating time of a ground fault detector/interrupter shall not exceed the time indicated in Table 54.1 when the ground fault current is as indicated in 54.2 – 54.8 under each of the specified conditions in the following sequence:

a) As received in a 25 ±3.0°C (77.0 ±5.4°F) ambient,

b) Immediately following conditioning 48 hours in 85 ±5 percent relative humidity at 32 ±2.0°C (89.6 ±3.6°F),

c) After 4 hours in 40 ±2.0°C (104 ±3.6°F) ambient,

d) After 5 cycles of thermal shock consisting of 4 hours at 40 ±2.0°C (104 ±3.6°F) followed by 4 hours at 0 ±2.0°C (32 ±3.6°F) for general use equipment or 4 hours at 66 ±2.0°C followed by 4 hours at -35 ±2°C for outdoor use equipment, and

e) At 25 ±3.0°C (77.0 ±4.5°F).

54.1 revised January 17, 2001

Table 54.1
Operating time

Table 54.1 effective November 7, 2000

Ground-fault current, amperes	Time, seconds
115 percent of pickup	shall ultimately trip
150 percent of pickup	2.0
250 percent of pickup	1.0

54.2 A ground-fault detector/interrupter current relaying device with an indicated delay in operating time, whether fixed or adjustable, is, as part of the test sequence of 54.1 and in each of the conditions, to be evaluated for such delay.

54.2 effective November 7, 2000

54.3 With respect to 54.2, the delay is to be within the tolerance band specified by the manufacturer for the particular setting. When the tolerance band is temperature dependent, the particular band for the temperature involved in the test is to be used. When a range of delay is provided, the determination is to be made at the maximum, middle, and minimum settings of the delay adjustment. A delay expressed in terms of cycles is to be converted to time assuming a 60-Hz frequency.

54.3 effective November 7, 2000

54.4 In determining the operating time (including delay) under the environmental conditions of 54.1, the test is to be performed at the end of the specified exposure time while the device is still in the test environment.

54.4 effective November 7, 2000

54.5 To determine whether a ground fault detector/interrupter complies with the calibration test requirements, the interrupter is to be tested three times under each test condition. The test circuit is to be preset to deliver the required ground fault current. After the test current is applied to the interrupter sensor, the time required for the interrupter relaying device to operate is to be observed. When the interrupter is intended to be connected to a separate source of control power, the control voltage is to be adjusted to its rated value.

54.5 effective November 7, 2000

54.6 A field pick up current adjustment is to be set at its maximum value.

54.6 effective November 7, 2000

54.7 When power from a control power source is required to operate the device, the test described in 54.1 – 54.3 is to be repeated with the ground fault detector/interrupter connected to 55 percent of its rated voltage for ac control power and 80 percent of its rated voltage for dc control power.

54.7 effective November 7, 2000

54.8 The operation of a ground fault detector/interruupter shall not result in the tripping of the circuit interrupter on ground fault currents less than 85 percent of the pickup current trip limit of the ground fault sensing and realying device.

54.8 effective November 7, 2000

55 Overvoltage Test

Section 55 effective November 7, 2000

55.1 A ground fault detector/interrupter intended to be continuously connected to a source of control voltage shall be capable of withstanding 110 percent of its rated control voltage continuously without damage.

55.2 Following the test in 55.1, the ground fault detector/interrupter shall comply with Dielectric Voltage-Withstand Test, Section 44.

56 Current Withstand Test

Section 56 effective November 7, 2000

56.1 After a ground fault detector/interrupter is subjected to a high fault current condition in accordance with 56.2 and its withstand rating (current and time), it shall comply with the requirements of Calibration Test, Section 53, under the condition described in 54.1(a).

56.2 The high fault current condition referred to in 56.1 is to be created by any number of turns in the sensor "window" producing the required ampere turn value.

No Text on This Page

57 Capacitor Voltage Determination Test

Section 57 effective November 7, 2000

57.1 In order to determine a capacitor's stored energy in accordance with 11.2.1 and 11.2.3, the unit is to be operated at a dc voltage equal to the peak value of the ac input sinewave for ac circuits, and at the maximum rated input for dc circuits, and then de-energized. Any access covers are to be quickly removed and immediately after removal, the residual voltage on any accessible capacitor is to be measured and the stored energy calculated in accordance with 11.2.3.

58 Stability

Section 58 effective November 7, 2000

58.1 A unit positioned in the least stable normal operating position shall return to its normal at-rest position and not tip over when:

a) Canted through an angle of 10 degrees in the direction of least stability from an at-rest position on a horizontal surface,

b) Placed on a plane inclined at an angle of 10 degrees from the horizontal, or

c) Positioned in accordance with the manufacturer's instructions, and subjected to an externally-applied horizontal force of 20 percent of the weight of the unit or 22.7 kg (50 pounds), whichever is less. See 58.3.

Exception: A unit provided with instructions indicating that it is to be fastened to the supporting structure is not required to be tested for stability.

58.2 When a part or surface of the unit that is not normally in contact with the horizontal supporting surface touches the supporting surface before the unit has been tipped to an angle of 10 degrees, the tipping is to be continued until the surface or plane of the surface of the unit originally in contact with the horizontal supporting surface is at an angle of 10 degrees from the horizontal supporting surface.

58.3 The force specified in 58.1(c) is to be applied in a horizontal direction at that point on the unit that is expected to overturn the unit. The force is not to be applied more than 1.5 m (5 feet) above floor level. The legs or points of support are to be blocked to prevent the unit from sliding during the application of the force.

59 Static Load

Section 59 effective November 7, 2000

59.1 When mounted as specified by the manufacturer, a unit intended to be fastened to a supporting structure shall be loaded as described in 59.2 with a force equal to three times the weight of the unit and not less than 89 N (20 lbf). As a result of the loading, there shall not be permanent deformation, breakage, dislocation, cracking, or other damage to the unit or its mounting hardware.

Exception: A unit intended for floor mounting or an ac module is not required to be subjected to this test.

59.2 The force is to be applied through the center of gravity of the unit, is to be increased gradually so as to reach the required value in 5 to 10 seconds, and is to be maintained at that value for 1 minute.

60 Compression Test

Section 60 effective November 7, 2000

60.1 An enclosure that is thinner than that specified in Tables 5.1, 5.2, or 5.3 shall be constructed so that during the test described in 60.2, the resulting deflection does not result in spacings less than specified in Spacings, Section 24, or Alternate Spacings – Clearances and Creepage Distances, Section 25.

60.2 A force of 445 N (100 pounds) is to be applied to the end, side, and walls of the enclosure. The enclosure is to rest on a smooth solid, horizontal surface. A vertical force is to be applied at any point through a rod having a 12.7 mm (1/2 inch) square flat steel face.

61 Rain and Sprinkler Tests

Section 61 effective November 7, 2000

61.1 General

61.1.1 Before a rain or sprinkler test is performed, the unit is to be fitted with the intended supply connection means as described in the unit's installation instructions.

61.1.2 A unit intended for multiple mounting orientations shall be tested in all the intended orientations.

61.1.3 The rain and sprinkler tests are to be performed in the operating sequence specified in Table 61.1.

Table 61.1
Operating sequence for rain and sprinkler tests

Duration in hours	Unit	Water
1	On	Off
1/2	Off	On
1	On	On
1/2	Off	On

61.1.4 As a result of the rain and sprinkler tests, no water shall enter the unit.

Exception: When water enters ground-mounted or surface-mounted units and the water does not wet any wiring or other electrical parts that are not inherently waterproof, and when the unit is provided with drain holes in accordance with 5.9.14, the unit is in compliance with the rain and sprinkler tests.

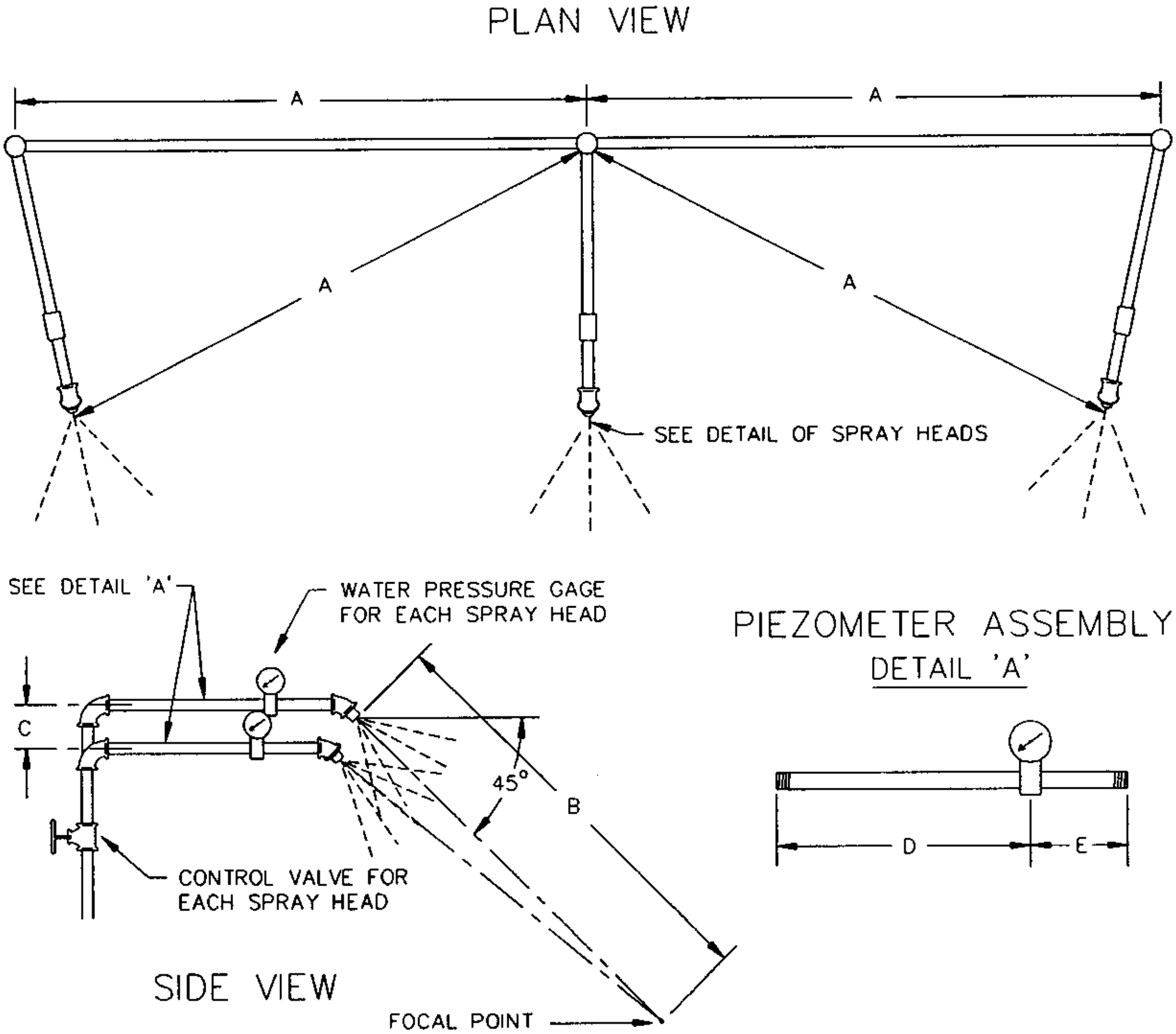
61.2 Rain test

61.2.1 A unit required to be subjected to a rain test is to be tested as described in 61.2.2 and 61.2.3.

61.2.2 The water spray test apparatus is to consist of three spray heads mounted in a water supply pipe rack as shown in Figure 61.1. Spray heads are to be constructed in accordance with the details shown in Figure 61.2. The unit is to be set up as in a normal installation with conduit connections. The enclosure is to be positioned in the focal area of the spray heads so that the greatest possible quantity of water enters the enclosure. The water pressure is to be maintained at 34.5 kPa (5 psi) at each spray head.

61.2.3 A gasketed unit shall be tested after the temperature test or after operation for 1/2 hour, followed by removal and reinstallation of doors, access panels, frames, covers, or other removable parts serving to compress the gasket.

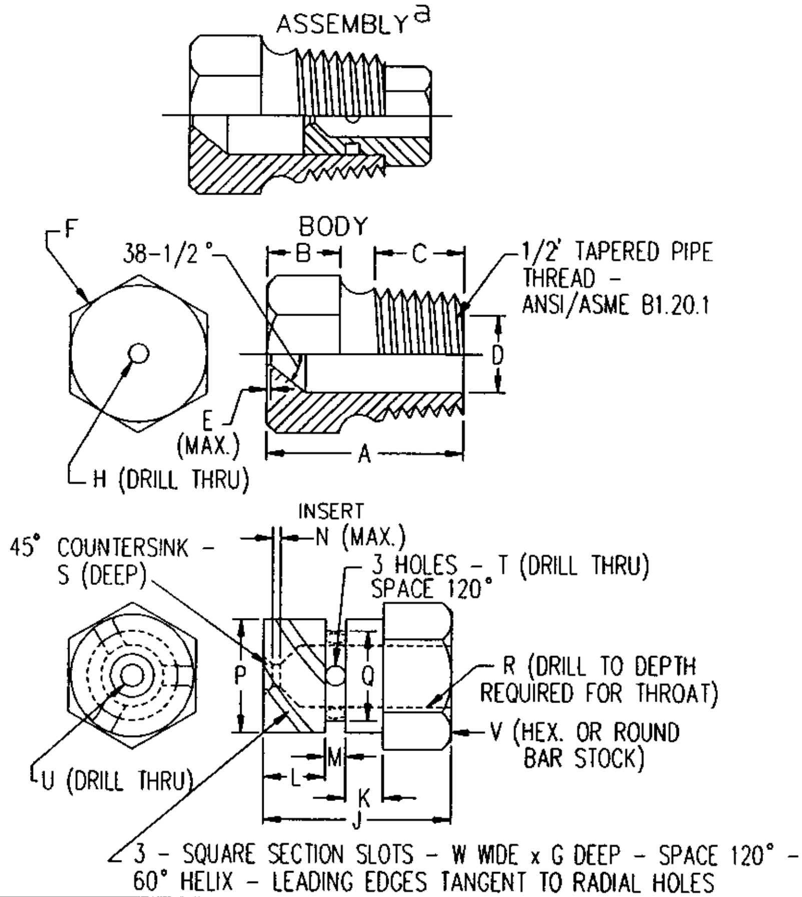
Figure 61.1
Spray head piping



Item	inch	mm
A	28	710
B	55	1400
C	2-1/4	55
D	9	230
E	3	75

RT101E

Figure 61.2
Spray head



Item	inch	mm	Item	inch	mm
A	1-7/32	31.0	N	1/32	0.80
B	7/16	11.0	P	.575	14.61
C	9/16	14.0		.576	14.63
D	.578	14.68	Q	.453	11.51
	.580	14.73		.454	11.53
E	1/64	0.40	R	1/4	6.35
F	c	c	S	1/32	0.80
G	.06	1.52	T	(No. 35)[b]	2.80
H	(No.9)[b]	5.0	U	(No. 40)[b]	2.50
J	23/32	18.3	V	5/8	16.0
K	5/32	3.97	W	0.06	1.52
L	1/4	6.35			
M	3/32	2.38			

[a] Nylon Rain-Test Spray Heads are available from Underwriters Laboratories

[b] ANSI B94.11M Drill Size

[c] Optional – To serve as a wrench grip.

RT100E

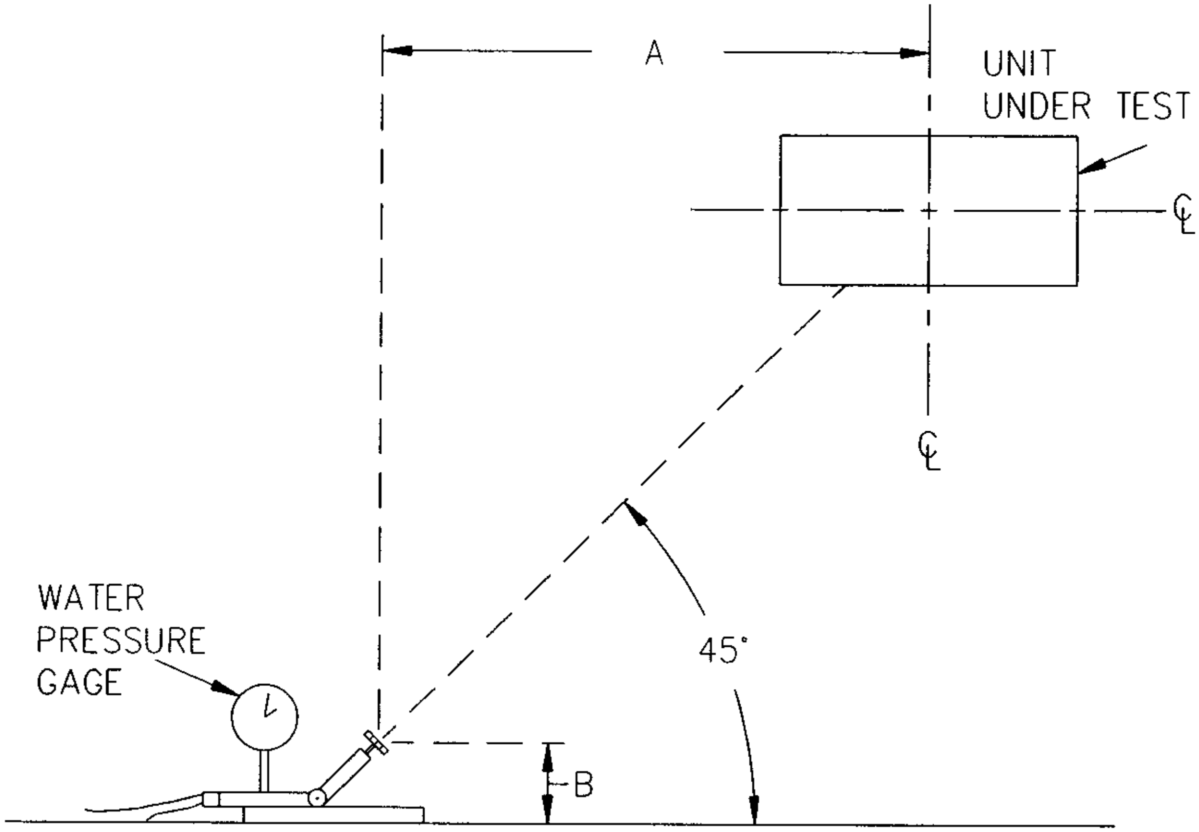
61.3 Sprinkler test

61.3.1 A unit required to be subjected to a sprinkler test is to be tested as described in 61.3.2 and 61.3.3.

61.3.2 An outdoor ground-mounted unit is to be turned about its vertical axis to each of four positions 90 degrees from each other, each for 30 minutes during the 2-hour portion of the test described in 61.1.3, with adjustable parts arranged for maximum vulnerability to the water spray. Wall-mounted units intended for mounting within 914 mm (3 feet) of the ground, are to be similarly tested in the most vulnerable normal mounting position.

61.3.3 The unit is to be positioned as shown in Figure 61.3 in front of a standard water spray head of the type shown in Figure 61.2, to which the water pressure is maintained at a gage pressure of 138 kPa (20 psi).

Figure 61.3
Representative sprinkler test setup



NOTES –

The unit is to be mounted as intended with the dimensional center of the unit on a line projected from the centerline of the nozzle head.

A – 914.4 mm (36 inches)

B – 76.2 – 152.4 mm (3 – 6 inches)

RATING

62 Details

62.1 A unit shall be rated as shown in Table 62.1.

62.1 effective November 7, 2000

Table 62.1
Unit ratings

Revised Table 62.1 effective May 7, 2007

Rating type		Utility-interactive	Stand-alone	Utility-interactive with charge control[d]	Stand-alone with charge control[d]	ISE	Charge controllers[d]
a)	Maximum input voltage[a]	X[b]	X	X	X	X	X
b)	Range of input operating voltage	X[b]	X	X	X	X	X
c)	Maximum input current (ac or dc)	X[b]	X	X	X		X
d)	Maximum input short circuit current	X[b]	X	X	X	X	X
e)	Maximum input source backfeed current to input source [see 47.6.2]	X		X			
f)	Output power factor rating	X	X	X	X		
g)	Operating voltage range (ac)	X	X	X	X	X	X
h)	Operating frequency range or single frequency	X	X	X	X		X
i)	Nominal output voltage (ac)	X	X	X	X		
j)	Normal output frequency	X	X	X	X		
k)	Maximum continuous output current (ac)	X	X	X	X		
l)	Maximum continuous output power (ac)	X	X	X	X		
m)	Maximum output fault current (ac) and duration [see 47.3.3]	X	X	X	X		
n)	Maximum output overcurrent protection[c]	X	X	X	X		
o)	Nominal output voltage (dc)			X	X		
p)	Charging output voltage operation range (dc)			X	X		X

Table 62.1 Continued on Next Page

Table 62.1 Continued

Rating type		Utility-interactive	Stand-alone	Utility-interactive with charge control[d]	Stand-alone with charge control[d]	ISE	Charge controllers[d]
q)	Utility interconnection voltage and frequency trip limits and trip times	X				X	
r)	Synchronization in-rush current	X					
s)	Trip limit and trip time accuracy	X		X		X	
t)	Normal operation temperature range	X	X	X	X	X	X
u)	Output power temperature derating and maximum full power operating ambient[e]	X	X	X	X		X

Note – A nationally accepted conventional abbreviation may be used for the rating type.

[a] The maximum input voltage determined in accordance with Section 690.7(a) of the National Electrical Code, NFPA 70, may be used for photovoltaic inverters and charge controllers.

[b] Not required for ac modules.

[c] Normally the branch-circuit overcurrent protection.

[d] Charging of batteries is able to originate from dc or ac sources. The rating types for either ac or dc are to be applied accordingly.

[e] Only for units that derate with output temperature.

MARKING

63 Details

63.1 Unless otherwise stated, all markings shall be permanent. The following types of markings or the equivalent meet this requirement:

a) Molded,

b) Die-stamped,

c) Paint-stenciled,

d) Stamped or etched metal that is permanently secured, or

e) Indelibly stamped on a pressure-sensitive label complying with the Standard for Marking and Labeling Systems, UL 969.

63.1 effective November 7, 2000

63.2 A unit shall be plainly and permanently marked where it is readily visible after installation with:

a) The manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product is able to be identified – hereinafter referred to as the manufacturer's name,

b) A distinctive catalog number or the equivalent,

c) The electrical ratings other than items a, d, e, m, n, q, r, s, t, and u specified in Table 62.1, and

d) The date or other dating period of manufacture not exceeding any three consecutive months. The repetition time cycle of a date code shall not be less than 20 years.

The date code shall not require reference to the manufacturer's records to determine when the unit was manufactured.

Exception No. 1: The manufacturer's identification is able to be in a traceable code when the unit is identified by the brand or trademark of a private labeler.

Exception No. 2: The date of manufacture is able to be abbreviated in a nationally accepted conventional code, or in a code affirmed by the manufacturer.

63.2 revised November 7, 2005

63.3 When an inverter, converter, or interconnection system equipment (ISE) is intended for connection with an EPS and complies with Utility Compatibility, Section 46, it shall be marked "Utility-Interactive," "Interconnection System Equipment," or the equivalent.

63.3 revised November 7, 2005

63.4 With reference to the Exception to 39.2, the inverter or interconnection system equipment (ISE) manual shall be marked with the following: "This unit or system is provided with fixed trip limits and shall not be aggregated above 30 kW on a single Point of Common Connection."

Revised 63.4 effective May 7, 2007

63.5 A unit or separate device provided with integral dc ground-fault detector/interrupter protection in accordance with DC Ground-Fault Detector/Interrupter, Section 31, shall be marked to indicate its presence. If the separate device is not self-contained and is intended for installation in another enclosure, the device shall be provided with a label for fixing to the outside of the enclosure to indicate its presence.

Revised 63.5 effective May 7, 2007

63.6 When a unit is produced or assembled at more than one factory, each unit shall have a distinctive marking – which is able to be in code – to identify the product of a particular factory.

63.6 effective November 7, 2000

63.7 The symbols described in items (a) – (c) are usable for markings to comply with the requirement in Table 62.1:

a) A circuit intended to be connected to a dc circuit shall be identified by markings indicating that the circuit shall be dc. The symbol illustrated in Figure 63.1 meets the requirement for this marking. See 63.8.

b) A circuit intended to be connected to an ac circuit shall be identified by markings indicating that the circuit shall be ac. The markings shall include the supply-circuit frequency or supply-circuit frequency-range rating (cycles per second, cycles/second, hertz, c/s, cps, or Hz). The symbol illustrated in Figure 63.2 meets the requirement for this marking. See 63.8.

c) The number of phases shall be indicated when the unit is designed for use on a polyphase circuit. The symbol illustrated in Figure 63.3 is equivalent to the word "phase." See 63.8.

63.7 effective November 7, 2000

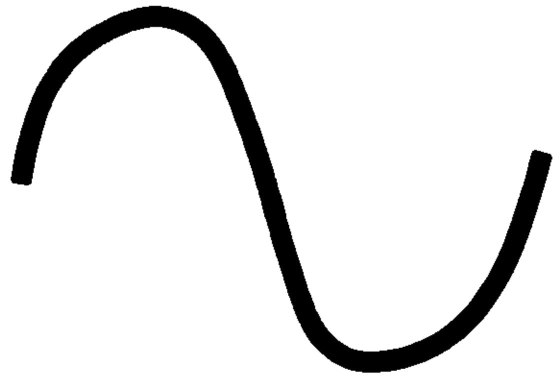
Figure 63.1
Direct current supply symbol

Figure 63.1 effective November 7, 2000

IEC5031

IEC Publication 417, Symbol 5031

Figure 63.2
Alternating current supply symbol
Figure 63.2 effective November 7, 2000



IEC5032

IEC Publication 417, Symbol 5032

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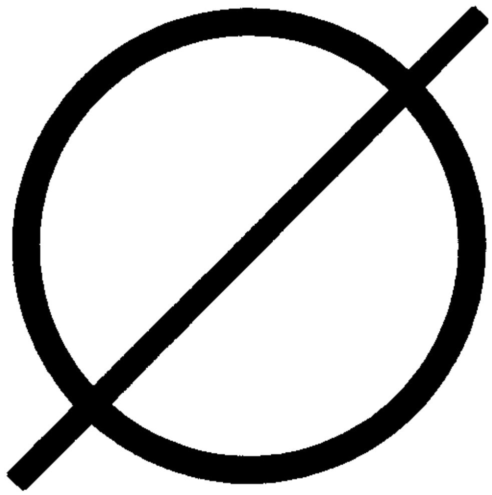
Figure 63.3
Phase symbol

Figure 63.3 effective November 7, 2000



S3862

63.8 When a symbol referenced in 63.7(a), (b), and (c) is used, the information described in 66.4(G) shall be provided as part of the Important Safety Instructions.

63.8 effective November 7, 2000

63.9 The operating positions of a handle, knob, or other means intended for manual operation by the user shall be marked.

63.9 effective November 7, 2000

63.10 Wiring terminals shall be marked to indicate the intended connections for the unit, or a wiring diagram coded to the terminal marking shall be securely attached to the unit.

Exception: The terminal markings are not required when the wire connections are evident.

63.10 effective November 7, 2000

63.11 Field-wiring terminals shall be marked in accordance with 66.4 (L) and (M), Table 66.3, and the following:

a) "Use Copper Conductors Only" when the terminal is rated only for connections to copper wire,

b) "Use Aluminum Conductors Only" or "Use Aluminum Or Copper-Clad Aluminum Conductors Only" when the terminal is rated only for connection to aluminum wire, or

c) "Use Copper Or Aluminum Conductors" or "Use Copper, Copper-Clad Aluminum, or Aluminum Conductors" when the terminal is rated for connection to copper or aluminum wire.

63.11 effective November 7, 2000

63.12 With reference to 18.1.13 a pressure wire connector or stud-and-nut type terminal intended for connection of an equipment-grounding conductor shall be identified by:

a) Being marked "G," "GR," "GND," "Ground," "Grounding," or equivalent,

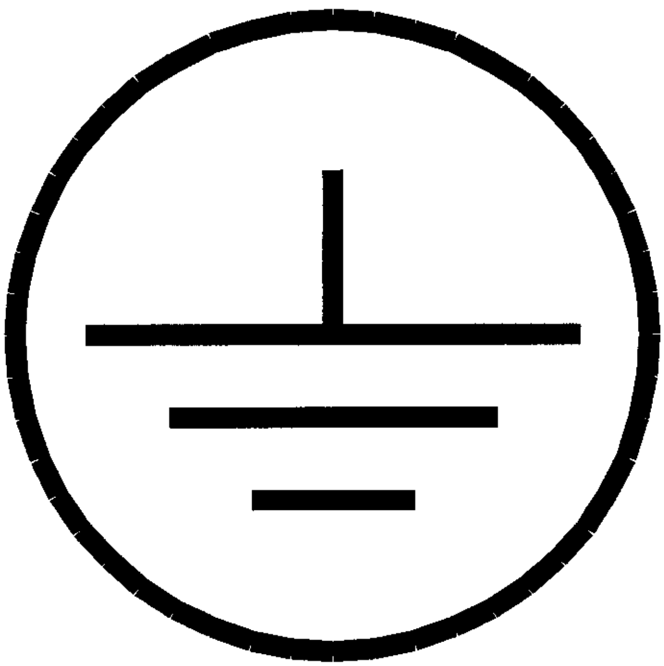
b) A marking on a wiring diagram attached to the unit, or

c) The symbol illustrated in Figure 63.4 on or adjacent to the connector or on a wiring diagram provided on the unit. See 63.14.

63.12 effective November 7, 2000

Figure 63.4
Symbol for equipment grounding conductor

Figure 63.4 effective November 7, 2000



63.13 In accordance with 43.4, a unit having an ambient temperature rating higher than 25°C (77°F) shall be marked to indicate the maximum ambient temperature rating. When tested in accordance with 43.1(c) and 45.2.5, this rating shall include the reduced output power rating.

63.13 effective November 7, 2000

63.14 With reference to 63.12(c), the following requirements apply when the symbol illustrated in Figure 63.4 is used:

a) The information described in 66.4(G) shall be provided in the Important Safety Instructions.

b) The symbol is usable for identifying only the field wiring equipment-grounding terminal. However, a symbol as shown in Figure 63.4 is usable with the circle omitted for identifying various points within the unit that are bonded to ground.

Exception: Where the symbol illustrated in Figure 63.4 is used with one of the alternate means of identification specified in 63.12(a) and (b), the information is not required to be provided in the Important Safety Instructions.

63.14 effective November 7, 2000

63.15 A terminal for the connection of a grounded conductor shall be identified by means of a metallic plated coating substantially white in color, and shall be readily distinguishable from the other terminals; or identification of the terminal for the connection of the grounded conductor shall be clearly shown in some other manner, such as:

a) A marking on the unit,

b) An indication on a wiring diagram attached to the unit, or

c) Information provided in the instruction manual.

A field wiring lead intended to be grounded shall have a white or gray color and shall be readily distinguishable from other leads.

Revised 63.15 effective May 7, 2007

63.16 A terminal, as described in 18.2.1, intended for connection of the grounding electrode conductor shall be marked "Grounding Electrode Terminal."

63.16 effective November 7, 2000

63.17 A unit employing pressure terminal connectors for field wiring connections shall be provided with a marking making reference to the instruction manual for the tightening torque to be applied to the wiring terminals. See 66.4(F).

63.17 effective November 7, 2000

63.18 A unit intended to be used with a remote battery supply shall be plainly marked indicating the polarity of the connections between the battery supply and the unit with:

a) The words "positive" and "negative,"

b) The signs "+" for positive and "-" for negative, or

c) A pictorial representation illustrating the proper polarity, orientation, and similar properties of the battery connections, as applicable for the type of battery supply involved.

63.18 effective November 7, 2000

63.19 A multiple-voltage output unit for permanent connection to the branch circuit shall be marked to indicate the particular voltage for which it is set when shipped from the factory. The marking is able to be in the form of a paper tag or any other nonpermanent material.

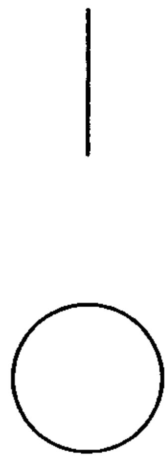
63.19 effective November 7, 2000

63.20 Both the on and off positions of the disconnect control devices specified in Switches and Controls, Section 12, shall be identified. The symbols illustrated in Figure 63.5 are usable for this purpose. The identification shall not be by illumination only. See 63.21.

63.20 effective November 7, 2000

Figure 63.5
On and off symbols

Figure 63.5 effective November 7, 2000



S3486

IEC Publication 417, Symbols 5007 and 5008

63.21 When the symbol illustrated in Figure 63.5 is used in accordance with 63.20, the information described in 66.2(G) shall be provided.

63.21 effective November 7, 2000

63.22 A clock, timing device, or alarm circuit– on or remote from a unit – that is not a low-voltage, limited-energy (LVLE) circuit and that remains energized during servicing functions shall be marked to indicate that the circuit remains energized while the unit is off.

63.22 effective November 7, 2000

63.23 With reference to 16.3.4(b), a unit containing a field-wiring lead that is intended to be connected to a wire binding screw located in the field-wiring compartment shall be marked with information clearly indicating the intended use of the lead.

63.23 effective November 7, 2000

63.24 With reference to the Exception to 18.1.8, low-voltage Class 2 field-wiring leads that are not color coded shall be identified. The identification shall not require the use of a separate wiring diagram to make proper connections.

63.24 effective November 7, 2000

63.25 A stand-alone unit having grounding type receptacles for the output ac current connections shall be marked: "One side of the output circuit is bonded to the inverter frame. Connect the grounding electrode terminal to a grounding electrode in accordance with the local codes."

63.25 effective November 7, 2000

63.26 With reference to 13.1(d), a marking shall be provided identifying the disconnect device, switch, or breaker for the output ac and dc power circuits.

63.26 effective November 7, 2000

63.27 With reference to the Exception to 17.2, a unit intended for use with a field installed conductor that is of a size smaller than maximum rated conductor size yet rated for use with the field connection pressure terminal shall be marked: "Use ____ maximum AWG wire only for field connector" or the equivalent.

63.27 effective November 7, 2000

63.28 In accordance with the Exception to 45.4.1, an inverter with a total harmonic distortion rms that exceeds 30 percent of the fundamental rms output voltage rating shall be marked to indicate the percentage that the total rms harmonic distortion exceeds the fundamental rms output voltage rating.

63.28 effective November 7, 2000

63.29 An enclosure other than Type 1 shall be permanently marked with the Type designation indicating the external conditions for which it is intended as specified in the Standard for Enclosures for Electrical Equipment, UL 50. An enclosure that complies with the requirements for more than one Type of enclosure is able to be marked with multiple designations. The marking shall be on the inside or outside surface and shall be visible after installation during inspection of the field wiring connections. In addition to the Type designation marking, the optional markings specified in Table 63.1 are able to be used.

63.29 effective November 7, 2000

Table 63.1
Optional Markings

Table 63.1 effective November 7, 2000

Type of enclosure	Optional marking[a]
1	"indoor use only"
3, 3S, 4, 4X, 6, or 6P	"raintight"
3R	"rainproof"
4 or 4X	"watertight"
4X or 6P	"corrosion resistant"
2, 12, 12K, or 13	"drip tight"
3, 3S, 12, 12K, or 13	"dust tight"

[a] These markings are to be additional to the enclosure Type designation marking required in 63.29.

63.30 When conduit hubs are not provided for a Type 2, 3, 3R, or 3S enclosure, the enclosure, the instruction sheet provided with the enclosure, or the packaging carton shall be marked to indicate that raintight or wet location hubs that comply with the requirements in the Standard for Fittings for Conduit and Outlet Boxes, UL 514B, are to be used.

63.30 effective November 7, 2000

63.31 A separable conduit hub and a closure fitting shall be marked with the manufacturer's name or trademark and the catalog number or equivalent. Such a hub or fitting is able to be shipped separately, and any gasket, hardware, and instructions, required for installation shall be shipped with the fitting or packaged with the enclosure.

63.31 effective November 7, 2000

63.32 A Type 2 or 3R enclosure that has knockouts for conduit in the sides or back of the enclosure and in which the equipment to be installed is not known shall be marked to indicate the area in which live parts are to be installed. See Exception No. 1 to 5.9.4 and Exception No. 1 to 5.9.6.

63.32 effective November 7, 2000

63.33 A Type 4X enclosure intended for indoor use only shall be marked "4X Indoor Use Only" in letters not less than 4.0 mm (5/32 inch) high.

63.33 effective November 7, 2000

63.34 When required by the Exception to 5.9.9, a marking shall be provided to instruct the installer to fill the opening with a Type 12 conduit fitting.

63.34 effective November 7, 2000

64 Cautionary Markings

Section 64 effective November 7, 2000

64.1 There shall be no substitute for the words "CAUTION," "WARNING," or "DANGER" in the text of a marking.

Exception: The words "WARNING" or "DANGER" are usable in lieu of the word "CAUTION."

64.2 A cautionary marking shall be prefixed by the word "CAUTION," "WARNING," or "DANGER" in letters not less than 3.2 mm (1/8 inch) high. The remaining letters shall not be less than 1.6 mm (1/16 inch) high.

64.3 A cautionary marking shall be:

a) Located on a part that is not removable without impairing the operation of the unit, and

b) Visible and legible to the operator during the normal operation of the unit.

Exception: Cautionary markings pertaining to internal parts that are applicable only to service personnel are to be located internally in an appropriate location with respect to the parts of concern.

64.4 A live heat sink or other part that:

a) Is mistakable for dead metal,

b) Involves a risk of electric shock in accordance with Electric Shock, Section 11, and

c) Is not guarded as specified in 10.7

shall be marked "CAUTION – Risk of Electric Shock– Plates (or other word describing the type of part) are live. Disconnect unit before servicing." The marking shall be located on or near the live part so as to make the risk known before the part is touched. A single marking for multiple parts is usable.

64.5 An inverter intended to be used with an isolation transformer that is not supplied with the inverter shall be marked "CAUTION – For Proper Circuit Isolation" and the following words or the equivalent "Connect a minimum ___ kVA rated isolating transformer between the output of the unit and the utility power line connections. The transformer is to be an isolation type having separate primary and secondary windings."

Revised 64.5 effective May 7, 2007

64.6 For compliance with Exception No. 2 to 5.2.1, a unit shall be marked with the word "CAUTION –" and the following or equivalent: "Risk of Electric Shock, Do Not Remove Cover. No User Serviceable Parts Inside. Refer Servicing To Qualified Service Personnel."

64.7 For each fuse that is used to comply with the requirements in this Standard, there shall be a legible and durable marking indicating the ampere, voltage and "ac" or "dc" rating of the fuse to be used for replacement. The marking shall be located so that it is obvious as to which fuse or fuseholder the marking applies. This marking is able to consist of a pictorial identifying the rating of one or more fuses. In addition, the following prominent marking shall be provided – a single marking is usable for a group of fuses: "WARNING – For Continued Protection Against Risk Of Fire, Replace Only With Same Type And Ratings Of Fuse."

Exception: The requirement does not apply to a fuse that is secured by solder.

64.8 An inverter shall be marked with the word "CAUTION" and the following words "Risk Of Electric Shock –" and the following or the equivalent. The marking shall be located on the outside of the unit or shall be prominently visible with any cover or panel opened or removed:

a) "Both ac and dc voltage sources are terminated inside this equipment. Each circuit must be individually disconnected before servicing," and

b) "When the photovoltaic array is exposed to light, it supplies a dc voltage to this equipment."

64.9 A unit that exceeds the temperature limits specified in Table 43.2 – see the Exception to 43.2 – shall be legibly marked externally where readily visible after installation with the word "CAUTION" and the following or the equivalent: "Hot surfaces – To reduce the risk of burns – Do not touch."

64.10 A unit provided with single-pole circuit breakers in the input or output circuit in accordance with the Exception to 30.1.8 shall be marked internally with the word "CAUTION" and the following or the equivalent: "To reduce the risk of electric shock and fire – Do not connect to a circuit operating at more than 150 volts to ground."

64.11 A removable panel covering a capacitor in accordance with Exception No. 1 to 11.2.3 shall be marked "CAUTION – Risk of electric shock from energy stored in capacitor" and the following or equivalent wording: "Do not remove cover until ___ minutes after disconnecting all sources of supply." The time indicated in the marking is to be the time required to discharge the capacitor to within the limitations specified in 11.2.1, and shall be less than 5 minutes.

64.12 With reference to Exception No. 2 to 11.2.3, a unit shall be marked "CAUTION – Risk of electric shock and/or electric energy-high current levels" and the following or equivalent wording: "Disconnect and discharge (identify capacitor) before removing panel as follows." Appropriate instructions shall follow indicating how to discharge the capacitor. The procedure indicated shall be limited to functions such as operating a switch, unplugging a connector, or the equivalent. When the time to discharge the capacitor or capacitor bank is longer than 1 second, the unit shall be additionally marked to indicate the minimum discharge time with the following or the equivalent: "Do not remove cover until ___ minutes after connecting the discharge circuit." The time indicated in this marking shall not exceed 1 minute for momentary type switches and 5 minutes for other means that actuate the discharge circuit.

64.13 An ungrounded dead metal part specified in the Exception to 20.2, item (f), shall be marked with the word "CAUTION" and the following or the equivalent: "(Identify part or parts not earth grounded) (is) (are) not grounded – (it) (they) involve a risk of electric shock. Test before touching." The marking shall be provided on or adjacent to the ungrounded dead metal part and shall be visible so that each part or group of parts is positively identified.

64.14 With reference to Exception No. 3 to 11.2.3, a marking shall be provided indicating "CAUTION – Risk of electric shock or electrical energy-high current levels" and the following or the equivalent: "High-energy electric charge is stored in (identify capacitor) and associated circuitry. Test before touching." The marking shall be located internally adjacent to the capacitor.

64.15 Deleted effective May 7, 2007

64.16 With reference to 31.10, units with integral ground-fault detector/interrupter or separate devices having the same function shall be marked with the word "CAUTION" and the following or equivalent: "Risk of Electric Shock. Normally Grounded Conductors May Be Ungrounded and Energized When a Ground-Fault is Indicated." If the separate device is not self-contained and is intended for installation in another enclosure, the device shall be provided with a label for fixing to the outside of the enclosure to indicate the caution statement.

Added 64.16 effective May 7, 2007

65 Equipment Information and Instructions

65.1 Separation of information

65.1.1 Operating and operator-servicing instructions shall be separated from servicing instructions.

65.1.1 effective November 7, 2000

65.1.2 Where servicing requires access to parts that involve a risk of electric shock, servicing instructions shall be preceded by a warning. The warning shall be worded as follows or the equivalent "Warning – These servicing instructions are for use by qualified personnel only. To reduce the risk of electric shock, do not perform any servicing other than that specified in the operating instructions unless you are qualified to do so." The letter height shall be in accordance with 64.2.

65.1.2 effective November 7, 2000

65.2 Operating and installation instructions

65.2.1 The operating and installation instructions shall:

a) Describe the equipment installation, including specifically:

1) Assembly, and mounting, where required,

2) Grounding means, and

3) Ventilation consideration;

b) Explain equipment markings, including specifically:

1) Symbols,

2) Controls, and

3) All applicable ratings in Table 62.1;

c) Identify and describe interconnections with:

1) The input source,

2) The utility, and

3) Auxiliary and accessory equipment;

d) Explain the operation of the equipment;

e) Indicate that the ac output (neutral) is (is not) bonded to ground;

f) In accordance with 14.2.3(a), an inverter provided with a fixed ac output shall inform the installer that the input and output circuits are isolated from the enclosure and that system grounding, when required by Sections 690.41, 690.42, and 690.43 of the National Electric Code, ANSI/NFPA 70, is the responsibility of the installer;

g) Field adjustable trip limits for voltage and frequency shall be described and include the adjustment range for voltage, frequency and trip time. The "as shipped" default settings shall be specified; and

h) Integral dc ground-fault detector/interrupter protection shall describe the proper method for connecting and grounding the photovoltaic system.

Revised 65.2.1 effective May 7, 2007

65.2.2 The important safety instructions shall appear before the battery installation procedures and maintenance.

65.2.2 effective November 7, 2000

65.2.3 The installation instructions shall indicate that the wiring methods in accordance with the National Electrical Code, ANSI/NFPA 70 are to be used.

65.2.3 effective November 7, 2000

65.2.4 An enclosure marked Type 4, 4X, 6, or 6P shall be provided with instructions for installation of a watertight conduit connection when the connection is not mounted on the enclosure.

65.2.4 effective November 7, 2000

65.2.5 Installation instructions shall be provided with an enclosure intended for field assembly of the bonding means that identifies the parts for bonding and specifies the method of installation.

65.2.5 effective November 7, 2000

65.2.6 When a hub or fitting is not provided or installed on a Type 4 or 4X enclosure, instructions identifying the specific hub or fitting and installation instructions shall be provided with the enclosure.

65.2.6 effective November 7, 2000

65.2.7 A polymeric enclosure shall have instructions stating that the hub is to be connected to the conduit before the hub is connected to the enclosure when it:

a) Is intended for connection to a rigid conduit system,

b) Has not been subjected to the torque test described in Polymeric Enclosure Rigid Metallic Conduit Connection Tests in the Standard for Enclosures for Electrical Equipment, UL 50, and

c) Is not provided with a preassembled hub.

65.2.7 effective November 7, 2000

65.2.8 With reference to 32A.3, a product, not covered by 32A.2, that uses a manufacturer-specified external isolation transformer shall be provided with instructions that specify the manufacturer, model, electrical ratings, and environmental ratings for the external isolation transformer with which it is intended to be used.

Added 65.2.8 effective May 7, 2007

66 Important Safety Instructions

66.1 The headings "IMPORTANT SAFETY INSTRUCTIONS" and "SAVE THESE INSTRUCTIONS" for the instruction manual, and the opening statements of the instructions in the important safety instructions shall be entirely in upper case letters not less than 4.8 mm (3/16 inch) high or emphasized to distinguish them from the rest of the text. Upper case letters in the instructions shall not be less than 2.0 mm (5/64 inch) high, and lower case letters shall not be less than 1.6 mm (1/16 inch) high.

66.1 effective November 7, 2000

66.2 There shall be no substitute for the words "CAUTION," "WARNING," or "DANGER" in the text of the instructions.

Exception: The words "WARNING" or "DANGER" are usable in lieu of the word "CAUTION."

66.2 effective November 7, 2000

66.3 The important safety instructions described in items A – S in 66.4, as appropriate, shall be provided with each unit. The information contained in items C – S is able to be marked on the unit or in the instruction manual.

Revised 66.3 effective May 7, 2007

66.4 The important safety instructions shall include instructions for the following items A – S. The statement "IMPORTANT SAFETY INSTRUCTIONS", and the statement "SAVE THESE INSTRUCTIONS" shall precede the list. The word "WARNING," "CAUTION," and "DANGER" shall be entirely in upper case letters.

IMPORTANT SAFETY INSTRUCTIONS

A. SAVE THESE INSTRUCTIONS– This manual contains important instructions for Models ________________ (blank space is to be filled in with appropriate model numbers) that shall be followed during installation and maintenance of the _________ (blank space is to indicate inverter or charge controller as appropriate).

Exception: When the instructions are exactly the same for all models, specific model numbers are not required.

B. In accordance with 16.2.4, when pressure terminal connectors or the fastening hardware are not provided on the unit as shipped, the instruction manual shall indicate which pressure terminal connector or component terminal assemblies are for use with the unit.

C. With reference to item B, the terminal assembly packages and the instruction manual shall include information identifying wire size and manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product is identifiable.

D. When a pressure terminal connector provided in the unit (or in a terminal assembly covered in 16.2.4(d)) for a field installed conductor requires the use of other than a common tool for securing the conductor, identification of the tool and any required instructions for using the tool shall be included in the instruction manual.

E. A unit provided with a wire connector for field installed wiring as covered in Exception No. 2 to 16.3.1 shall be provided with instructions specifying that the connector provided is to be used in making the field connection.

F. A unit employing pressure terminal connectors for field wiring connections shall be provided with instructions specifying a range of values or a nominal value of tightening torque to be applied to the clamping screws of the terminal connectors. The minimum specified tightening torque shall not be less than 90 percent of the value specified in Tables 66.1 or 66.2 applicable to the wire size determined in accordance with 16.1.3.

Exception: A torque less than 90 percent is usable when the connector – using the lesser assigned torque value – complies with the Standard for Wire Connectors and Soldering Lugs for Use With Copper Conductors, UL 486A, the Standard for Wire Connectors for Use With Aluminum Conductors, UL 486B, or the Standard for Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors, UL 486E.

G. When a symbol is used for compliance with marking requirements specified in 63.8, 63.13, or 63.21, the instruction manual shall identify the symbol.

H. The instruction manual for a unit that exceeds the temperature limits of Table 43.2 (see the Exception to 43.2) shall specify that the unit is to be installed so that it is not expected to be contacted by persons.

I. The instruction manual for a charge controller or an inverter intended to charge batteries shall indicate the nominal voltage rating of the battery supply and a generic description of the batteries, such as lead acid, nickel cadmium, and vented or sealed.

J. In accordance with 43.3, the instruction manual for an inverter having an ambient temperature rating higher than 25°C (77°F) shall indicate the maximum ambient temperature rating.

K. For a unit having a single equipment field-wiring terminal that is intended for connection of more than one conductor, the instruction manual shall include information identifying the number of conductors and range of conductor sizes.

L. For a unit provided with field-wiring terminals or leads, the instruction manual shall include the information indicated in Row 1, 2, 3, or 4 of Table 66.3 or with equivalent wording, when it is:

1) Intended for use on a supply circuit rated 110 amperes or less, or

2) Intended for field connection with No. 1 AWG (42.4 mm^2) or smaller conductors.

M. For a unit provided with field-wiring terminals or leads, the instruction manual shall include the information indicated in Row 3 or 4 of Table 66.3, or with equivalent wording, when it is:

1) Intended for use on a supply circuit rated more than 110 amperes, or

2) Intended for field connection with conductors larger than No. 1 AWG (42.4 mm^2).

N. When required by the Exception to 16.6.1, the instruction manual shall include a statement indicating that Class 1 wiring methods are to be used for field wiring connections to terminals of a Class 2 circuit.

O. In accordance with 47.1.7, when an abnormal test is terminated by operation of the intended branch-circuit overcurrent protective device, the instruction manual for a unit shall include the word "CAUTION" and the following or the equivalent: "To reduce the risk of fire, connect only to a circuit provided with _______ amperes maximum branch-circuit overcurrent protection in accordance with the National Electrical Code, ANSI/NFPA 70." The blank space is to be filled in with the ampere rating of branch-circuit overcurrent protection described in 47.1.7.

P. When required by the Exception to 30.3.1, the instruction manual shall include a statement indicating that overcurrent protection for the ac output circuit is to be provided by others.

Q. When required by the Exception to 30.4.1, the instruction manual shall include a statement indicating that overcurrent protection for the battery circuit is to be provided by others.

R. An inverter with 120 V output shall be provided with instructions that include the word "WARNING" and the following or the equivalent: "To reduce the risk of fire, do not connect to an ac load center (circuit breaker panel) having multiwire branch circuits connected."

S. When required by Exception No. 2 to 31.1, the manual shall include the word "WARNING" and the following or equivalent: "This unit is not provided with a GFDI device. This inverter or charge controller must be used with an external GFDI device as required by the Article 690 of the National Electrical Code for the installation location."

Revised 66.4 effective May 7, 2007

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Table 66.1
Tightening torque for pressure wire connectors

Table 66.1 effective November 7, 2000

Size of wire that is to be used for connection of the unit		Tightening torque, N·m (pound-inch)							
		Slotted head no. 10 and larger				Hexagonal head - external drive socket wrench			
AWG/kcmil	(mm^2)	Slot width - 1.2 mm (0.047 inch) or less and slot length 6.4 mm (1/4 inch) or less		Slot width - over 1.2 mm (0.047 inch) or slot length-over 6.4 mm (1/4 inch)		Split-bolt connectors		Other connectors	
18 – 10	(0.82 – 5.3)	2.3	(20)	4.0	(35)	9.0	(80)	8.5	(75)
8	(8.4)	2.8	(25)	4.5	(40)	9.0	(80)	8.5	(75)
6 – 4	(13.3 – 21.2)	4.0	(35)	5.1	(45)	18.6	(165)	12.4	(110)
3	(26.7)	4.0	(35)	5.6	(50)	31.1	(275)	16.9	(150)
2	(33.6)	4.5	(40)	5.6	(50)	31.1	(275)	16.9	(150)
1	(42.4)	–		5.6	(50)	31.1	(275)	16.9	(150)
1/0 – 2/0	(53.5 – 67.4)	–		5.6	(50)	43.5	(385)	20.3	(180)
3/0 – 4/0	(85.0 – 107.2)	–		5.6	(50)	56.5	(500)	28.2	(250)
250 – 350	(127 – 177)	–		5.6	(50)	73.4	(650)	36.7	(325)
400	(203)	–		5.6	(50)	93.2	(825)	36.7	(325)
500	(253)	–		5.6	(50)	93.2	(825)	42.4	(375)
600 – 750	(304 – 380)	–		5.6	(50)	113.0	(1000)	42.4	(375)
800 – 1000	(406 – 508)	–		5.6	(50)	124.3	(1100)	56.5	(500)
1250 – 2000	(635 – 1016)	–		–		124.3	(1100)	67.8	(600)

Table 66.2
Tightening torque for pressure wire connectors having internal drive, socket-head screws

Table 66.2 effective November 7, 2000

Socket size across flats,		Tightening torque,	
mm	(inch)	N·m	(pound-inch)
3.2	(1/8)	5.1	(45)
4.0	(5/32)	11.4	(100)
4.8	(3/16)	13.8	(120)
5.6	(7/32)	17.0	(150)
6.4	(1/4)	22.6	(200)
7.9	(5/16)	31.1	(275)
9.5	(3/8)	42.4	(375)
12.7	(1/2)	56.5	(500)
14.3	(9/16)	67.8	(600)

Table 66.3
Termination markings

Table 66.3 revised January 17, 2001

Temperature rating of wire that is intended to be used for connection of the unit		Copper conductors only	Aluminum conductors or copper-clad conductors[a]
Row 1	60 or 75°C	"Use either No. [b] AWG, 60°C or No. [c] AWG, 75°C copper wire"	"Use 60°c wire, either No. [b] AWG copper or No. [b] AWG aluminum; or 75°C wire, either No. [c] AWG aluminum.
Row 2	60°C	"Use No. [b] AWG, 60°C copper wire"	"Use 60°C wire, either No. [b] AWG copper or No. [b] AWG aluminum"
Row 3	75°C	"Use No. [c] AWG, 75° copper wire"	"Use 75°C wire either No. [c] AWG copper or No. [c] AWG aluminum"
Row 4	90°C	"Use No. [c] AWG, 90°C copper wire"	"Use 90°C wire, either No. [c] AWG copper or No. [c] AWG aluminum"

[a] Reference to copper wire is not to be included when wiring terminals are marked in accordance with 63.11(b).

[b] The wire size for 60°C wire is not required to be included in the marking; however, when it is included, it shall be based on the ampacities given in Table 310.16 of the National Electrical Code, ANSI/NFPA 70, for 60°C wire and the derating factor described in 16.1.3.

[c] The conductor size shall not be smaller than the larger of the following:

a) The conductor size used for the temperature test; or

b) The 75°C wire size based on the ampacities given in Table 310.16 of the National Electrical Code, ANSI/NFPA 70, and the derating factor described in 16.1.3.

MANUFACTURING AND PRODUCTION TESTS

67 Dielectric Voltage-Withstand Test

67.1 Each unit shall withstand without breakdown, as a routine production-line test, the application of a potential:

a) From input and output wiring, including connected components, to accessible dead metal parts that are able to become energized, and

b) From input and output wiring to accessible low-voltage, limited-energy metal parts, including terminals.

67.1 effective November 7, 2000

67.2 Other than as noted in 67.3, the potential for the production-line test shall be in accordance with Condition A or Condition B of Table 67.1 at a frequency within the range of 40-70 Hertz.

67.2 revised January 17, 2001

Table 67.1
Production-line test conditions

Table 67.1 effective November 7, 2000

Unit rating, volts	Condition A		Condition B		Condition C		Condition D	
	Potential, volts ac	Time, seconds	Potential, volts ac	Time, seconds	Potential, volts dc	Time, seconds	Potential, volts dc	Time, seconds
250 or less	1000	60	1200	1	1400	60	1700	1
More than 250	1000+2 V[a]	60	1200+ 2.8 V[a]	1	1400+ 2.8 V[a]	60	1700+3.4 V[a]	1

[a] Maximum marked voltage.

67.3 A unit employing circuitry that is able to be damaged by an ac potential is able to be tested using a dc potential in accordance with Condition C or Condition D of Table 67.1.

67.3 effective November 7, 2000

67.4 Testing of a unit in a heated or unheated condition meets the intent of the requirement for manufacturing and production tests.

67.4 effective November 7, 2000

67.5 The test is to be performed on a complete, fully assembled unit. It is not intended that the unit be unwired, modified, or disassembled for the test.

Exception No. 1: A part, such as a snap cover or a friction-fit knob, that interferes with the performance of the test is to be removed.

Exception No. 2: The test is able to be performed on a partial or modified unit as long as it has been evaluated to be representative of a complete unit.

Exception No. 3: The grounding connection of a grounded input terminal is able to be disconnected.

67.5 effective November 7, 2000

67.6 A unit employing a solid-state component that is not relied upon to reduce a risk of electric shock and that is susceptible to damage by the dielectric potential, is able to be tested before the component is electrically connected or after the component is electrically disconnected. The circuitry is able to be rearranged for the purpose of the test to minimize the potential of solid-state-component damage while retaining representative dielectric stress of the circuit.

67.6 effective November 7, 2000

67.7 The test equipment for supplying an ac potential is to include a transformer having a sinusoidal output. The test equipment is to include a means of indicating the test potential, an audible or visual indicator of breakdown, and a manually reset device to restore the equipment after breakdown or a feature to automatically reject a noncomplying unit.

67.7 effective November 7, 2000

67.8 Where the output rating of the test equipment transformer is less than 500 VA, the equipment is to include a voltmeter in the output circuit to directly indicate the test potential.

67.8 effective November 7, 2000

67.9 Where the output rating of the test equipment transformer is 500 VA or more, the test potential is to be indicated:

a) By a voltmeter in the primary circuit or in a tertiary-winding circuit,

b) By a selector switch marked to indicate the test potential, or

c) In the case of equipment having a single test-potential output, by a marking in a readily visible location to indicate the test potential. When marking is used without an indicating voltmeter, the equipment shall include a positive means, such as an indicator lamp, to indicate that the manually reset switch has been reset following a dielectric breakdown.

67.9 effective November 7, 2000

67.10 Test equipment, other than that described in 67.7 – 67.9, is usable when found to accomplish the intended factory control.

67.10 effective November 7, 2000

67.11 During the test, the unit switches are to be in the on position, both sides of the input and output circuits of the unit are to be connected together and to one terminal of the test equipment, and the second test-equipment terminal is to be connected to the accessible dead metal.

Exception: A switch is not required to be in the on position when the testing means applies full test potential from the input and output wiring to dead metal parts with the switch not in the on position.

67.11 effective November 7, 2000

68 Utility Voltage and Frequency Variation Test

68.1 As a routine production line test, each utility-interactive inverter initially exporting power within its normal operating range shall cease to export power to the simulated utility source after the output voltage and frequency of the simulated utility source are adjusted to each condition specified in Table 68.1 within the time specified in the table. The inverter is to be tested to each condition once to verify compliance.

Exception: After it has been determined that an inverter with an automatic reset control complies with the 5 minute minimum, programming the control to reset in less than 5 min to reduce test time meets the intent of the requirement. The 5–min wait time shall be reset and verified prior to shipping the product.

68.1 revised January 17, 2001

Table 68.1
Voltage and frequency limits for utility interaction

Table 68.1 revised January 17, 2001

Condition	Simulated utility source		Maximum time, seconds (cycles) at 60 Hz[a] before cessation of current to the simulated utility	
	Voltage, V	Frequency, Hz		
A	$< 0.50\ V_{nor}$[b]	rated	0.1	(6)
B	$0.50\ V_{nor} \leq V < 0.88\ V_{nor}$	rated	2	(120)
C	$1.10\ V_{nor} < V < 1.37\ V_{nor}$	rated	2	(120)
D	$1.37\ V_{nor} \leq V$	rated	2/60	(2)
E	rated	f > rated + 0.5[c]	0.1	(6)
F	rated	f < rated -0.7[c]	0.1	(6)

[a] When a utility frequency other than 60 Hz is used for the test, the maximum number of cycles it takes to cease to export power to the simulated utility shall not exceed the number of cycles a utility frequency of 60 Hz takes regardless of the time the inverter takes to cease to export power to the simulated utility.

[b] V_{nor} is the nominal output voltage rating.

[c] The rate of change in frequency shall be less than 0.5 Hz per second.

68.2 Each inverter with field adjustable trip points shall have the trip factory set points confirmed in accordance with the manufacturer's installation instructions.

68.2 effective November 7, 2000

68.3 The inverter is not required to be tested at full rated output power and the simulated utility source is not required to comply with 41.3.

68.3 revised January 17, 2001

CHARGE CONTROLLERS

INTRODUCTION

69 General

Section 69 effective November 7, 2000

69.1 These requirements cover permanently connected charge controllers that are intended to be installed in photovoltaic panels, photovoltaic power distribution equipment, and control panels or systems.

69.2 The requirements in Sections 69 – 79 supplement and, in some cases, amend the requirements in Sections 4 – 67.

CONSTRUCTION

70 General

Section 70 effective November 7, 2000

70.1 One of the internal current-carrying conductors (normally the negative), connecting the charge controller's input to output, shall be identified as the grounded conductor where the controller is used in grounded circuits or systems. The grounded conductor shall not contain any components, such as relays, transistors or similar devices.

Exception: A shunt provided in the negative line is in compliance with the requirement.

70.2 When a shunt is provided in accordance with the Exception to 70.1, the point of connection to system ground shall be identified. The cross-sectional area of the shunt shall not be less than the minimum size conductor for the intended current and material type. See Table 19.2 for examples.

Exception: A smaller size shunt meets the intent of the requirement when:

a) The measured temperatures do not exceed the ratings of the support materials or surrounding components under normal operation, and

b) The shunt does not open as a result of the tests in Abnormal Tests, Section 47.

70.3 Controls for the adjustment of the state-of-charge of a battery shall be accessible for qualified service personnel only.

Exception: An on/off switch or disconnect device of a charge controller, power distribution panel, or inverter shall not be deemed a control for the state-of-charge of a battery.

70.4 When a charge controller employs temperature compensating monitoring, the monitoring means shall be remote from the charge controller, see 78.3 and 78.4.

Exception: The monitoring means is able to be internal to a unit when the unit is marked in accordance with 78.4 and, the unit is provided with instructions as described in 79.6.

70.5 The polymeric material in a charge controller that is intended to be installed internally to the wiring compartment of a photovoltaic module shall have a relative thermal index of 90°C (194°F) minimum.

PERFORMANCE

71 General

Section 71 effective November 7, 2000

71.1 A charge controller shall be tested as described in 72.1 – 76.4.

71.2 A charge controller intended for use in a photovoltaic control panel is to be installed in the smallest specified size enclosure.

71.3 A charge controller intended for use in a photovoltaic module wiring compartment is to be installed in the smallest sized compartment in which the controller is able to be installed. Prior to testing, the charge controller is to be subjected to 20 cycles of the Temperature Cycle Test in accordance with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703. When performing the tests, the charge controller, without an electrical enclosure, is to be in an ambient of 60°C (140°F) minimum or as rated by the manufacturer.

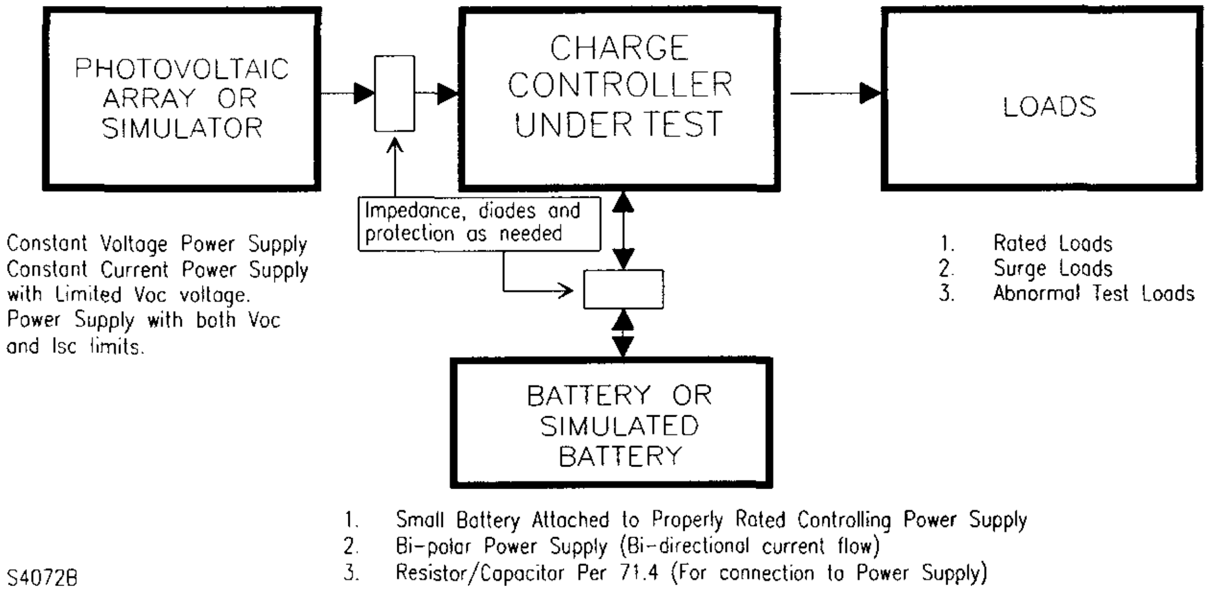
71.4 When performing tests on a charge controller, the input dc voltage is to be equal to 125 percent of the open-circuit voltage rating and is to be capable of delivering 125 percent of the rated short-circuit current of the photovoltaic source circuit intended for use with the charge controller. A battery or a simulated battery load is able to be used. A simulated battery load is to consist of one of the following loads:

Table 71.1
Simulated battery loads

Battery current rating, amperes	Capacitance in microfarads
0-20	100,000
20-40	185,000
>40	300,000

The capacitance is to be in parallel with a resistor and a power supply adjusted to simulate the battery voltage and adjusted to draw a specified operational battery charge current as required by the charge controller design. A series charge controller is also able to be tested as shown in Figure 71.1.

Figure 71.1
Charge controller test configuration



72 Normal Operations

Section 72 effective November 7, 2000

72.1 When tested as described in 72.3 – 72.5, a charge controller shall not exceed its rated input, output, or battery charge/discharge current by more than +10 percent.

72.2 When tested as described in 72.3 – 72.5, a charge controller shall not exceed its rated voltages. An on/off and constant voltage charge controller shall not have an output voltage at the battery terminals or at load terminals that exceeds its rated value by more than +10 percent after the first minute of operation.

72.3 The charge controller is to be connected to a photovoltaic array or simulated source capable of providing 125 percent of the rated current and 125 percent of the rated voltage of the intended photovoltaic circuit. The battery interface terminals of the charge controller are to be open circuited. The output or load terminals of the charge controller are to be connected to a load. The load is to be adjusted to draw the maximum attainable output current from the charge controller and the voltage is to be measured at the load terminals and at the battery terminals. When the charge controller does not function with open-circuited battery terminals, the test method described in 72.5 is to be used.

72.4 Once operational, the load is then to be adjusted over a range of operation, excluding short-circuit, and the voltage is to be measured at the output (load) terminals and at the battery interface for each value of load.

72.5 For a charge controller that does not function with open-circuited battery terminals, the charge controller is to be connected to a photovoltaic source or simulated source capable of providing 125 percent of the rated current of the intended photovoltaic circuit. The output of the charge controller is to be connected to a load. The battery terminals are to be connected to a battery or battery simulator operating at the charge controller rated battery voltage. The load is to be adjusted to draw the maximum rated current of the charge controller. The test method specified in 72.4 is to be conducted while measuring output current.

73 Temperature

Section 73 effective November 7, 2000

73.1 When tested as specified in Temperature, Section 43, the temperatures measured on polymeric materials in a charge controller intended to be installed in accordance with 70.5 shall not exceed the relative thermal index rating of the material determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

74 Temperature Compensation

Section 74 effective November 7, 2000

74.1 While the temperature sensor input is in a short- or open-circuit condition, a charge controller provided with integral temperature compensation shall shut down or limit the output charge to the load when tested as specified in 74.2.

74.2 The charge controller is to be connected to its rated input supply and rated load. The temperature sensor input is to be open-circuited and then short-circuited, one at a time.

75 Connection Sequence

Section 75 effective November 7, 2000

75.1 When tested as described in 75.2 – 75.4, the voltages and currents for a charge controller shall remain within their rated values.

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75.2 A charge controller marked with a connection sequence is to be connected in the prescribed manner and then tested in accordance with Normal Operations, Section 72.

75.3 A charge controller not marked with a prescribed connection sequence is to be tested first, with the battery connected before the photovoltaic source, and then with the photovoltaic source connected and energized before the battery is connected. Output to the battery or load is to be measured in accordance with Normal Operations, Section 72.

75.4 For all charge controllers, the battery voltage is to be disconnected and reconnected during normal operation. The voltages and currents are to be measured at the photovoltaic input, load output, and battery terminals.

75.4 revised November 7, 2005

76 Abnormal Tests

Section 76 effective November 7, 2000

76.1 General

76.1.1 When tested as described in 47.2 – 47.6 and 76.2 – 76.4, a charge controller shall comply with 47.1.1.

76.1.2 During any of the tests in 76.2 – 76.4, when shorting of the battery output terminals is required while under load, relaying shall be used to short the terminals of the unit under test while open-circuiting the battery.

76.2 Input and output faults

76.2.1 The photovoltaic array connections of a charge controller are to be connected to a dc simulator and the load (output) terminals are to be loaded to their rated load. While in a loaded state, the photovoltaic input to the charge controller is to be short-circuited.

76.2.2 The photovoltaic array connections of a charge controller are to be connected to a dc supply and the rated load (output). While in a loaded state, the output of the charge controller is to be short-circuited.

76.3 Charge controller miswiring

76.3.1 A charge controller is to be connected to its rated photovoltaic source or simulated photovoltaic source and battery as noted in Table 76.1. The connection order and polarity shall be as noted in the Table. When connecting the second supply source, battery or array, it is to be connected through a relaying device, such that the first source is already energized prior to the second source.

Exception: Those tests which limit the connection sequence do not apply to a charge controller which is marked in accordance with 77.1. For example, when a controller is marked in accordance with 77.1 indicating to connect array first, tests A, C, D, and E are not required to be performed.

Table 76.1
Connection order and polarity

Test condition	Supply to be connected first	Lead to be connected to positive terminal	Lead to be connected to negative terminal	Supply to be connected second[a] via relay	Lead to be connected to positive terminal	Lead to be connected to negative terminal
A	Battery	+	-	Array	+	-
B	Array	+	-	Battery	+	-
C	Battery	-	+	No connection		
D	Battery	-	+	Array	+	-
E	Battery	-	+	Array	-	+
F	Array	-	+	No connection		
G	Array	-	+	Battery	+	-
H	Array	–	+	Battery	–	+

[a] When connecting the second supply source, battery or array, it is to be connected through a relaying device, such that the first source is already energized prior to the second source.

76.3.2 When a simulated array source is used, a reverse-biased diode shall be placed across the supply to simulate the possible activation of an array bypass diode.

76.3.3 As a result of the test for charge controllers which have load control terminals, there shall not be reverse polarity voltage present on the terminals or current unless condition A of Table 76.1 occurs.

76.3.4 During the test, no additional external overcurrent protection is to be in the test circuit.

76.4 Low-voltage disconnect

76.4.1 When tested as described in 76.4.2, a charge controller shall operate in a stable, controlled manner over all ranges of charge and discharge of a battery load.

76.4.2 A charge controller with a low-voltage disconnect is to be connected to a source providing the charge controller's rated input, a battery or simulated battery load, and a rated load. The battery source is to be adjusted to 25 percent, 50 percent, 75 percent, and 100 percent of the rated battery voltage. The load is to be adjusted so that the charge controller cycles in accordance with the charge controller design from battery charge to battery discharge state. Adjustable charge set-points are to be set to their closest tolerance so that the charge controller cycles during the battery charge.

MARKING

77 Cautionary Markings

Section 77 effective November 7, 2000

77.1 A charge controller which requires a specific connection method in accordance with 76.3.1 shall be marked "CAUTION: Risk of fire and shock, connect ________ terminals prior to the connection of __________ terminals" indicating the battery or array terminals as appropriate.

78 Details

78.1 A charge controller shall be marked in accordance with Details, Section 63, and Cautionary Markings, Section 64.

78.1 effective November 7, 2000

78.2 A charge controller intended to be installed in the wiring compartment of a photovoltaic module shall be marked to identify the manufacturer and model number of the photovoltaic module in which the controller is intended to be installed.

78.2 effective November 7, 2000

78.3 A charge controller with a temperature compensating set-point that is intended to be adjusted by service personnel shall be marked with set-point details.

78.3 effective November 7, 2000

78.4 A charge controller with an internal temperature compensating means shall be marked "CAUTION: Internal Temperature Compensation. RISK OF FIRE, USE WITHIN ____ m (ft) of BATTERIES" or "RISK OF FIRE, MOUNT IN CONTACT WITH BATTERIES."

78.4 revised January 17, 2001

78.5 A charge controller shall be marked with the minimum interrupting rating of the overcurrent protective device to be used for short-circuit protection. For example, "Minimum interrupting rating ______ A dc."

78.5 effective November 7, 2000

79 Important Safety Instructions

Section 79 effective November 7, 2000

79.1 The installation instructions shall identify the conductor or the terminal described in 70.1 as the conductor or the terminal to be used as the grounded conductor in grounded circuits.

79.2 The installation instructions shall specify the type and chemical composition of the battery with which the charge controller is intended to be used [see 66.4(l)].

79.3 A charge controller intended for field installation shall be provided with a wiring diagram or installation instructions that specify the method of installation including the connection method and wire size range in accordance with Article 690 of the National Electrical Code, NFPA 70.

79.4 The installation instructions for a charge controller intended to be installed in the wiring compartment of a photovoltaic module shall specify the manufacturer and model of the photovoltaic module.

79.5 The installation instructions for a charge controller shall describe the maximum overcurrent protection to be provided in accordance with Article 690 of the National Electrical Code, NFPA 70.

79.6 The installation instructions for a charge controller with an internal temperature compensating means shall indicate where the controller is to be used with respect to the batteries (See 78.4) and the risks associated with the improper installation.

79.7 The installation instructions for a charge controller with service personnel adjustable temperature compensating set-points shall describe the battery chemistry and types for each set point. The instructions shall detail the risks associated with improper settings.

AC MODULES

INTRODUCTION

80 General

Section 80 effective November 7, 2000

80.1 The requirements in Sections 81 – 86 supplement and, in some cases, amend the general requirements in Sections 4 – 68.

CONSTRUCTION

81 General

Section 81 effective November 7, 2000

81.1 An ac module shall be utility interactive and shall not be capable of stand alone operation. All requirements for utility-interactive inverters in Sections 4 – 68 shall apply.

81.2 The photovoltaic panel or module of an ac module shall comply with the requirements in the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703.

81.3 All components across the dc input circuit of an ac module shall be rated for 125 percent of rated crystalline silicon photovoltaic module open-circuit voltage.

81.4 For amorphous silicate or thin film photovoltaic modules, the components across the line shall be rated for the photovoltaic module open-circuit voltage regardless of the temperature.

81.5 An ac disconnection means such as a terminal, connector, or similar means shall be provided.

81.6 Polymeric materials shall have a relative thermal index in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, not less than the temperature measured during the normal temperature test and not less than 90°C (194°F).

81.7 Connectors employed external to the module shall comply with the material and conditioning requirements in the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, in addition to the Standard for Attachment Plugs and Receptacles, UL 498. Connection shall not be of a NEMA configuration.

81.8 Equipment grounding for a dc input circuit specified in 18.1.2 does not apply to an ac module.

81.9 A gasket provided as part of the protective housing used on an ac module enclosure shall comply with the requirements in the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703.

PERFORMANCE

82 General

Section 82 effective November 7, 2000

82.1 One sample of the ac module shall comply with Dielectric Voltage-Withstand Test, Section 44, after being conditioned in accordance with the Temperature Cycling and Humidity Cycling Tests in the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703.

82.2 Where an inverter is mounted to the photovoltaic module with adhesive, the securement of the inverter to the module shall be in accordance with AC Module Inverter Securement Test, Section 83.

82.3 The Temperature Test, Section 43, is to be conducted in an ambient of 40°C (104°F) or greater.

82.4 The entire ac module assembly shall be subjected to Rain and Sprinkler Tests, Section 61. Following the tests the unit shall comply with Dielectric Voltage-Withstand Test, Section 44.

83 AC Module Inverter Securement Test

83.1 An ac module inverter secured to the back of the photovoltaic module with adhesive shall comply with 83.3 – 83.7.

83.1 effective November 7, 2000

83.2 An ac module inverter secured to the back of the photovoltaic module with means other than adhesive shall comply with only 83.4 – 83.7.

83.2 effective November 7, 2000

83.3 The test described in 83.5 – 83.7 is to be performed on three separate specimens: an ac module that is in an as-received condition, one that has been subjected to the Temperature Cycle Test, and one that has been subjected to the Humidity Cycling Test both in accordance with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703.

83.3 effective November 7, 2000

83.4 As a result of the test described in 83.5 – 83.7, the force shall not:

a) Separate the enclosure from the substrate or superstrate, or

b) Fracture the enclosure, substrate, or superstrate.

83.4 effective November 7, 2000

83.5 When a mounting orientation is not specified, the test described in 83.6 and 83.7 is to be performed in the most severe orientation.

83.5 revised January 17, 2001

83.6 A shear force of 47.5 N (35 lb/ft) or 4 times the weight of the complete inverter assembly, whichever is greater, is to be applied to the top most outer portion of the enclosure furthest from the mounting surface in the direction parallel to the adhesive or similar attachment bond.

83.6 effective November 7, 2000

83.7 The force is to be applied for a minimum of one minute.

83.7 effective November 7, 2000

RATING

84 General

Section 84 effective November 7, 2000

84.1 An ac module inverter that is provided integral to the photovoltaic module is not required to be provided with the dc input ratings specified in items (a) – (e) in Table 62.1.

MARKING

85 Details

85.1 The output of an ac module shall be marked with the maximum parallel combination of modules that it is intended for.

85.1 effective November 7, 2000

85.2 An ac module shall be marked "to be connected only to a dedicated branch circuit" or the equivalent.

85.2 effective November 7, 2000

85.3 An ac module shall be marked with the maximum size branch-circuit overcurrent-protection to which it is to be connected.

85.3 revised January 17, 2001

86 Important Safety Instructions

Section 86 effective November 7, 2000

86.1 The important safety instructions shall include a statement indicating that the ac module shall be connected only to a dedicated branch circuit.

APPENDIX A

Standards for Components

Standards under which components of the products covered by this standard are evaluated include the following:

Title of Standard – UL Standard Designation

Analog Instruments – Panelboard Types, Electrical – UL 1437
Attachment Plugs and Receptacles, Electrical – UL 498
Capacitors – UL 810
Capacitors and Suppressors for Radio- and Television-Type Appliances – UL 1414
Circuit Breakers, Molded-Case; Molded-Case Switches and Circuit-Breaker Enclosures – UL 489
Controls, Limit – UL 353
Cord Sets and Power-Supply Cords – UL 817
Determination of Sharpness of Edges on Equipment – UL 1439
Electromagnetic Interference Filters – UL 1283
Emergency Lighting and Power Equipment – UL 924
Enclosures for Electrical Equipment – UL 50
Equipment Wiring Terminals for Use With Aluminum and/or Copper Conductors – UL 486E
Filter Units, Air, Test Performance of – UL 900
Fittings for Conduit and Outlet Boxes – UL 514B
Flexible Cord and Fixture Wire – UL 62
Fuseholders – UL 512
Fuses, Class H – UL 248B
Fuses, Class R – UL 248E
Fuses, Class T – UL 248H
Fuses, DC for Industrial Use – UL 248L
Fuses for Supplementary Overcurrent Protection – UL 248G
Fuses, High-Interrupting-Capacity, Class K – UL 248D
Fuses, Plug – UL 248F
Ground-Fault Circuit Interrupters – UL 943
Ground-Fault Sensing and Relaying Equipment – UL 1053
Industrial Control Equipment, Electric – UL 508
Insulating Materials – General, Systems of – UL 1446
Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment – UL 840
Lampholders, Edison-Base – UL 496
Marking and Labeling Systems – UL 969
Optical Isolators – UL 1577
Outlet Boxes, Flush-Device Boxes and Covers, Nonmetallic – UL 514C
Outlet Boxes, Metallic – UL 514A
Panelboards, Electric – UL 67
Plastic Materials for Parts and Devices and Appliances, Tests for Flammability of – UL 94
Polymeric Materials – Fabricated Parts – UL 746D
Polymeric Materials – Long Term Property Evaluations – UL 746B
Polymeric Materials – Short Term Property Evaluations – UL 746A
Polymeric Materials – Use in Electrical Equipment Evaluations – UL 746C
Printed-Wiring Boards, Electrical –UL 796
Protectors, Supplementary for Use in Electrical Equipment – UL 1077
Software in Programmable Components – UL 1998

Switches, Snap, General-Use – UL 20
Switches, Special-Use – UL 1054
Tape, Insulating – UL 510
Temperature-Indicating and -Regulating Equipment, Electrical – UL 873
Terminal Blocks, Electrical – UL 1059
Terminals, Electrical Quick-Connect – UL 310
Tests for Safety-Related Controls Employing Solid-State Devices – UL 991
Thermal-Links for Use in Electrical Appliances and Components – UL 60691
Transformers, Class 2 and 3 – UL 1585
Transformers, Specialty – UL 506
Transient Voltage Surge Suppressors – UL 1449
Wire Connectors and Soldering Lugs for Use With Copper Conductors – UL 486A
Wire Connectors for Use With Aluminum Conductors – UL 486B
Wires and Cables, Thermoplastic-Insulated – UL 83

Superseded requirements for
the Standard for
Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

UL 1741, First Edition

The requirements shown are the current requirements that have been superseded by requirements in this edition. The numbers in parentheses refer to the new requirements with future effective dates that have superseded these requirements. To retain the current requirements, do not discard the following requirements until the future effective dates are reached.

5.1.5 Sheet-metal screws threading directly into metal shall not be used to attach a cover, door, or other part that is to be removed to install field wiring or for operation of the equipment. Sheet-metal screws that are threaded into sheet-metal nuts that are permanently mounted and protected against corrosion. Machine screws and self-tapping machine screws are able to thread directly into sheet-metal walls.

31.1 A unit with an integral ground fault detector/interrupter in accordance with Section 690-5 of the National Electrical Code, ANSI/NFPA 70 shall comply with 31.2 – 31.6 and Sections 53 – 56.

31.2 The ground fault detector/interrupter shall interrupt the ground fault current path and provide an indication of the fault.

38.2 A utility-interactive inverter shall comply with the applicable tests in Output Power Characteristics, Section 45.

39.1 A utility-interactive inverter shall be provided with a means to automatically cease and automatically or manually resume exporting power to the utility as specified in Utility Voltage and Frequency Variation Test, 46.2, and Anti-Islanding Test, 46.3.

Exception: This requirement does not apply to a utility-interactive inverter rated more than 10 kW when it is marked in accordance with 64.15.

39.2 In order to cease exporting power automatically in accordance with specific utility requirements, utility interactive inverters are able to be provided with field adjustable trip points for voltage, frequency, or both. The trip points shall comply with 46.2.4.

39.3 For a utility-interactive inverter with field adjustable trip points, the controls shall be accessible to service personnel only.

39.4 For units with field adjustable trip points, the installation manual shall describe the trip time and adjustable ranges in addition to default factory settings, see 65.2.1(g).

39.5 Units with field adjustable trip points shall be marked to indicate the presence of such controls, see 63.4.

40 DC Isolation From the Utility

40.1 A utility-interactive inverter shall limit the direct current flowing from the photovoltaic array into the utility:

a) During normal operation in accordance with 45.5, and

b) As a result of a single component malfunction or failure within the inverter in accordance with 47.6.

Devices, such as an isolation transformer, a blocking capacitor or a direct current sensor with high-speed disconnect switch are usable to limit the direct current flow.

Exception No. 1: An inverter marked in accordance with 64.5 complies with this requirement.

Exception No. 2: A component described in (b) that complies with 29.11, complies with this requirement.

45.1.1 When a utility-interactive inverter or ac module is required to be connected to a simulated utility source by Sections 45.2 – 45.5, the simulated utility source shall be in accordance with 41.3.

45.2.2 The output of a utility-interactive inverter shall have a power factor of 0.85 or higher when the unit is connected to the rated dc input and to a simulated utility source and operated at 100 percent of the rated output. The unit shall also be tested at 25 and 50 percent of rated output.

45.4.2 For a utility-interactive inverter, the total harmonic distortion (THD) of the rms current, see 2.40A, shall be less than 5 percent of the fundamental at full load. Individual odd harmonics shall not exceed the limits specified in Table 45.1. Individual even harmonics shall not exceed the limits specified in Table 45.2. The measurements are to be made with the inverter delivering 100 percent of its rating to a simulated utility source. For a 3-phase unit, each of the three phases shall individually comply with the specified limits for THD and odd and even harmonic distortion.

Table 45.1
RMS current distortion limits for individual odd harmonics

Odd harmonics	Distortion limit (percent)
3rd through 9th	4.0
11th through 15th	2.0
17th through 21st	1.5
23rd through 33rd	0.6
above the 33rd	0.3

Table 45.2
RMS current distortion limits for individual even harmonics

Even harmonics	Distortion limit (percent)
2nd through 10th	1.0
12th through 16th	0.5
18th through 22nd	0.375
24th through 34th	0.15
above the 36th	0.075

45.4.3 The total rms of the voltage harmonic distortion of the simulated utility source shall be less than 2 percent without the inverter operating.

45.5 DC injection

45.5.1 A utility-interactive inverter shall not inject dc current into the ac output greater than 0.5 percent of the rms value of the rated inverter output current when the inverter is connected to its rated dc supply and a simulated utility source.

46.1.1 When a utility-interactive inverter or ac module is required to be connected to a simulated utility source by Sections 46.2 – 46.4, the simulated utility source shall be in accordance with 41.3.

46.2 Utility voltage and frequency variation test

46.2.1 With reference to 39.1 and 46.2.3, a utility-interactive inverter initially exporting power within its norml operating range shall cease to export power to the simulated utility source after the output voltage and frequency of the simulated utility source are adjusted to each condition specified in Table 46.1 within the time specified in the table. The inverter is not required to be tested at full rated output power and the simulated utility source is not required to comply with 41.3.

46.2.2 A utility-interactive 3-phase inverter shall cease to export power on all 3 phases to the simulated utility source within the time specified in Table 46.1 when any individual phase voltage (line-to-neutral) extends outside the normal operating range as specified in Condition C of Table 46.1.

Table 46.1
Voltage and frequency limits for utility interaction

Condition	Simulated Utility Source		Maximum time, seconds (cycles) at 60 Hz[a] before cessation of current to the simulated utility	
	Voltage, V	Frequency, Hz		
A	$0.50\ V_{nor}$[b]	rated	0.1	(6)
B	$0.50\ V_{nor} \le V < 0.88\ V_{nor}$	rated	2	(120)
C	$0.88\ V_{nor} \le V_{nor} \le 1.10\ V_{nor}$	rated	c	c
D	$1.10\ V_{nor} < V < 1.37\ V_{nor}$	rated	2	(120)
E	$1.37\ V_{nor} \le V$	rated	2/60	(2)
F	rated	f < rated - 0.7[d]	0.1	(6)
G	rated	f > rated + 0.5[d]	0.1	(6)

[a] When a utility frequency other than 60 Hz is used for the test, the maximum number of cycles it takes to cease to export power to the simulated utility shall not exceed the number of cycles a utility frequency of 60 Hz takes regardless of the time the inverter takes to cease to export power to the simulated utility.

[b] V_{nor} is the nominal output voltage rating.

[c] Normal operating range, no cessation required.

[d] The rate of change in frequency shall be less than 0.5 Hz per second.

46.2.2A The unit is to be connected to a simulated utility and each of the transient events described in Table 46.1 are to be induced. Each condition is to be repeated 10 times. The unit shall comply with 46.2.1 and 46.2.2 each of the 10 times. Time shall be measured from the leading zero crossing of the transient event to the time when the inverter ceases to export power to the simulated utility.

46.2.3 Following each cessation of power the simulated utility source's voltage and frequency are to be restored to the rated output voltage and frequency for the unit. An inverter with a manual reset control shall not resume transfer of power to the simulated utility source. An inverter with an automatic reset control shall not resume transfer of power to the simulated utility source for at least 5 min after the utility voltage and frequency have been restored to the normal operating ranges.

Exception: After it has been determined that an inverter with an automatic reset control complies with the 5 minute minimum, programming the control to reset in less than 5 min to reduce test time meets the intent of the requirement.

46.2.4 For a unit with field adjustable trip points, in accordance with 39.2, trip points are to be set and tested in accordance with Table 46.1. In addition, the adjustable trip points are to be set, tested, and verified at the minimum and maximum points within the unit's rated voltage and frequency range in accordance with the manufacturer's specified trip time.

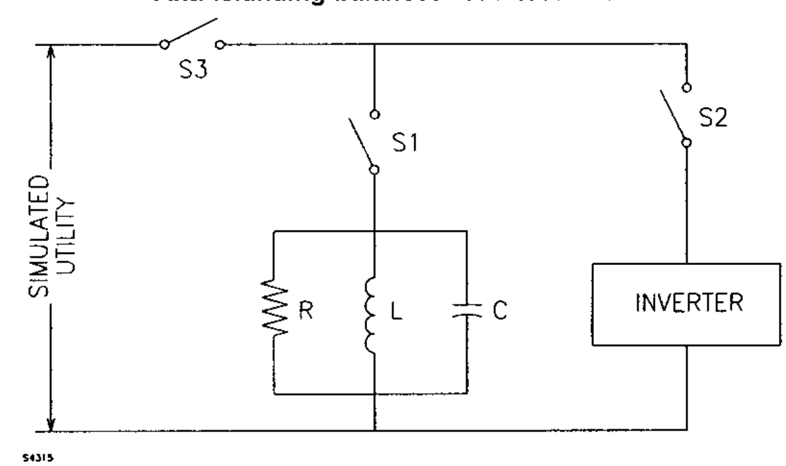
46.3 Anti-Islanding test

46.3.1 A single phase utility-interactive inverter is to be connected to a simulated utility source and the balanced load circuit described in Figure 46.1.

46.3.2 A 3-phase utility-interactive inverter is to be connected to a simulated utility source, and the balanced load circuit described in Figure 46.1 is to be applied to each phase.

46.3.3 For inverters intended for use with a separate isolation transformer, the transformer is to be connected between the inverter and RLC load specified in Figure 46.1.

Figure 46.1
Anti-Islanding balanced load test circuit



NOTES –

1 When testing a unit with a 3-phase output, the single phase test circuit shall be applied to each phase.

2 Switch S1 is able to be replaced with individual switches on each of the RLC load components.

46.3.4 The islanding load circuit in Figure 46.1 is to be set or balanced to have a quality factor Q of 2.5 or less (when Q is equal to 2.5, the power factor is 0.37). The value of Q is to be determined by using the following equations as appropriate:

$$Q = R \times (C/L)^{1/2}$$

or

$$Q = [(P_{qL} \times P_{qC})^{1/2}] / P$$

In which:

Q is the quality factor of the parallel (RLC) resonant load.

R is the effective load resistance in Ohms.

C is effective load capacitance in Farads.

L is effective load inductance in Henrys.

P_{qL} is the reactive power consumed by the inductive load component in KVARS.

P_{qC} is the reactive power consumed by the capacitive load component in KVARS.

P is the real power in kW.

The balanced reactive load resonant frequency f is to match the rated frequency of the inverter as determined using the following equation:

$$f = 1 / [2\pi\ (L \times C)^{1/2}]$$

In which:

f is the resonant frequency of the parallel (RLC) load at which the load has a unity power factor and appears to be purely resistive. The resonant frequency is in Hertz.

With the simulated utility energized at the nominal line voltage, S3 closed, and the inverter disconnected from the circuit (S2 open), the inductive load (P_{qL}) is to be set to 2.5 times the real output power of the inverter as specified in Table 46.2. The inductance and capacitance are to be calculated using the following equations:

$$L = V^2 / (2P \times Q \times \pi \times f)$$

$$C = P \times Q / (2\pi \times f \times V^2)$$

In which:

L is effective load inductance in Henrys.

C is effective load capacitance in Farads.

V is the nominal line voltage in Volts.

P is the real power in kW.

Q is the quality factor of the parallel (RLC) resonant load.

f is the resonant frequency of the parallel (RLC) load at which the load has a unity power factor and appears to be purely resistive. The resonant frequency is in Hertz.

The capacitive reactive load is to be adjusted to match (or cancel out) the inductive reactive power at S1 within ± 1 percent of the real power output of the inverter as specified in Table 46.2.

R is to have power dissipation equal to the rated power output of the inverter as specified in Table 46.2.

46.3.5 After the reactive loads have been set and S1 and S2 are closed, the output power of the inverter or the resistive load is to be adjusted to minimize the current flow to, or from, the simulated utility at S3.

46.3.6 The inverter shall cease to export power to the load within 2 seconds of Switch S3 being opened. The test is to be repeated with the reactive load (either capacitive or inductive) adjusted in 1 percent increments from 95 percent to 105 percent of the initial balanced load component value.

Table 46.2
Anti-Islanding test load

Real load (percent of rated)	Inverter output (percent of rated)
25	25
50	50
100	100
125	100

46.4 (47.8) Loss of Control Circuit

46.4.1 (47.8.1) A utility-interactive inverter shall cease power production to the utility until the control circuit regains power when tested as specified in 46.4.2.

46.4.2 (47.8.2) The inverter is to be connected to its rated input dc supply, a simulated utility source, and its rated load. A single fault is to be placed such that it disables the power to the control circuit.

Exception: When the control circuit is unable to be disabled under any single fault condition, this test is not required to be performed.

Table 62.1
Unit ratings

	Rating type	Utility-interactive	Stand alone	Utility-interactive with charge control[d]	Stand alone with charge control[d]	Charge controllers[d]
a)	Maximum system voltage[a]	X[b]	X	X	X	X
b)	Range of operating dc voltage	X[b]	X	X	X	X
c)	Maximum operating current (dc)	X[b]	X	X	X	X
d)	Maximum array short circuit current (dc)	X[b]	X	X	X	X
e)	Maximum utility backfeed current (ac) [see]	X		X		
f)	Maximum input current (ac)			X	X	X
g)	Operating voltage range (ac)	X	X	X	X	X
h)	Operating frequency range or single frequency	X	X	X	X	X
i)	Nominal output voltage (ac)	X	X	X	X	
j)	Normal output frequency	X	X	X	X	
k)	Maximum continuous output current (ac)	X	X	X	X	
l)	Maximum continuous output power (ac)	X	X	X	X	
m)	Maximum output fault current (ac) [see 47.3.3]	X	X	X	X	
n)	Maximum output overcurrent protection[c]	X	X	X	X	
o)	Nominal output voltage (dc)			X	X	
p)	Charging output voltage operation range (dc)			X	X	X

[a] Determined in accordance with Section 690-7(a) of the National Electrical Code, NFPA 70.

[b] Not required for ac modules.

[c] Normally the branch-circuit overcurrent protection.

[d] Charging of batteries is able to originate from dc or ac sources. The rating types for either ac or dc are to be applied accordingly.

63.4 A utility-interactive inverter with field adjustable trip points for voltage, frequency, or both in accordance with 39.5 shall be marked to indicate the presence of such controls.

63.5 A unit provided with integral dc ground fault detector/interrupter protection in accordance with DC Ground Fault Detector/Interrupter, Section 31, shall be marked to indicate its presence.

63.15 A terminal for the connection of a grounded conductor shall be identified by means of a metallic plated coating substantially white in color, and shall be readily distinguishable from the other terminals; or identification of the terminal for the connection of the grounded conductor shall be clearly shown in some other manner, such as:

a) A marking on the unit,

b) An indication on a wiring diagram attached to the unit, or

c) Information provided in the instruction manual.

A field wiring lead intended to be grounded shall have a white or natural gray color and shall be readily distinguishable from other leads.

Exception: A dc field wiring lead intended to be grounded is not required to have a white or natural gray color when it is clearly distinguishable in some other manner.

64.5 In accordance with Exception No. 1 to 40.1, an inverter not having an isolation transformer, capacitor, or a dc sensor having a high-speed disconnect switch shall be marked "CAUTION – For Proper Circuit Isolation" and the following words or the equivalent "Connect a minimum ___ kVA rated isolating transformer between the output of the unit and the utility power line connections. The transformer is to be an isolation type having separate primary and secondary windings."

64.15 With reference to the Exception to 39.1, the unit shall be plainly and permanently marked where it is readily visible after installation with the word "WARNING" and the following or equivalent: "To reduce the risk of islanding – This unit shall be provided with external relaying protection in accordance with local codes and local utility requirements. This unit has not been evaluated for utility interaction and compatibility."

65.2.1 The operating and installation instructions shall:

a) Describe the equipment installation, including specifically:

1) Assembly, and mounting, where required,

2) Grounding means, and

3) Ventilation consideration;

b) Explain equipment markings, including specifically:

1) Symbols,

2) Controls, and

3) All applicable ratings in Table 62.1;

c) Identify and describe interconnections with:

1) The photovoltaic array,

2) The utility, and

3) Auxiliary and accessory equipment;

d) Explain the operation of the equipment;

e) Indicate that the ac output (neutral) is (is not) bonded to ground;

f) In accordance with 14.2.3(a), an inverter provided with a fixed ac output shall inform the installer that the input and output circuits are isolated from the enclosure and that system grounding, when required by Sections 690-41, 690-42, and 690-43 of the National Electric Code, ANSI/NFPA 70, is the responsibility of the installer;

g) Field adjustable trip points for voltage, frequency, or both shall be described and include a range of voltage/frequency and triptime and inform the user of the default settings in accordance with 39.4; and

h) Integral dc ground fault detector/interrupter protection shall describe the proper method for connecting and grounding the photovoltaic system.

66.3 The important safety instructions described in items A – R in 66.4, as appropriate, shall be provided with each unit. The information contained in items C – R is able to be marked on the unit or in the instruction manual.

66.4 The important safety instructions shall include instructions for the following items A – R. The statement "IMPORTANT SAFETY INSTRUCTIONS", and the statement "SAVE THESE INSTRUCTIONS" shall precede the list. The word "WARNING," "CAUTION," and "DANGER" shall be entirely in upper case letters.

IMPORTANT SAFETY INSTRUCTIONS

A. SAVE THESE INSTRUCTIONS– This manual contains important instructions for Models ________________ (blank space is to be filled in with appropriate model numbers) that shall be followed during installation and maintenance of the _________ (blank space is to indicate inverter or charge controller as appropriate).

Exception: When the instructions are exactly the same for all models, specific model numbers are not required.

B. In accordance with 16.2.4, when pressure terminal connectors or the fastening hardware are not provided on the unit as shipped, the instruction manual shall indicate which pressure terminal connector or component terminal assemblies are for use with the unit.

C. With reference to item B, the terminal assembly packages and the instruction manual shall include information identifying wire size and manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product is identifiable.

D. When a pressure terminal connector provided in the unit (or in a terminal assembly covered in 16.2.4(d)) for a field installed conductor requires the use of other than a common tool for securing the conductor, identification of the tool and any required instructions for using the tool shall be included in the instruction manual.

E. A unit provided with a wire connector for field installed wiring as covered in Exception No. 2 to 16.3.1 shall be provided with instructions specifying that the connector provided is to be used in making the field connection.

F. A unit employing pressure terminal connectors for field wiring connections shall be provided with instructions specifying a range of values or a nominal value of tightening torque to be applied to the clamping screws of the terminal connectors. The minimum specified tightening torque shall not be less than 90 percent of the value specified in Tables 66.1 or 66.2 applicable to the wire size determined in accordance with 16.1.3.

Exception: A torque less than 90 percent is usable when the connector – using the lesser assigned torque value – complies with the Standard for Wire Connectors and Soldering Lugs for Use With Copper Conductors, UL 486A, the Standard for Wire Connectors for Use With Aluminum Conductors, UL 486B, or the Standard for Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors, UL 486E.

G. When a symbol is used for compliance with marking requirements specified in 63.8, 63.13, or 63.21, the instruction manual shall identify the symbol.

H. The instruction manual for a unit that exceeds the temperature limits of Table 43.2 (see the Exception to 43.2) shall specify that the unit is to be installed so that it is not expected to be contacted by persons.

I. The instruction manual for a charge controller or an inverter intended to charge batteries shall indicate the nominal voltage rating of the battery supply and a generic description of the batteries, such as lead acid, nickel cadmium, and vented or sealed.

J. In accordance with 43.3, the instruction manual for an inverter having an ambient temperature rating higher than 25°C (77°F) shall indicate the maximum ambient temperature rating.

K. For a unit having a single equipment field-wiring terminal that is intended for connection of more than one conductor, the instruction manual shall include information identifying the number of conductors and range of conductor sizes.

L. For a unit provided with field-wiring terminals or leads, the instruction manual shall include the information indicated in Row 1, 2, 3, or 4 of Table 66.3 or with equivalent wording, when it is:

1) Intended for use on a supply circuit rated 110 amperes or less, or

2) Intended for field connection with No. 1 AWG (42.4 mm^2) or smaller conductors.

M. For a unit provided with field-wiring terminals or leads, the instruction manual shall include the information indicated in Row 3 or 4 of Table 66.3, or with equivalent wording, when it is:

1) Intended for use on a supply circuit rated more than 110 amperes, or

2) Intended for field connection with conductors larger than No. 1 AWG (42.4 mm^2).

N. When required by the Exception to 16.6.1, the instruction manual shall include a statement indicating that Class 1 wiring methods are to be used for field wiring connections to terminals of a Class 2 circuit.

O. In accordance with 47.1.7, when an abnormal test is terminated by operation of the intended branch-circuit overcurrent protective device, the instruction manual for a unit shall include the word "CAUTION" and the following or the equivalent: "To reduce the risk of fire, connect only to a circuit provided with _______ amperes maximum branch-circuit overcurrent protection in accordance with the National Electrical Code, ANSI/NFPA 70." The blank space is to be filled in with the ampere rating of branch-circuit overcurrent protection described in 47.1.7.

P. When required by the Exception to 30.3.1, the instruction manual shall include a statement indicating that overcurrent protection for the ac output circuit is to be provided by others.

Q. When required by the Exception to 30.4.1, the instruction manual shall include a statement indicating that overcurrent protection for the battery circuit is to be provided by others.

R. An inverter with 120 V output shall be provided with instructions that include the word "WARNING" and the following or the equivalent: "To reduce the risk of fire, do not connect to an ac load center (circuit breaker panel) having multiwire branch circuits connected."

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Subject 1741

333 Pfingsten Road
Northbrook, IL 60062
May 7, 1999

TO: **Electrical Council of Underwriters Laboratories Inc.,**
Subscribers to UL's Standards Service for
***Power Conditioning Units for Use in Residential* Photovoltaic Power Systems**

SUBJECT: Announcement of the Withdrawal of the Second Issue of the Outline of Investigation for Power Conditioning Units for Use in Residential Photovoltaic Power Systems, Subject 1741

The requirements in the Outline of Investigation for Power Conditioning Units for Use in Residential Photovoltaic Power Systems, Subject 1741, dated June, 1991 are now provided in the Standard for Static inverters and Charge Controllers for Use in Photovoltaic Power Systems, UL 1741. Therefore, UL has decided to withdraw Subject 1741 effective on the date of this bulletin.

You may send your questions or comments on this matter to the attention of the undersigned.

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IEEE Standards

1547™

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Standards Coordinating Committee 21

Sponsored by the
Standards Coordinating Committee 21 on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE

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IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Sponsor

Standards Coordinating Committee 21
(Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage)

Approved 12 June 2003

IEEE-SA Standards Board

Abstract: This standard is the first in the 1547 series of interconnection standards and is a benchmark milestone demonstrating the open consensus process for standards development. Traditionally, utility electric power systems (EPS--grid or utility grid) were not designed to accommodate active generation and storage at the distribution level. As a result, there are major issues and obstacles to an orderly transition to using and integrating distributed power resources with the grid. The lack of uniform national interconnection standards and tests for interconnection operation and certification, as well as the lack of uniform national building, electrical, and safety codes, are understood. IEEE Std 1547 and its development demonstrate a model for ongoing success in establishing additional interconnection agreements, rules, and standards, on a national, regional, and state level. IEEE Std 1547 has the potential to be used in federal legislation and rule making and state public utilities commission (PUC) deliberations, and by over 3000 utilities in formulating technical requirements for interconnection agreements for distributed generators powering the electric grid.

This standard focuses on the technical specifications for, and testing of, the interconnection itself. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. It includes general requirements, response to abnormal conditions, power quality, islanding, and test specifications and requirements for design, production, installation evaluation, commissioning, and periodic tests. The stated requirements are universally needed for interconnection of distributed resources (DR), including synchronous machines, induction machines, or power inverters/converters and will be sufficient for most installations. The criteria and requirements are applicable to all DR technologies, with aggregate capacity of 10 MVA or less at the point of common coupling, interconnected to electric power systems at typical primary and/or secondary distribution voltages. Installation of DR on radial primary and secondary distribution systems is the main emphasis of this document, although installation of DR on primary and secondary network distribution systems is considered. This standard is written considering that the DR is a 60 Hz source.
Keywords: certification; codes; commissioning, dc injection; design, field, installation, production tests; communications; diesel generators; distributed generation, power; resources; electric distribution systems; dispersed generation, storage; energy storage; faults; flicker; fuel cells; generators; grid; harmonics; IEEE; induction machines; inverters; interconnection requirements and specifications; islanding; microturbines; monitoring and control; paralleling; power converters, networks, quality; photovoltaic power systems; point of common coupling; public utility commissions; reclosing coordination; regulations; rule making, federal, national, regional, state; standards; synchronous machines; testing; utilities; wind energy systems

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Introduction

(This introduction is not part of IEEE Std 1547-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.)

IEEE Std 1547-2003 is the first of a series of standards being developed by Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (SCC21) concerning distributed resources interconnection. The titles of the additional documents in that series follow.

— IEEE P1547.1™ Draft Standard For Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
— IEEE P1547.2™ Draft Application Guide for IEEE Std 1547-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
— IEEE P1547.3™ Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems

This first publication of IEEE Std 1547-2003 is an outgrowth of the changes in the environment for production and delivery of electricity and builds on prior IEEE recommended practices and guidelines developed by SCC21 [e.g., IEEE Std 929™-2000, IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems], and Standards Coordinating Committee 23 on Dispersed Storage and Generation (e.g., IEEE Std 1001™-1988, Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems).

Traditionally, utility electric power systems (EPS) were not designed to accommodate active generation and storage at the distribution level. The technologies and operational concepts to properly integrate distributed resources (DR) into the existing EPS continue to be further developed to fully realize benefits and to avoid negative impacts on system reliability and safety.

There is a critical need to have a single document of consensus standard technical requirements for DR interconnection rather than having to conform to numerous local practices and guidelines. This standard addresses that critical need by providing uniform criteria and requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.

The intent of this standard is to define the technical requirements in a manner that can be universally adopted. The universality relates not only to the technical aspects, but also to the adoption of this standard as being pertinent across a number of industries and institutions, e.g., hardware manufacturers, utilities, energy service companies, codes and standards organizations, regulators and legislators, and other interested entities.

This standard focuses on the technical specifications for, and testing of, the interconnection itself, and not on the types of the DR technologies. This standard aims to be technology neutral, although cognizant that the technical attributes of DR and the types of EPSs do have a bearing on the interconnection requirements. The addition of DR to an EPS will change the system and its response in some manner. Although this standard establishes criteria and requirements for interconnection, this standard is not a design handbook nor is it an application guideline. This standard provides the minimum functional technical requirements that are universally needed to help assure a technically sound interconnection. Any additional local requirements should not be implemented to the detriment of the functional technical requirements of this standard.

It is beyond the scope of this standard to address the methods used for performing EPS impact studies, mitigating limitations of the Area EPS, or for addressing the business or tariff issues associated with interconnection.

Participants

At the time this standard was completed, the Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage had the following membership:

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At the time this standard was completed, the Distributed Resources and Electric Power Systems Interconnection Working Group (P1547 WG) of the Standard Coordinating Committee 21 (SCC21) on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage had the following membership who participated in the preparation of this standard:

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When the IEEE-SA Standards Board approved this standard on 12 June 2003, it had the following membership:

Contents

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

1. Overview

This standard provides interconnection technical specifications and requirements, and test specifications and requirements. Additionally, there is a bibliography included as Annex A that lists citations referred to in this standard for informative purposes, but that are not required to be used in conjunction with this standard.

1.1 Scope

This standard establishes criteria and requirements for interconnection of distributed resources (DR) with electric power systems (EPS).

1.2 Purpose

This standard provides a uniform standard for interconnection of distributed resources with electric power systems. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.

The requirements shall be met at the point of common coupling (PCC), although the devices used to meet these requirements can be located elsewhere. This standard applies to interconnection based on the aggregate rating of all the DR units that are within the Local EPS. The functions of the interconnection system hardware and software that affect the Area EPS are required to meet this standard regardless of their location on the EPS.

The stated specifications and requirements, both technical and testing, are universally needed for interconnection of DR, including synchronous machines, induction machines, or power inverters/converters, and will be sufficient for most installations.[1]

[1]Additional technical requirements and/or tests may be necessary for some limited situations.

1.3 Limitations

The criteria and requirements in this document are applicable to all distributed resource technologies, with aggregate capacity of 10 MVA or less at the PCC, interconnected to EPSs at typical primary and/or secondary distribution voltages. Installation of DR on radial primary and secondary distribution systems is the main emphasis of this standard, although installation of DR on primary and secondary network distribution systems is considered. This standard is written considering that the DR is a 60 Hz source.

- This standard does not define the maximum DR capacity for a particular installation that may be interconnected to a single PCC or connected to a given feeder.
- This standard does not prescribe DR self-protection or all operating requirements for DR units.
- This standard does not address planning, designing, operating, or maintaining the Area EPS.
- This standard does not apply to automatic transfer schemes in which load is transferred between the DR and the EPS in a momentary make-before-break operation provided the duration of paralleling the sources is less than 100 ms, except as noted in 4.1.4.

2. References

The following standards shall be used in conjunction with this standard. When the stated version of the following standards is superseded by an approved revision, then that revision shall apply.

The applicability of the following standards is determined by the specific requirements stated in this standard, such as requiring certain sections.

ANSI C84.1-1995, Electric Power Systems and Equipment—Voltage Ratings (60 Hz).[2]

IEEE Std C37.90.1™-2002, IEEE Standard Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.[3,4]

IEEE Std C37.90.2™-1995, IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

IEEE Std C62.41.2™-2002, IEEE Recommended Practice on Characterization of Surges in Low Voltage (1000 V and less) AC Power Circuits.

IEEE Std C62.45™-2002, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000V and Less) AC Power Circuits.

NEMA MG 1-1998, Motors and Generators, Revision 2.[5]

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3]The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[5]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

3. Definitions and acronyms

For purposes of this standard, the following terms and definitions apply. IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B4],[6] should be referenced for terms not defined in this clause.

3.1 Definitions

3.1.1 area electric power system operator (Area EPS Operator): The entity responsible for designing, building, operating, and maintaining the Area EPS.

3.1.2 cease to energize: Cessation of energy outflow capability.

3.1.3 design test: Test of one or more devices made to a certain design to show that the design meets certain specifications.

3.1.4 distributed generation (DG): Electric generation facilities connected to an Area EPS through a PCC; a subset of DR.

3.1.5 distributed resources (DR): Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.

NOTE—See Figure 1 and Figure 2.

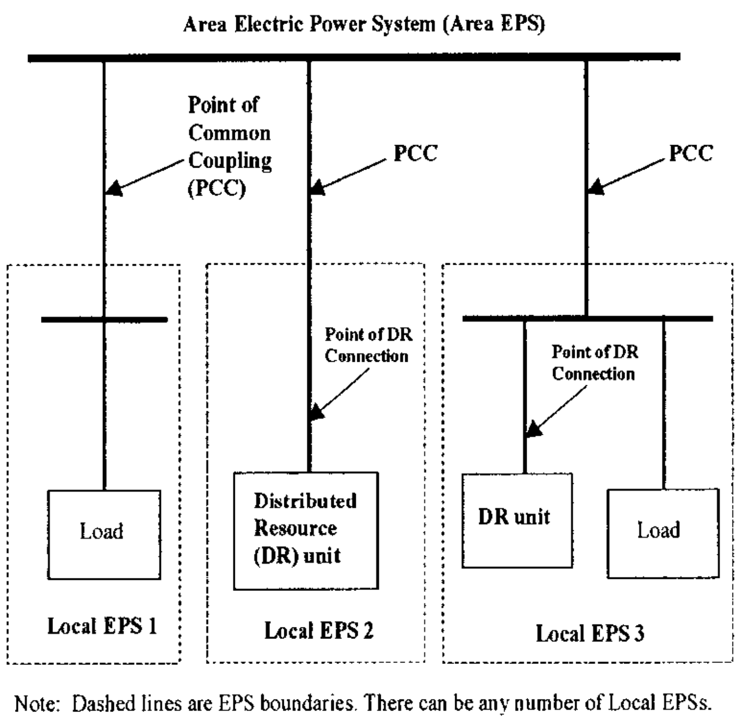

Figure 1—Relationship of interconnection terms

[6]The numbers in brackets correspond to those of the bibliography in Annex A.

3.1.6 electric power system (EPS): Facilities that deliver electric power to a load.

NOTE—This may include generation units. See Figure 1.

3.1.6.1 electric power system, area (Area EPS): An EPS that serves Local EPSs.

NOTE—Typically, an Area EPS has primary access to public rights-of-way, priority crossing of property boundaries, etc., and is subject to regulatory oversight. See Figure 1.

3.1.6.2 electric power system, local (Local EPS): An EPS contained entirely within a single premises or group of premises.

NOTE—See Figure 1.

3.1.7 interconnection: The result of the process of adding a DR unit to an Area EPS.

NOTE—See Figure 2.

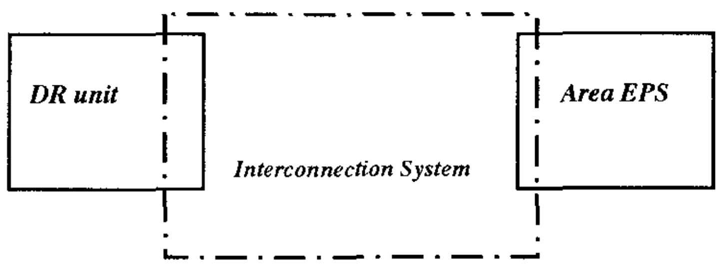

Figure 2—Schematic of interconnection

3.1.8 interconnection equipment: Individual or multiple devices used in an interconnection system.

3.1.9 interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect a DR unit(s) to an Area EPS.

NOTE—See Figure 2.

3.1.10 inverter: A machine, device, or system that changes direct-current power to alternating-current power.

3.1.11 island: A condition in which a portion of an Area EPS is energized solely by one or more Local EPSs through the associated PCCs while that portion of the Area EPS is electrically separated from the rest of the Area EPS.

3.1.11.1 island, intentional: A planned island.

3.1.11.2 island, unintentional: An unplanned island.

3.1.12 non-islanding: Intended to prevent the continued existence of an island.

3.1.13 point of common coupling (PCC): The point where a Local EPS is connected to an Area EPS.

NOTE—See Figure 1.

3.1.14 point of distributed resources connection (point of DR connection): The point where a DR unit is electrically connected in an EPS.

NOTE—See Figure 1.

3.1.15 simulated utility: An assembly of variable frequency and variable voltage test equipment used to simulate a normal utility source.

3.1.16 total demand distortion (TDD): The total root-sum-square harmonic current distortion, in percent of the maximum demand load current (15 or 30 minute demand).

3.1.17 total rated-current distortion (TRD): The total root-sum-square of the current harmonics created by the DR unit operating into a linear balanced load divided by the greater of the test load current demand (I_L) or the rated current capacity of the DR unit (I_{rated}).

3.2 Acronyms

Area EPS	Area electric power system
DG	distributed generation
DR	distributed resources
EPS	electric power system
I	current
I_L	load current
I_{SC}	short circuit current
Local EPS	Local electric power system
PCC	point of common coupling
TDD	total demand distortion
TRD	total rated-current distortion

4. Interconnection technical specifications and requirements

The requirements in this clause shall be met at the PCC, although the devices used to meet these requirements can be located elsewhere. The requirements apply to interconnection of either a single DR unit based on that unit's rating or multiple DR units within a single Local EPS, based on the aggregate rating of all the DR units that are within the Local EPS. The functions of the interconnection system hardware and software that affect the Area EPS are required to meet this standard regardless of their location on the EPS.

The requirements in this clause are functional and do not specify any particular equipment or equipment type.

The stated technical specifications and requirements are universally needed for interconnection of DR, including synchronous machines, induction machines, or static power inverters/converters, and will be sufficient for most installations.[7]

4.1 General requirements

4.1.1 Voltage regulation

The DR shall not actively regulate the voltage at the PCC. The DR shall not cause the Area EPS service voltage at other Local EPSs to go outside the requirements of ANSI C84.1-1995, Range A.

4.1.2 Integration with Area EPS grounding

The grounding scheme of the DR interconnection shall not cause overvoltages that exceed the rating of the equipment connected to the Area EPS and shall not disrupt the coordination of the ground fault protection on the Area EPS.

4.1.3 Synchronization

The DR unit shall parallel with the Area EPS without causing a voltage fluctuation at the PCC greater than ±5% of the prevailing voltage level of the Area EPS at the PCC, and meet the flicker requirements of 4.3.2.

4.1.4 Distributed resources on distribution secondary grid and spot networks

4.1.4.1 Distribution secondary grid networks

This topic is under consideration for future revisions of this standard.

4.1.4.2 Distribution secondary spot networks[8]

Network protectors shall not be used to separate, switch, serve as breaker failure backup or in any manner isolate a network or network primary feeder to which DR is connected from the remainder of the Area EPS, unless the protectors are rated and tested per applicable standards for such an application.[9]

Any DR installation connected to a spot network shall not cause operation or prevent reclosing of any network protectors installed on the spot network. This coordination shall be accomplished without requiring any changes to prevailing network protector clearing time practices of the Area EPS.

Connection of the DR to the Area EPS is only permitted if the Area EPS network bus is already energized by more than 50% of the installed network protectors.

The DR output shall not cause any cycling of network protectors.

The network equipment loading and fault interrupting capacity shall not be exceeded with the addition of DR.

[7]Additional technical requirements may be necessary for some limited situations.

[8]When required by the authority who has jurisdiction over the DR interconnection, a study may be conducted to determine that all of the requirements of this subclause can be met when the aggregate DR installed on a spot network exceeds 5% of the spot network's maximum load.

[9]IEEE C37.108™-2002 [B8] and IEEE C57.12.44™-2000 [B9] provide guidance on the capabilities of network systems to accept distributed resources.

DR installations on a spot network, using an automatic transfer scheme in which load is transferred between the DR and the EPS in a momentary make-before-break operation, shall meet all the requirements of this clause regardless of the duration of paralleling.

4.1.5 Inadvertent energization of the Area EPS

The DR shall not energize the Area EPS when the Area EPS is de-energized.

4.1.6 Monitoring provisions

Each DR unit of 250 kVA or more or DR aggregate of 250 kVA or more at a single PCC shall have provisions for monitoring its connection status, real power output, reactive power output, and voltage at the point of DR connection.

4.1.7 Isolation device

When required by the Area EPS operating practices, a readily accessible, lockable, visible-break isolation device shall be located between the Area EPS and the DR unit.

4.1.8 Interconnect integrity

4.1.8.1 Protection from electromagnetic interference

The interconnection system shall have the capability to withstand electromagnetic interference (EMI) environments in accordance with IEEE Std C37.90.2-1995. The influence of EMI shall not result in a change in state or misoperation of the interconnection system.

4.1.8.2 Surge withstand performance

The interconnection system shall have the capability to withstand voltage and current surges in accordance with the environments defined in IEEE Std C62.41.2-2002 or IEEE Std C37.90.1-2002 as applicable.

4.1.8.3 Paralleling device

The interconnection system paralleling-device shall be capable of withstanding 220% of the interconnection system rated voltage.

4.2 Response to Area EPS abnormal conditions[10]

Abnormal conditions can arise on the Area EPS that require a response from the connected DR. This response contributes to the safety of utility maintenance personnel and the general public, as well as the avoidance of damage to connected equipment, including the DR. All voltage and frequency parameters specified in these subclauses shall be met at the PCC, unless otherwise stated.

4.2.1 Area EPS faults

The DR unit shall cease to energize the Area EPS for faults on the Area EPS circuit to which it is connected.

[10]The isolation of a portion of the Area EPS, presenting the potential for an unintended DR island, is a special concern and is addressed in 4.4.1.
Setting adjustments may only be made as approved by the authority who has jurisdiction over the DR interconnection.

4.2.2 Area EPS reclosing coordination

The DR shall cease to energize the Area EPS circuit to which it is connected prior to reclosure by the Area EPS.

4.2.3 Voltage

The protection functions of the interconnection system shall detect the effective (rms) or fundamental frequency value of each phase-to-phase voltage, except where the transformer connecting the Local EPS to the Area EPS is a grounded wye-wye configuration, or single-phase installation, the phase-to-neutral voltage shall be detected. When any voltage is in a range given in Table 1, the DR shall cease to energize the Area EPS within the clearing time as indicated. Clearing time is the time between the start of the abnormal condition and the DR ceasing to energize the Area EPS. For DR less than or equal to 30 kW in peak capacity, the voltage set points and clearing times shall be either fixed or field adjustable. For DR greater than 30 kW, the voltage set points shall be field adjustable.

The voltages shall be detected at either the PCC or the point of DR connection when any of the following conditions exist:

a) The aggregate capacity of DR systems connected to a single PCC is less than or equal to 30 kW,

b) The interconnection equipment is certified to pass a non-islanding test for the system to which it is to be connected,

c) The aggregate DR capacity is less than 50% of the total Local EPS minimum annual integrated electrical demand for a 15 minute time period, and export of real or reactive power by the DR to the Area EPS is not permitted.

Table 1—Interconnection system response to abnormal voltages

Voltage range (% of base voltage[a])	Clearing time(s)[b]
$V < 50$	0.16
$50 \le V < 88$	2.00
$110 < V < 120$	1.00
$V \ge 120$	0.16

[a]Base voltages are the nominal system voltages stated in ANSI C84.1-1995, Table 1.
[b]DR ≤ 30 kW, maximum clearing times; DR > 30kW, default clearing times.

4.2.4 Frequency

When the system frequency is in a range given in Table 2, the DR shall cease to energize the Area EPS within the clearing time as indicated. Clearing time is the time between the start of the abnormal condition and the DR ceasing to energize the Area EPS. For DR less than or equal to 30 kW in peak capacity, the frequency set points and clearing times shall be either fixed or field adjustable. For DR greater than 30 kW, the frequency set points shall be field adjustable.

Adjustable under-frequency trip settings shall be coordinated with Area EPS operations.

Table 2—Interconnection system response to abnormal frequencies

DR size	Frequency range (Hz)	Clearing time(s)[a]
≤ 30 kW	> 60.5	0.16
	< 59.3	0.16
> 30 kW	> 60.5	0.16
	< {59.8 – 57.0} (adjustable set point)	Adjustable 0.16 to 300
	< 57.0	0.16

[a]DR ≤ 30 kW, maximum clearing times; DR > 30 kW, default clearing times.

4.2.5 Loss of synchronism

Loss of synchronism protection is not required except as necessary to meet 4.3.2.

4.2.6 Reconnection to Area EPS

After an Area EPS disturbance, no DR reconnection shall take place until the Area EPS voltage is within Range B of ANSI C84.1-1995, Table 1, and frequency range of 59.3 Hz to 60.5 Hz.

The DR interconnection system shall include an adjustable delay (or a fixed delay of five minutes) that may delay reconnection for up to five minutes after the Area EPS steady-state voltage and frequency are restored to the ranges identified above.

4.3 Power quality

4.3.1 Limitation of dc injection

The DR and its interconnection system shall not inject dc current greater than 0.5% of the full rated output current at the point of DR connection.

4.3.2 Limitation of flicker induced by the DR

The DR shall not create objectionable flicker for other customers on the Area EPS.[11]

4.3.3 Harmonics

When the DR is serving balanced linear loads, harmonic current injection into the Area EPS at the PCC shall not exceed the limits stated below in Table 3. The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area EPS without the DR connected.

[11]Flicker is considered objectionable when it either causes a modulation of the light level of lamps sufficient to be irritating to humans, or causes equipment misoperation. For guidance, refer to IEEE Std 519™-1992 [B5], IEEE P1453™ [B10], IEC/TR3 61000-3-7 [B1], IEC 61000-4-15 [B2], IEC 61400-21 [B3].

Table 3—Maximum harmonic current distortion in percent of current (I)[a]

Individual harmonic order h (odd harmonics)[b]	$h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	Total demand distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

[a] I = the greater of the Local EPS maximum load current integrated demand (15 or 30 minutes) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).
[b]Even harmonics are limited to 25% of the odd harmonic limits above.

4.4 Islanding

4.4.1 Unintentional islanding

For an unintentional island in which the DR energizes a portion of the Area EPS through the PCC, the DR interconnection system shall detect the island and cease to energize the Area EPS within two seconds of the formation of an island.[12]

4.4.2 Intentional islanding

This topic is under consideration for future revisions of this standard.

5. Interconnection test specifications and requirements

This clause provides the test requirements to demonstrate that the interconnection system meets the requirements of Clause 4. The applicable tests from this clause are required for all interconnection systems. The results of these tests shall be formally documented.

The stated test specifications and requirements are universally needed for interconnection of DR including synchronous machines, induction machines, or static power inverters/converters, and will be sufficient for most installations.[13]

5.1 Design test

This design test shall be performed as applicable to the specific interconnection system technology. The test shall be performed on a representative sample, either in the factory, at a testing laboratory, or on equipment in the field.[14]

[12]Some examples by which this requirement may be met are:

1. The DR aggregate capacity is less than one-third of the minimum load of the Local EPS.
2. The DR is certified to pass an applicable non-islanding test.
3. The DR installation contains reverse or minimum power flow protection, sensed between the Point of DR Connection and the PCC, which will disconnect or isolate the DR if power flow from the Area EPS to the Local EPS reverses or falls below a set threshold.
4. The DR contains other non-islanding means, such as a) forced frequency or voltage shifting, b) transfer trip, or c) governor and excitation controls that maintain constant power and constant power factor.

[13]Additional tests may be necessary for some limited situations.

[14]The design test of 5.1 may be adopted as the testing basis for certification of interconnection systems.

This test applies to a packaged interconnection system using embedded components or to an interconnection system that uses an assembly of discrete components.

The design test shall be conducted on the same sample in the sequence of Table 4.

Table 4—Sequence for conducting design test

Required order	Design test clause and title
1	5.1.1 Response to abnormal voltage and frequency
2	5.1.2 Synchronization
3	5.1.3 Interconnect integrity test
Suggested order	
4	5.1.1 Response to abnormal voltage and frequency
5	5.1.2 Synchronization
6	5.1.4 Unintentional islanding
7	5.1.5 Limitation of dc injection
8	5.1.6 Harmonics

5.1.1 Response to abnormal voltage and frequency

This test shall demonstrate that the DR ceases to energize the Area EPS when the voltage or frequency exceeds the limits as specified in 4.2.3 and 4.2.4. Interconnection systems provided with field adjustable set points shall also be tested at the minimum, midpoint, and maximum of the adjustable set point ranges. These tests shall be conducted using either the simulated utility or secondary injection method.

5.1.2 Synchronization

Test results conforming to requirements of A, B, or C below are accepted as indicating compliance with the requirements of 4.1.3. The appropriate conditions to be met for specific interconnection system technology follow.

A. Synchronous interconnection to an EPS, or an energized local EPS to an energized Area EPS

This test shall demonstrate that at the moment of the paralleling-device closure, all three parameters in Table 5 are within the stated ranges. This test shall also demonstrate that if any of the parameters are outside of the ranges stated in the table, the paralleling-device shall not close.

B. Induction interconnection

Self-excited induction generators shall be tested as per A in 5.1.2.

This test shall determine the maximum start-up (in-rush) current drawn by the unit.[15] The results shall be used, along with Area EPS impedance information for the proposed location, to estimate the starting voltage

[15]NEMA MG 1-1998 contains an acceptable method for determining inrush current.

Table 5—Synchronization parameter limits for synchronous interconnection to an EPS, or an energized local EPS to an energized Area EPS

Aggregate rating of DR units (kVA)	Frequency difference (Δf, Hz)	Voltage difference (ΔV, %)	Phase angle difference ($\Delta \Phi$, °)
0 – 500	0.3	10	20
> 500 – 1 500	0.2	5	15
> 1 500 – 10 000	0.1	3	10

drop and verify that the unit shall not exceed the synchronization requirements in 4.1.3 and the flicker requirements in 4.3.2.

C. Inverter interconnection[16]

An inverter-based interconnection system that produces fundamental voltage before the paralleling device is closed shall be tested according to the procedure for synchronous interconnection as stated in A of 5.1.2.

All other inverter-based interconnection systems shall be tested to determine the maximum start-up current. The results shall be used, along with Area EPS impedance for the proposed location, to estimate the starting voltage magnitude change and verify that the unit shall meet the synchronization requirements in 4.1.3 and the flicker requirements in 4.3.2.

5.1.3 Interconnect integrity test

5.1.3.1 Protection from EMI

The interconnection system shall be tested in accordance with IEEE Std C37.90.2-1995 to confirm that the results are in compliance with 4.1.8.1. The influence of EMI shall not result in a change in state or mis-operation of the interconnection system.

5.1.3.2 Surge withstand performance

The interconnection system shall be tested for the requirement in 4.1.8.2 in all normal operating modes in accordance with IEEE Std C62.45-2002 for equipment rated less than 1000 V to confirm that the surge withstand capability is met by using the selected test level(s) from IEEE Std C62.41.2-2002. Interconnection system equipment rated greater than 1000 V shall be tested in accordance with manufacturer or system integrator designated applicable standards. For interconnection system equipment signal and control circuits, use IEEE Std C37.90.1-2002. The results of these tests shall indicate the unit did not fail, did not misoperate, and did not provide misinformation.

5.1.3.3 Paralleling device

A dielectric test across the open-circuited paralleling device shall be conducted to confirm compliance with the requirements of 4.1.8.3.

5.1.4 Unintentional Islanding

A test or field verification shall be conducted to confirm that 4.4.1 is met regardless of the selected method of detecting isolation.[17]

[16]Some inverter-based interconnection systems may need to be tested to both requirements of C in 5.1.2.

5.1.5 Limitation of dc injection

Inverter based DR shall be tested to confirm that the DR does not inject dc current greater than prescribed limits that are listed in 4.3.1.

5.1.6 Harmonics

The intent of the harmonics interconnection test is to assess that under a controlled set of conditions the DR unit meets the harmonic limits specified in 4.3.3.

The DR shall be operated in parallel with a predominantly inductive voltage source with a short circuit current capacity I_{SC} of not less than 20 times the DR rated output current at fundamental frequency. The voltage and frequency output of the voltage source shall correspond to the rated voltage and frequency of the DR. The unloaded voltage waveform produced by the Area EPS or simulated utility voltage source shall have a total harmonic distortion (THD) less than 2.5%.

The DR shall be operated at an output test load current, I_L, of 33%, 66%, and at a level as close to 100% of rated output current as practical. Use total rated-current distortion (TRD) in place of TDD. TRD is the total rms value of the sum of the current harmonics created by the DR unit operating into a linear balanced load divided by the greater of the test load current (I_L) demand or the rated current capacity of the DR unit (Irated). The individual harmonic distortion and TRD of the DR output current shall be measured for the first 40 harmonics. The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area EPS without the DR connected. The test results shall not exceed the values in 4.3.3, Table 3.[18]

As an alternative, a synchronous generator DR shall be tested to meet the requirements of 4.3.3; either after installation or while powering a balanced resistive load and isolated from any other sources. The voltage harmonics while powering a resistive load at 100% of the machine kVA rating shall not exceed the levels in Table 6. Voltage harmonics shall be measured line to line for 3-phase/3 wire systems, and line to neutral for 3-phase/4-wire systems.

Table 6—Maximum harmonic voltage distortion in percent of rated voltage for synchronous machines

Individual harmonic order	$h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	Total harmonic distortion
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

5.2 Production tests

Each interconnection system shall be subjected to requirements of 5.1.1 and 5.1.2. Interconnection systems with adjustable set points shall be tested at a single set of set points as specified by the manufacturer. This test may be conducted as a factory test or may be performed as part of a commissioning test (see 5.4).

[17]An example test is in UL 1741 [B14].

[18]These values or lower values may be required to meet the TDD of 5% at the PCC.

5.3 Interconnection installation evaluation

5.3.1 Grounding integration with Area EPS

A system design verification shall be made to ensure that the requirements of 4.1.2 have been met.

5.3.2 Isolation device

A system design verification shall be made to ensure that the requirements of 4.1.7 have been met.

5.3.3 Monitoring provisions

A system design verification shall be made to ensure that the provisions for monitoring are in accordance with 4.1.6.

5.3.4 Area EPS faults

A system design verification shall be made to ensure that the requirements of 4.2.1 have been met.

5.3.5 Area EPS reclosing coordination

A system design verification shall be made to verify the interconnection system is coordinated with the Area EPS reclosing practices in accordance with 4.2.2.

5.4 Commissioning tests

All commissioning tests shall be performed based on written test procedures.[19] The following visual inspections shall be performed.

— A visual inspection shall be made to ensure that the grounding coordination requirement of 4.1.2 has been implemented.
— A visual inspection shall be made to confirm the presence of the isolation device if required by 4.1.7.

Initial commissioning tests shall be performed on the installed DR and interconnection system equipment prior to the initial parallel operation of the DR. The following tests are required:

— Operability test on the isolation device
— Unintentional-islanding functionality as specified in 5.4.1
— Cease to energize functionality as specified in 5.4.2
— Any tests of 5.1 that have not been previously performed on a representative sample and formally documented
— Any tests of 5.2 that have not been previously performed

The applicable tests of 5.1 shall be repeated when:

— Functional software or firmware changes have been made on the interconnection system
— Any hardware component of the interconnection system has been modified in the field, or, replaced or repaired with parts different from the tested configuration.

Sublauses 5.4.1 and 5.4.2, and the applicable tests of 5.2 shall be repeated if:

[19]Test procedures are commonly provided by equipment manufacturer(s) or system integrator(s) and approved by the equipment owner and Area EPS operator.

— Protection settings have been changed after factory testing.
— Protection functions have been adjusted after the initial commissioning process.

5.4.1 Unintentional islanding functionality test

5.4.1.1 Reverse-power or minimum power test

A reverse-power or minimum power function, if used to meet the requirements of 4.4.1, shall be tested using injection techniques or by adjusting the DR output and local loads to verify that the reverse power or minimum power function is met.

5.4.1.2 Non-islanding functionality test

For non-islanding interconnection systems, 5.4.2 satisfies this requirement.

5.4.1.3 Other unintentional islanding functionality tests

If tests in 5.4.1.1 and 5.4.1.2 are not applicable to the interconnection system, the interconnection system shall be tested in accordance with procedures provided by the manufacturer or system integrator.

5.4.2 Cease to energize functionality test

Check the cease to energize functionality by operating a load interrupting device and verify the equipment ceases to energize its output terminals and does not restart/reconnect for the required time delay. The test shall be performed on each phase individually. This test verifies conformance to the cease to energize requirement of 4.1.4, 4.2.1, 4.2.2, 4.2.3, 4.2.4, and 4.4.1.

5.5 Periodic interconnection tests

All interconnection-related protective functions and associated batteries shall be periodically tested at intervals specified by the manufacturer, system integrator, or the authority who has jurisdiction over the DR interconnection. Periodic test reports or a log for inspection shall be maintained.

Annex A

(informative)

Bibliography

The following citations are referred to in this standard for informative purposes and are not required to be used in conjunction with this standard.

[B1] IEC TR3 61000-3-7, Assessment of Emission Limits for Fluctuating Loads in MV and HV Power Systems.

[B2] IEC 61000-4-15, Flickermeter—Functional and Design Specifications.

[B3] IEC 61400-21, Wind Turbine Generator Systems—Part 21: Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines—Ed. 1.0 (2001-12).

[B4] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition, New York, Institute of Electrical and Electronics Engineers, Inc.

[B5] IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.[20]

[B6] IEEE Std 929™-2000, IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems.

[B7] IEEE Std 1001™-1988, IEEE Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems.

[B8] IEEE Std C37.108-1989 (R2002), IEEE Guide for the Protection of Network Transformers.

[B9] IEEE Std C57.12.44-2000, IEEE Standard Requirements for Secondary Network Protectors.

[B10] IEEE P1453, Draft Recommended Practice for Measurement and Limits of Voltage Flicker on AC Power Systems.

[B11] IEEE P1547.1™, Draft Standard For Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.

[B12] IEEE P1547.2™, Draft Application Guide for IEEE Std 1547-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.

[B13] IEEE P1547.3™, Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems.

[B14] UL 1741, Inverters, Converters, and Controllers for Use in Independent Power Systems.

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IEEE Standards

1547.1™

IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

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IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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Abstract: This standard specifies the type, production, and commissioning tests that shall be performed to demonstrate that the interconnection functions and equipment of the distributed resources (DR) conform to IEEE Std 1547™.
Keywords: distributed resources, interconnection, test procedures

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Introduction

This introduction is not part of IEEE Std 1547.1-2005, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.

IEEE Std 1547.1 is one of a series of standards developed by Standards Coordinating Committee 21 (SCC21) concerning distributed resources (DR) interconnection. The titles of the additional documents in that series follow:

— IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems[a]

— IEEE P1547.2™, Draft Application Guide for IEEE Std 1547, Interconnecting Distributed Resources with Electric Power Systems [B6][b]

— IEEE P1547.3™, Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems [B7]

— IEEE P1547.4™, Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems [B8]

— IEEE P1547.5™, Draft Technical Guidelines for Interconnection of Electric Power Sources Greater Than 10 MVA to the Power Transmission Grid [B9]

— IEEE P1547.6™, Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks [B10]

The root standard, IEEE Std 1547, defines a set of uniform requirements for the interconnection of DR to the distribution segment of the electric power system (EPS). IEEE Std 1547 is an outgrowth of the changes in the environment for production and delivery of electricity and builds on prior IEEE recommended practices and guidelines developed by SCC21.

IEEE Std 1547 includes requirements relevant to the operation of the interconnection. It generally defines limitations and set points for various parameters that must be satisfied prior to the connection of a DR unit to the EPS, at the instant of connection, and for the separation of such resources from the EPS for abnormal conditions.

IEEE Std 1547.1 provides conformance test procedures to establish and verify compliance with the requirements of IEEE Std 1547. When applied, the IEEE 1547.1 test procedures can provide a means for manufacturers, utilities, or independent testing agencies to confirm the suitability of any given interconnection system (ICS) or component intended for use in the interconnection of DR with the EPS. Such certification can lead to the ready acceptance of confirmed equipment as suitable for use in the intended service by the parties concerned. While this standard defines test procedures, it does not specify measurement techniques. Suitable measurement techniques can be found in various technical publications including, but not limited to, IEEE Std 120™ [B13].

It is beyond the scope of IEEE 1547.1 to specify the design and performance criteria for ICSs or components. It is left to the parties concerned to determine that the equipment manufacturer's specifications and confirmed performance satisfy the technical needs of the EPS distribution circuit to which the DR unit is to be connected. Similarly, this standard does not address the local electrical power system technical needs nor load requirements for the facility or premises where the point of DR connection is made.

[a]Information on references can be found in Clause 2.

[b]The numbers in brackets correspond to the numbers of the bibliography in Annex B.

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At the time this standard was completed, the DR Interconnection Conformance Test Procedures Working Group (P1547.1 WG) of the SCC21 had the following membership. These members also composed the individual balloting committee that voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

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When the IEEE-SA Standards Board approved this standard on 9 June 2005, it had the following membership:

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

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IEEE Standards Project Editor

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IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

1. Overview

This standard provides tests and procedures for verifying conformance of interconnection systems (ICSs) to IEEE Std 1547™.[1] It is recognized that an ICS can be a single device providing all required functions or an assembly of components, each having limited functions. Components having limited functions shall be tested for those functions in accordance with this standard. Conformance may be established through combination of type (referred to as "design" tests in IEEE Std 1547), production, and commissioning tests. Additionally, conformance to IEEE Std 1547 requires interconnection installation evaluation and periodic tests.

This standard also includes Annex A, which describes test signals and ramp functions used in conducting some tests. Additionally, a bibliography is included as Annex B; it lists documents that are referred to in this standard for informative purposes, but that are not required to implement the procedures defined in this standard.

1.1 Scope

This standard specifies the type, production, and commissioning tests that shall be performed to demonstrate that the interconnection functions and equipment of the distributed resources (DR) conform to IEEE Std 1547.

1.2 Purpose

Interconnection equipment that connects DR to an electric power system (EPS) must meet the requirements specified in IEEE Std 1547. Standardized test procedures are necessary to establish and verify compliance with those requirements. These test procedures must provide both repeatable results, independent of test location, and flexibility to accommodate the variety of DR technologies.

[1]Information on references can be found in Clause 2.

1.3 Limitations

This standard does not cover testing for safety.

Although this standard does not define a certification process, these tests may be used as part of such a process.

2. Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

The applicability of the following standards is determined by the specific requirements stated in this standard, such as requiring certain sections.

ANSI C37.06, American National Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.[2]

ANSI C84.1, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hz).

IEEE C37.09™, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.[3, 4]

IEEE Std C37.90.1™, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.2™, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

IEEE Std C62.41.2™, IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.

IEEE Std C62.45™, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits.

IEEE Std 1547™, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.

NEMA MG-1, Motors and Generators.[5]

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[2]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

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[5]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

3. Definitions and acronyms

For purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B5] should be referenced for terms not defined in this clause.

3.1 ICS boundaries

An ICS consists of system controls, electrical protection, and steady-state control and may include energy conversion and/or generator. The DR may include all or part of the ICS. Figure 1 shows the boundary between the ICS, the EPS, and the energy source.

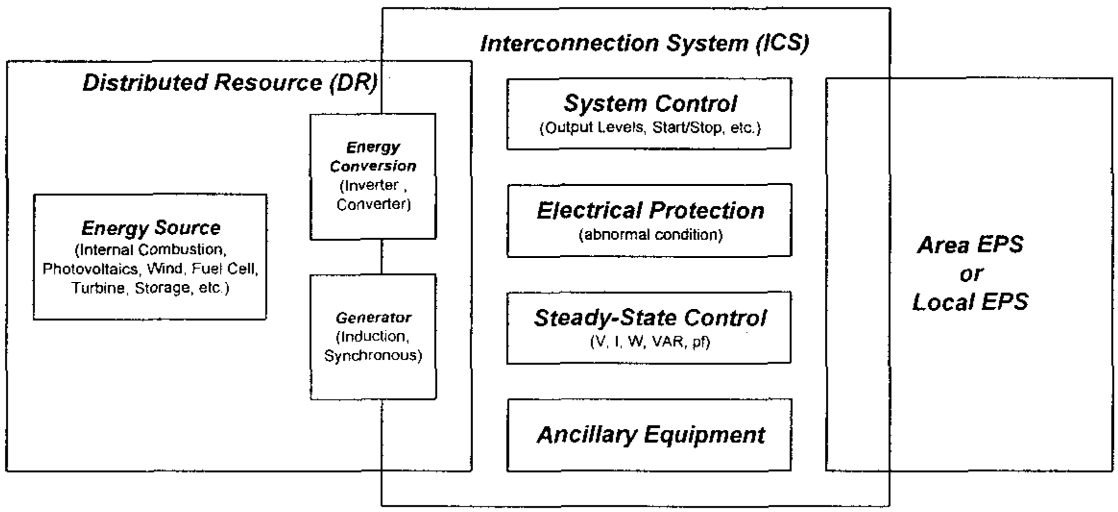

Figure 1—Boundaries between the ICS, the EPS, and the DR

3.2 Definitions

3.2.1 area electric power system (EPS): An EPS that serves local EPSs. Note that, typically, an area EPS has primary access to public rights-of-way, priority crossing of property boundaries, etc., and is subject to regulatory oversight.

3.2.2 clearing time: The time between the start of the abnormal condition and the distributed resources' (DR's) ceasing to energize the area electric power system (EPS). It is the sum of the detection time, any adjustable time delay, the operating time for any interposing devices (if used), and the operating time for the interrupting device (used to interconnect the DR with the area EPS).

3.2.3 commissioning test: A test conducted when the equipment is installed to verify correct operation.

3.2.4 design test: *See:* **type test.**

3.2.5 detection time: The minimum length of time from the inception of the abnormal condition to the change in state of the device or function dedicated to controlling the interrupting device. *Syn:* processing time.

3.2.6 distributed generation (DG): Electric generation facilities connected to an area electric power system (EPS) through a point of common coupling (PCC); a subset of distributed resources (DR).

3.2.7 distributed resources (DR): Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.

3.2.8 electric power system (EPS): Facilities that deliver electric power to a load. Note that EPS may include generation units. *See also:* **area electric power system (EPS)**; **local electric power system (EPS)**.

3.2.9 interconnection system (ICS): the collection of all equipment and functions, taken as a group, used to interconnect a distributed resources (DR) unit to an area electric power system (EPS).

3.2.10 interrupting device: A device capable of being opened and reclosed whose purpose is to interrupt faults and restore service or disconnect loads. These devices can be manual, automatic, or motor-operated. Examples include circuit breakers, motor-operated switches, and electronic switches.

3.2.11 inverter: A machine, device, or system that changes dc power to ac power.

3.2.12 island: A condition in which a portion of an area electric power system (EPS) is energized solely by one or more local EPSs through the associated points of common coupling (PCCs) while that portion of the area EPS is electrically separated from the rest of the area EPS.

3.2.13 local electric power system (EPS): An EPS contained entirely within a single premises or group of premises.

3.2.14 nominal: The value or range of a parameter being within expected norms or being the normal operating level of that parameter.

3.2.15 paralleling device: A device (e.g., circuit breaker) operating under the control of a synchronizing function to electrically connect two energized power sources together.

3.2.16 point of common coupling (PCC): The point where a local electric power system (EPS) is connected to an area EPS.

3.2.17 ***point of distributed resources (DR) connection:*** *The point where a DR unit is electrically con*nected in an electric power system (EPS).

3.2.18 production test: A test conducted on every unit of equipment prior to shipment.

3.2.19 signal injection test methods: Test methods where signals are injected into the sense terminals of the equipment under test (EUT). These methods include both primary injection test methods and secondary injection test methods.

3.2.20 simulated area electric power system (EPS): An assembly of voltage and frequency test equipment replicating a utility power source. Where appropriate, the actual area EPS can be used as the simulated area EPS.

3.2.21 simulated utility: *See:* **simulated area electric power system (EPS)**.

3.2.22 total rated-current distortion (TRD): The total root-sum-square of the current harmonics created by the distributed resources (DR) unit operating into a linear balanced load divided by the greater of the test load current demand IL or the rated-current capacity of the DR unit Irated.

3.2.23 trip time: The interval that begins at the leading zero-crossing of the first half cycle of the voltage waveform in which the measured parameter (e.g., frequency, voltage, power) exceeds the trip limit and ends when the equipment under test (EUT) responds as required.

3.2.24 type test: Test of one or more devices made to a certain design to demonstrate that the design meets certain specifications. *Syn:* design test.

3.3 Acronyms

CT	current transformer
d.p.f.	displacement power factor
DR	distributed resources
EMI	electromagnetic interference
EPS	electric power system
EUT	equipment under test
ICS	interconnection system
PCC	point of common coupling
p.f.	power factor
PUT	parameter under test
RLC	resistance, inductance, and capacitance
rms	root mean square
THD	total harmonic distortion
TRD	total rated-current distortion
VT	voltage transformer

4. General requirements

Implementation of these test procedures shall be conducted in accordance with appropriate safety procedures, sequences, and precautions.

4.1 Test result accuracy

The test results shall verify that the equipment under test (EUT) meets the requirements of IEEE Std 1547 within the manufacturer's specified accuracy.

4.2 Testing environment

The manufacturer shall specify the range of environmental conditions for the EUT. Therefore, tests shall be conducted in an environment that is within the manufacturer's specified environmental operating conditions.

4.3 Measurement accuracy and calibration of the testing equipment

Measurement equipment used to confirm performance of an EUT shall have calibration traceablity. The accuracy of the measuring equipment shall be suitable for the test being conducted.

4.4 Product information

The setting of limits and the structure of this standard are based on the understanding that the installer and user are responsible for following the installation recommendations of the manufacturer.

The manufacturer shall supply the EUT tester with documentation necessary for the correct installation into a typical system or process in the intended environment. A functional description and a definition of specification limits for the acceptance criteria shall be provided by the manufacturer and noted in the test report.

Any external devices or equipment or special connection requirements necessary to conduct the tests shall be clearly stated (including rationale) in the user documentation. Special requirements can include the amount of network impedance, voltampere burden of the EUT, the use of shielded or special cables, maximum cable length, the use of filters, and the correct bonding to functional earth (grounding). If different devices or connection requirements apply in different environments, this shall also be stated. A list of auxiliary equipment (e.g., options or enhancements) that can be added to the EUT and that can impact the result of EUT tests shall be made available. This information shall also be covered in the test report to clarify the as-tested arrangement(s).

Accuracy and tolerances of device parameters shall be stated by the manufacturers.

4.5 Test reports

The test results shall be documented in a test report. The report shall clearly and unambiguously present all relevant information of the tests (e.g., load conditions, conductor type or routing, functional description, acceptance criteria).

Within the test report, test procedures, as performed, shall be detailed; and engineering considerations, including test modifications and exemptions, shall be justified. When used in conjunction with this standard, the test report shall include sufficient critical operating information to rerun the test and reproduce the results.

Each test method shall be specified; and engineering considerations, including range of operating conditions, shall be justified.

4.6 Testing equipment requirements

4.6.1 Simulated area EPS (utility) source requirements

Where testing allows the use of a simulated area EPS source, the following requirements shall be met:

- The simulated area EPS source shall be capable of confirming the manufacturer's stated performance.
- The voltage harmonics of the simulated area EPS source shall be less than 2.5% total harmonic distortion (THD).
- The individual voltage harmonics of the simulated utility shall be less than 50% of the limits in Table 3 of IEEE Std 1547.
- During the tests, the steady-state voltage of the simulated area EPS source shall not vary by more than ± 1% of the nominal voltage.
- For voltage trip magnitude tests, the voltage change resolution of the simulated utility source shall be within $0.5a$ of the nominal voltage, where a is the manufacture's stated accuracy.
- For frequency trip magnitude tests, the frequency change resolution of the simulated utility source shall be within $0.5a$ of the nominal frequency, where a is the manufacture's stated accuracy.

- The number of phase and neutral connections provided by simulated area EPS shall be compatible with the EUT. A multiphase simulated area EPS that provides a neutral connection shall produce phase-to-neutral voltages that are balanced within ± 3% of nominal and phase displacement to within ± 3°. For multiphase simulated area EPSs without a neutral connection, the phase-to-phase voltage balance shall be ± 3% of nominal in magnitude.
- For voltage trip timing tests, the simulated utility source shall be capable of a step change from V_1 to $V_1 + 0.5(V_2 - V_1)$ within the greater of one cycle of the voltage waveform or 1% of the trip time setting of the EUT.[6]
- For frequency trip timing tests, the simulated utility source shall be capable of a step change from f_1 to $f_1 + 0.5(f_2 - f_1)$ within the greater of one cycle of the voltage waveform or 1% of the trip time setting of the EUT.[7]

4.6.2 Measurement system requirements

Each measurement shall have an uncertainty of no more than 0.5 times the accuracy of the EUT. Measurement equipment shall be capable of confirming the manufacturer's stated performance.

5. Type tests

Type tests are performed on a representative unit and may be conducted in the factory, at a testing laboratory, or on equipment in the field. Unless otherwise specified, equipment shall be installed per the manufacturer's specification and operated under nominal operating conditions.

Where the EUT cannot be evaluated using one or more of the test regimens specified in this standard, alternative test regimens agreed to by the manufacturer and the testing agency and accomplishing the same measurements with the same accuracy may be used. When used, the details of such alternative test regimens shall be recorded in the test report along with an explanation of why the alternative test regimen was used.

Signal injection test methods may be used to conduct tests in 5.1, 5.2, 5.3, 5.4, 5.8, and 5.10.

Several test procedures require the EUT be operated at different discrete power levels (e.g., 33%, 66%, and 100% of rated power). Adjustments may be made to the EUT to achieve the discrete power levels, provided that these adjustments do not otherwise affect the performance of the EUT for the parameter under test (PUT). Alternatively, to accomplish testing at discrete power levels, the input source may be power limited to result in the desired EUT output power levels.

IEEE Std 1547 allows for type testing to be performed on complete systems, multifunction relays, discrete devices, or any combination. If type testing is performed on anything other than a fully integrated system, some of the component times in Figure A.1 may not be available. In these cases, production and/or commissioning tests shall be conducted to fully demonstrate the ability of the complete system to comply with the timing required by IEEE Std 1547. As an alternative, that the sum of individual component timings meets the requirement may be shown in the test report.

For the purposes of this standard, multiphase ICSs include single-phase three-wire ICSs.

[6]See Annex A for additional information.

[7]See Footnote 6.

5.1 Temperature stability

5.1.1 Purpose

This test verifies that the EUT maintains measurement accuracy of parameters over its specified temperature range. EUT functions shall be tested to confirm that they operate within the manufacturer's stated accuracy over the stated operating temperature range. A functional test procedure to exercise each EUT input and output function shall be agreed to by the manufacturer and the testing agency. The functional test procedure shall confirm EUT operation within the manufacturer's stated accuracy for magnitude and time. It is the intent of this test to confirm the manufacturer's specified accuracy over the specified operating temperature range for measurements and timing references used to provide compliance with IEEE Std 1547.

The test consists of two sections. The operational test verifies that the EUT functions per manufacturer's specification over its operating temperature range. The storage test verifies that the EUT can be stored without damage over the manufacturer's specified storage temperature range.

Where protective, monitoring, and control functions can be conveniently separated from the ICS, the remainder of the ICS may be omitted from this test. However, the manufacturer shall provide the testing agency with substantive information to verify that the complete ICS will perform acceptably over the claimed operating temperature range.

5.1.2 Procedure

5.1.2.1 Operational temperature test procedure

To ensure that the equipment has reached the desired temperature, it should be allowed to stabilize at the specified chamber temperature. Stabilized temperature is reached after a minimum of 2.5 hr and when three successive temperature readings taken at 30 min intervals are within 1 °C. For the minimum operating temperature point, the equipment shall remain deengergized until the stable temperature has been achieved.

a) Select test temperatures per the EUT specification. The EUT should be tested at the minimum, nominal (or average of maximum and minimum if not specified), and maximum operating temperatures. If nonlinear response is observed, additional test temperatures should be selected between the minimum and maximum temperatures.
b) The trip and reset parameters to be measured over the temperature range include voltage, current, power, phase angle, frequency, and time function as appropriate for the EUT. The objective is to confirm each subsection of the EUT. The selection of parameters or functions to be evaluated for this test shall be made so that all hardware components (including those that execute software functions) likely to be affected by temperature are evaluated. Where hardware components are common to more that one function, only one of the common functions need be evaluated to confirm accuracy over the specified temperature range.
c) Perform the tests and record the data. Perform a minimum set of tests that will verify that the EUT protective functions will operate properly over the operating temperature range as specified by the manufacturer.
d) At each temperature point selected in step a), repeat each test selected in step b) for a total of five times.

5.1.2.2 Storage temperature test procedure

Select test temperatures per the EUT specification. The EUT should be conditioned at the minimum and maximum storage temperatures. Where the EUT's operating and storage temperatures are the same, this test is not required.

Select the test method. Storage temperature performance can be established in one of two ways:

— The first method is to review the storage temperature specifications of the individual components of the EUT. If all the components meet the requirements, the EUT meets the requirements.
— The second method is to place the EUT without power for a minimum of 72 hr at each of the temperature extremes. The equipment should be returned to room temperature and proper operation should be verified.

Perform the tests and record the data.

5.1.3 Criteria

5.1.3.1 Operational temperature test

The EUT protective functions shall operate properly over the operating temperature range as specified by the manufacturer.

5.1.3.2 Storage temperature test

The EUT shall function properly after 72 hr at the manufacturer's minimum, nominal, and maximum temperature specifications.

5.1.4 Comments

It may not be necessary or feasible to temperature-test the complete EUT. Per the manufacturer's recommendation, just the components that control the parameters under test need be tested over the specified temperature range. Signal injection testing may be performed with these components per the manufacturer's recommendation.

The EUT should be arranged in the environmental chamber in such a manner that reduces, if not eliminates, opening of the chamber during testing. If the chamber must be left partially open, steps should be taken to minimize heat loss or gain. This is especially important at cold temperatures where opening of the chamber door may cause instant condensation that may affect the test. If the chamber door must be opened during test, allow sufficient time for the temperature to return to the desired test value.

If the EUT has an enclosure, it should be used especially at high temperatures to account for the additional temperature rise due to the enclosure. If including the enclosure is not practical, then the ambient temperature should be increased to a level that is agreed to by the testing agency and EUT manufacturer to account for the additional rise.

Conversely, the use of the enclosure can prevent the equipment from reaching its minimum operating temperature due to the internal rise. To account for this, the equipment should not be energized until the desired low temperature is attained or the temperature is lowered to account for the additional rise. If the manufacturer specifies a cold temperature start-up procedure, that procedure should be followed.

It is recommended that the cold temperature testing be completed first since cooling a heated chamber requires a much longer time than heating a cool chamber.

Care should be taken to mitigate condensation and frosting when performing tests after the cold soak period.

5.2 Test for response to abnormal voltage conditions

If the EUT senses voltage either at the point of common coupling (PCC) with the area EPS or at the point of DR connection as specified in IEEE Std 1547, it may be tested at any convenient load level.

If the EUT senses voltage at a different point than the PCC with the area EPS or at the point of DR connection as specified in IEEE Std 1547, it shall be tested under load in conjunction with any external isolation transformer supplied or required by the EUT manufacturer.

For a EUT that must be tested under load, these tests may be performed at an output current level convenient to the testing laboratory. When an isolation transformer is provided with or required by the EUT, IEEE 1547 compliance will be based on voltage on the area EPS side of the transformer. Testing under load shall be at both

— Its minimum operating current and
— At both unity power factor (p.f.) and the minimum DR p.f. (leading and lagging) as specified by the manufacturer at as close as possible to 100% full rated output current.

These tests shall be performed at the terminals of the EUT.

Where appropriate, signal injection test methods may be used.

5.2.1 Test for overvoltage

5.2.1.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 with respect to overvoltage conditions. This test determines the magnitude and trip time for each overvoltage function.

5.2.1.2 Procedure—magnitude

This procedure uses the ramp function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set all source parameters to the nominal operating conditions for the EUT.
c) Set (or verify) all EUT parameters to the nominal operating settings. If the overvoltage setting is adjustable, set the EUT to the minimum overvoltage setting, but no less than the nominal voltage plus twice the manufacturer's stated accuracy.
d) Record applicable settings.
e) For single-phase units, adjust voltage to starting point V_b, as defined in Annex A. The source shall be held at this voltage for period t_h.[8] At the end of this period, initiate the ramp using the procedure specified in Annex A. For multiphase units, adjust voltage on one phase to starting point V_b and initiate the ramp using the procedure specified in Annex A. Ensure that remaining phases are held at nominal.
f) Record all voltage magnitudes when the unit trips.
g) Repeat steps d) through f) four times for a total of five tests.
h) For multiphase units, repeat steps d) through g) for each phase individually and all phases simultaneously.
i) If the trip magnitude is adjustable, repeat steps d) through h) at the midpoint and maximum of the range.

5.2.1.2.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

[8]The variable t_h is at least two times the trip time setting. This number may be adjusted to avoid conflict with other trip points.

If in step h) of the procedure in 5.2.1.2, the simultaneous multiphase test results vary from the individual phase test results by more than the manufacturer's specified accuracy, additional testing may be necessary to verify that the EUT is responding to phase to neutral magnitude changes instead of phase-to-phase magnitude changes.

5.2.1.2.2 Criteria

The EUT shall be considered in compliance if it trips in the overvoltage range specified in IEEE Std 1547.

5.2.1.3 Procedure—trip time

This procedure uses the step function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set all source parameters to the nominal operating conditions for the EUT.
c) Set (or verify) all EUT parameters to the nominal operating settings. If the overvoltage trip time setting is adjustable, set it to the minimum.
d) Record applicable settings.
e) Set the source voltage to a value within 10% of, but not exceeding, the overvoltage trip point setting. The source shall be held at this voltage for period t_h.[9] At the end of this period, step the source voltage to a value that causes the unit to trip. Hold this value until the unit trips. For multiphase units, this test may be performed on one phase only.
f) Record the trip time.
g) Repeat steps d) through f) four times for a total of five tests.
h) If the overvoltage time setting is adjustable, repeat steps d) through g) at the midpoint and maximum overvoltage time settings.

5.2.1.3.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.2.1.3.2 Criteria

The EUT shall be considered in compliance if the measured trip time is within the clearing time for the overvoltage range specified in IEEE Std 1547.

5.2.2 Test for undervoltage

5.2.2.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 with respect to undervoltage conditions. This test determines the magnitude and trip time for each undervoltage function.

5.2.2.2 Procedure—magnitude

This procedure uses the ramp function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set all source parameters to the nominal operating conditions for the EUT.

[9] See Footnote 8.

c) Set (or verify) all EUT parameters to the nominal operating settings. If the undervoltage setting is adjustable, set the EUT to the minimum undervoltage setting.

d) Record applicable settings.

e) For single-phase units, adjust voltage to starting point V_b, as defined in Annex A. The source shall be held at this voltage for period t_h.[10] At the end of this period, initiate the ramp using the procedure specified in Annex A. For multiphase units, adjust voltage on one phase to starting point V_b and initiate the ramp using the procedure specified in Annex A. Ensure that remaining phases are held at nominal.

f) Record all voltage magnitudes when the unit trips.

g) Repeat steps d) through f) four times for a total of five tests.

h) For multiphase units, repeat steps d) through g) for each individual phase and all phases simultaneously.

i) If the trip magnitude is adjustable, repeat steps d) through h) at the midpoint and maximum of the range.

5.2.2.2.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

If in step h) of the procedure in 5.2.2.2, the simultaneous multiphase test results vary from the individual phase test results by more than the manufacturer's specified accuracy, additional testing may be necessary to verify that the EUT is responding to phase-to-neutral magnitude changes instead of phase-to-phase magnitude changes.

5.2.2.2.2 Criteria

The EUT shall be considered in compliance if it trips in the undervoltage range specified in IEEE Std 1547.

5.2.2.3 Procedure—trip time

This procedure uses the step function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Set all source parameters to the nominal operating conditions for the EUT.

c) Set (or verify) all EUT parameters to the nominal operating settings. If the undervoltage trip time setting is adjustable, set it to the minimum.

d) Record applicable settings.

e) Set the source voltage to a value within 10% of, but not exceeding, the undervoltage trip point setting. The source shall be held at this voltage for period t_h.[11] At the end of this period, step the source voltage to a value that causes the unit to trip. Hold this value until the unit trips. For multiphase units, this test may be performed on one phase only.

f) Record the trip time.

g) Repeat steps d) through f) four times for a total of five tests.

h) If the undervoltage time setting is adjustable, repeat steps d) through g) at the midpoint and maximum undervoltage time settings.

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[10] See Footnote 8.

[11] See Footnote 8.

5.2.2.3.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.2.2.3.2 Criteria

The EUT shall be considered in compliance if the measured trip time is within the clearing time for the undervoltage range specified in IEEE Std 1547.

5.3 Response to abnormal frequency conditions

5.3.1 Test for overfrequency

5.3.1.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 with respect to overfrequency conditions. This test determines the magnitude and trip time for each overfrequency function.

5.3.1.2 Procedure—magnitude

This procedure uses the ramp function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set all source parameters to the nominal operating conditions for the EUT.
c) Set (or verify) all EUT parameters to the nominal operating settings. If the overfrequency setting is adjustable, set the EUT to the minimum overfrequency setting.
d) Record applicable settings.
e) Adjust the source frequency to starting point fb. The source shall be held at this frequency for period t_h.[12] At the end of this period, initiate the ramp using the procedure specified in Annex A.
f) Record the frequency at which the unit trips.
g) Repeat steps d) through f) four times for a total of five tests.
h) If the overfrequency setting is adjustable, repeat steps d) through g) at the midpoint and maximum overfrequency settings.

5.3.1.2.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.3.1.2.2 Criteria

The EUT shall be considered in compliance if it trips in the overfrequency range specified in IEEE Std 1547.

5.3.1.3 Procedure—trip time

This procedure uses the step function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

[12]See Footnote 8.

b) Set all source parameters to the nominal operating conditions for the EUT.

c) Set (or verify) all EUT parameters to the nominal operating settings. If the overfrequency trip time setting is adjustable, set it to the minimum.

d) Record applicable settings.

e) Set the source frequency to a value within 1% of, but not exceeding, the overfrequency trip point setting. The source shall be held at this frequency for period t_h.[13] At the end of this period, step the source frequency to a value that causes the unit to trip. Hold this value until the unit trips.

f) Record the trip time.

g) Repeat steps d) through f) four times for a total of five tests.

h) If the overfrequency time setting is adjustable, repeat steps d) through g) at the midpoint and maximum overfrequency time settings.

5.3.1.3.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.3.1.3.2 Criteria

The EUT shall be considered in compliance if the measured trip time is within the clearing time for the overfrequency range specified in IEEE Std 1547.

5.3.1.3.3 Comments

For some EUT, the step size past the frequency trip limit should be as small as possible to reduce false results. Large frequency step changes can interfere with EUT phase lock loop operation.

5.3.2 Test for underfrequency

5.3.2.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 with respect to underfrequency conditions. This test determines the magnitude and trip time for each underfrequency function.

5.3.2.2 Procedure—magnitude

This procedure uses the ramp function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Set all source parameters to the nominal operating conditions for the EUT.

c) Set (or verify) all EUT parameters to the nominal operating settings. If the underfrequency setting is adjustable, set the EUT to the minimum underfrequency setting.

d) Record applicable settings.

e) Adjust the source frequency to starting point fb. The source shall be held at this frequency for period t_h.[14] At the end of this period, initiate the ramp using the procedure specified in Annex A.

f) Record the frequency at which the unit trips.

g) Repeat steps d) through f) four times for a total of five tests.

[13] See Footnote 8.

[14] See Footnote 8.

h) If the underfrequency setting is adjustable, repeat steps d) through g) at the midpoint and maximum underfrequency settings.

5.3.2.2.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.3.2.2.2 Criteria

The EUT shall be considered in compliance if it trips in the underfrequency range specified in IEEE Std 1547.

5.3.2.3 Procedure—trip time

This procedure uses the step function defined in Annex A.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Set all source parameters to the nominal operating conditions for the EUT.

c) Set (or verify) all EUT parameters to the nominal operating settings. If the underfrequency trip time setting is adjustable, set it to the minimum.

d) Record applicable settings.

e) Set the source frequency to a value within 1% of, but not exceeding, the underfrequency trip point setting. The source shall be held at this frequency for period t_h.[15] At the end of this period, step the source frequency to a value that causes the unit to trip. Hold this value until the unit trips.

f) Record the trip time.

g) Repeat steps d) through f) four times for a total of five tests.

h) If the underfrequency time setting is adjustable, repeat steps d) through g) at the midpoint and maximum underfrequency time settings.

5.3.2.3.1 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.3.2.3.2 Criteria

The EUT shall be considered in compliance if the measured trip time is within the clearing time for the underfrequency range specified in IEEE Std 1547.

5.3.2.3.3 Comments

For some EUT, the step size past the frequency trip limit should be as small as possible to reduce false results. Large frequency step changes can interfere with EUT phase lock loop operation.

5.4 Synchronization

The purpose of the tests in this subclause is to demonstrate that the EUT will accurately and reliably synchronize to the area EPS according to the requirements of IEEE Std 1547. Separately excited induction generators shall be tested using the procedure for synchronous generators.

[15]See Footnote 8.

Two basic test methods are provided:

- Method 1 verifies that a synchronization control function will cause the paralleling device to close only when key synchronization parameters are within allowable limits.
- Method 2 determines the magnitude of the synchronization startup current.

Equipment that can generate voltage independently of the area EPS and is thus capable of out-of-phase paralleling with the area EPS (e.g., a synchronous generator or inverter operating in a stand-alone mode) is tested to verify compliance of its synchronizing capability using Method 1.

Equipment that utilizes energy from the area EPS service to begin operation (e.g., an induction generator) and that may draw high current levels is tested to determine the synchronization current using Method 2. Equipment that generates a voltage inherently synchronized to the area EPS is also tested to determine the synchronization current using Method 2. This current value can then be used along with area EPS impedance at a specific location to estimate the maximum voltage fluctuation related to synchronization.

The EUT addressed in these procedures includes a wide range of capabilities, ranging from discrete components providing control and protection functions to complete generator equipment facilities. The intent of the testing requirement in this subclause is that the user identify the procedure most appropriate for the particular situation and use that procedure to validate equipment performance. IEEE Std 1547 requires that when paralleling with the area EPS, the DR should not cause excessive voltage fluctuation. Therefore, when in doubt, Method 2 should be used. Some equipment with multiple operating modes may have to be tested using both of the basic methods.

Three variations of Method 1 are provided. The first variation (5.4.1) assumes a simulated generator source and would be performed, for example, on a discrete relay or multifunction controller with synchronization control function. The second variation (5.4.2) assumes a real generator source is used. The third variation (5.4.3) is designed for testing of equipment in which the synchronizing functions cannot be switched off or the sensing voltage cannot be conveniently disconnected.

5.4.1 Synchronization control function test using simulated sources (Method 1, variation 1)

5.4.1.1 Purpose

The purpose of these tests is to demonstrate that interconnection equipment will synchronize to the area EPS across an open paralleling device (e.g., a power circuit breaker), within allowable limits of voltage, frequency, and phase-angle difference before the paralleling device is allowed to close. The procedure is intended for a discrete or multifunction interconnection control device that includes a synchronization function and may be used in laboratory tests with simulated generator equipment and a simulated area EPS source.

If the EUT does not include a paralleling device, the acceptability of the ICS for a specific site depends on the speed of operation of the paralleling device to be used with the EUT.

5.4.1.2 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Connect the test equipment to monitor the paralleling device close command, the phase relationship between simulated generator output and area EPS sources, the frequency of each source, and the voltage of each source.

c) Set simulated area EPS source to operate at nominal voltage and frequency. Record applicable settings.

d) Demonstrate that the equipment will not close outside of the voltage acceptance range defined in IEEE Std 1547, but will close within that acceptance range. By holding the voltage and frequency of the simulated area EPS source at constant nominal values and varying the voltage of the generator source, the test will demonstrate that the EUT will not initiate closing outside of acceptable ranges of voltage and will close within acceptable ranges. The test will demonstrate that the EUT functions properly both from a low voltage that is raised to within an acceptable level and from a high voltage that is lowered to within an acceptable level. The following process may be used for testing the voltage:
   1) Set the voltage and frequency of the area EPS source to nominal values.
   2) Set the voltage of the simulated generator source to a level above the area EPS source voltage so that the voltage difference is outside the acceptance range, but the generator voltage is below the overvoltage trip limit of the EUT (if so equipped). The voltage difference should be at least twice the manufacturer's stated accuracy.[16]
   3) Set and hold the frequency of the simulated generator source to that of the simulated area EPS so that frequency difference and phase angle[17] are within the limits allowed by the requirements of IEEE Std 1547. Include an allowance for EUT accuracy so that frequency and phase angle do not inadvertently keep the EUT from initiating a paralleling device closure.
   4) Verify for a period of at least 3 min that the EUT does not initiate closing.
   5) Gradually reduce the generator source voltage until the voltage difference is within the acceptance values of IEEE Std 1547 including an allowance for EUT accuracy. The voltage ramp rate should be controlled to allow reliable indication of the point at which paralleling device closure is initiated. A procedure for determining ramp rates is described in Annex A.
   6) Record the voltage and frequency for the area EPS and generator sources, as well as the voltage, frequency, and phase-angle differences between the two sources at the point at which the EUT initiates paralleling device closure.
   7) Repeat steps a) through f) four times for a total of five sets of readings.
   8) Repeat steps a) through g) except with the initial simulated generator source voltage set at a level below the area EPS source voltage so that the voltage difference is outside the acceptance range, but the generator voltage is above the undervoltage trip limit of the EUT.

e) Demonstrate that the equipment will not close outside of the frequency and phase-angle acceptance range defined in IEEE Std 1547, but will close within that acceptance range. By holding the voltage and frequency of the area EPS source constant and varying the frequency of the generator source, the test will demonstrate that the EUT will not initiate paralleling device closure outside of acceptable ranges of frequency difference and phase angle and will initiate paralleling device closure within acceptable ranges. The test will demonstrate that the EUT functions properly starting from both a low frequency that is raised to within an acceptable level and from a high frequency that is lowered to within an acceptable level.
   1) Set the voltage and frequency of the area EPS source to nominal values. Set the generator source voltage to that of the area EPS.
   2) Set the frequency of the simulated generator source to a level above the area EPS source frequency so that the frequency difference is outside the acceptance range, but the generator frequency is below the overfrequency trip limit of the EUT (if so equipped). The frequency difference should be at least twice the stated accuracy of the EUT.
   3) Set and hold the voltage of the simulated generator source to that of the simulated area EPS so that voltage difference is within the limits allowed by the requirements of IEEE Std 1547. Include an allowance for EUT accuracy so that voltage difference does not inadvertently keep the EUT from initiating a paralleling device closure.

[16]If the EUT stated measurement accuracy is 1%, the initial voltage difference should be at least 2% greater than the allowable limit.

[17]If the generator source frequency and utility source frequency are not identical, phase angle will periodically be within allowable limits.

4) Verify for a period of at least 3 min that the EUT does not initiate paralleling device closure.
5) Gradually reduce the generator source frequency until the frequency difference is within the acceptance values of IEEE Std 1547 including an allowance for EUT accuracy. The frequency ramp rate should be controlled to allow reliable indication of both the frequency and phase angle at which paralleling device closure is initiated. A procedure for determining ramp rates is described in Annex A.
6) Record the voltage and frequency for the area EPS and generator sources, as well as the voltage, frequency, and phase-angle differences between the two sources at the point at which the EUT initiates paralleling device closure.
7) Repeat steps a) through f) four times for a total of five sets of readings.
8) Repeat steps a) through g) except with the initial simulated generator source frequency set at a level below the area EPS source frequency so that the frequency difference is outside the acceptance range, but the generator frequency is above the underfrequency trip limit of the EUT.

5.4.1.3 Requirements

Programmable arbitrary waveform generators (multiphase as necessary) may be used to provide simulated generator and area EPS voltage waveforms. The waveform generator will provide voltage and frequency signals in a form compatible with the EUT.

Simulated generator voltage and frequency control will come either from the EUT or, for passive devices, from a control computer programmed to provide the desired waveforms.

Equipment steady-state operating performance shall meet the manufacturer's standards for speed and voltage stability at no load for at least 15 min.

5.4.1.4 Criteria

The testing shall demonstrate that the equipment complies with the requirements of IEEE Std 1547 for synchronization parameter limits.

Test results shall demonstrate that the EUT will not initiate closure out of range for any parameter during any test.

5.4.1.5 Comments

Since the EUT in this test procedure may not incorporate a paralleling device, the documentation should note that, when applied, the phase angle at the instant of closing would be different from what is recorded during this test due to the closing time required for the anticipated paralleling device. The EUT may incorporate provisions to allow compensation for paralleling device operation time.

If parallel device closing time compensation was used, verify that the synchronization device accurately predicted the proper closing angle prior to the specified phase-angle window. Following is a sample calculation:

Given:

paralleling device closing time = 5 cycles

frequency differential at time of parallel device close command = 0.10 Hz

maximum phase-angle window = 10°

Then:

phase rotation rate = frequency differential × 360° = 0.10 Hz × 360° = $36° s^{-1}$

paralleling device closing time = 5 cycles @ 60 Hz = 0.0833 s

predictive closing angle = $36°s^{-1} \times 0.0833$ s = 3°

Therefore, if the maximum allowable phase angle at paralleling device closure is 10° and the equipment is approaching synchronization, the initiation point could be 10° + 3° = 13°. If the equipment was moving away from synchronization, maximum deviation at initiation would be 10° – 3° = 7°.

5.4.2 Synchronization control function test using actual generator equipment (Method 1, variation 2)

5.4.2.1 Purpose

The purpose of these tests is to demonstrate that synchronous generator equipment will accurately and reliably synchronize to the area EPS across an open paralleling device (e.g., a power circuit breaker), according to the requirements of IEEE Std 1547.

These procedures may also be used with separately excited induction equipment or with inverter equipment that is able to operate in isolation from the area EPS and to resynchronized with the area EPS.

5.4.2.2 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer. Installation must include verification of the ratings, phasing, and connection of the current transformers (CTs) and voltage transformers (VTs) (if used) in the system that provides input to the control and protection functions.

b) Connect the test equipment to monitor the paralleling device close command, the phase relationship between sources, the frequency of each source, and all phases of the voltage of the generator and of the area EPS.

c) Verify that the EUT is operating at a stable voltage and frequency. Set equipment to operate at rated voltage and frequency. Verify that the equipment operates within the frequency and voltage regulation specifications of the manufacturer while operating in isolation from the area EPS. Stability should be verified at various load levels up to the maximum that it will be required to carry. Record applicable settings, and record voltage and frequency regulation performance.

d) Measure and record the closing time of the paralleling device. Repeat four times for a total of five tests.

e) Set the generator to the nominal frequency and voltage of the area EPS. Disable paralleling device closure and initiate synchronizing action. Verify that the synchronizing function will correctly operate to close the paralleling device when the generator is properly synchronized. If the paralleling device includes a test position that does not allow connection to the area EPS, use of the test position to verify paralleling device operation is acceptable.

f) Enable paralleling device closing.

g) Demonstrate that the equipment will not close outside of the allowed acceptance range for voltage and will close within the voltage range values required by IEEE Std 1547. The required process holds the frequency of the generator source constant and nearly identical to the area EPS source and, by varying the voltage, will demonstrate that the equipment will not initiate closing out of acceptable ranges of voltage, and will close within acceptable parameters. The test will demonstrate that the equipment functions properly both from a low voltage that is raised to an acceptable level, and from a high voltage that is lowered to within acceptable range. The following process may be used (at various points in the following procedure, it may be necessary to reset various parameters to proceed):

   1) If applicable, disable the synchronizing function.

2) Set and hold the voltage of the generator to a level so that the voltage difference is outside the acceptance range, but within the acceptable voltage and frequency operating range of the ICS. The level selected should be higher than the acceptance range and high enough so that the accuracy of the EUT will not inadvertently initiate operation.
3) Set and hold the frequency of the generator source to that of the area EPS. Maintain the phase angle to within the acceptance limits of IEEE Std 1547.
4) Verify for a period of at least 3 min that the interconnection equipment does not initiate closing.
5) Gradually reduce the voltage difference to within the acceptance values of IEEE Std 1547. The rate of ramp of the voltage parameter should be controlled to a value that allows reliable indication of the initiation point. A procedure for determining ramp rates is described in Annex A. Record the voltage differential at the time of initiation of closure.
6) Repeat steps a) through e) except with the initial generator voltage below the area EPS source voltage. The level should be lower than the acceptance range and should be selected so that the accuracy of the EUT will not inadvertently initiate operation.

h) Demonstrate that the equipment will not close outside of the acceptance range due to improper frequency sensing or phase-angle sensing and will close within the values of IEEE Std 1547. The required process holds the voltage of the simulated generator source constant and nearly identical to the area EPS source and, by varying the frequency, will demonstrate that the equipment will not initiate closing out of acceptable ranges of frequency and phase angle and will close within acceptable parameters. The test will demonstrate that the equipment functions properly both from a low frequency that is raised to an acceptable level and from a high frequency that is lowered to within acceptable range. The following process may be used:
   1) Set the frequency of the generator source to a level so that the frequency difference is outside the acceptance range, but within the acceptable voltage and frequency operating range of the ICS. The level selected should be higher than the acceptance range and high enough so that the accuracy of the EUT will not inadvertently initiate operation.
   2) Set the voltage of the generator source to that of the area EPS source.
   3) Hold the voltage and frequency constant. Verify for a period of at least 3 min that the interconnection equipment does not initiate closing. (This step may require disabling the automatic synchronizing function of the generator.)
   4) Gradually reduce the frequency difference to within the acceptance values of IEEE Std 1547. The ramp rate of the frequency parameter should be controlled to a value that allows reliable indication of the initiation point. A procedure for determining ramp rates is described in Annex A. Record the frequency differential and phase-angle deviation at the time of initiation of closure.
   5) Repeat steps a) through d) except with the initial generator frequency below the area EPS source frequency. The level should be lower than the acceptance range and should be selected so that the accuracy of the EUT will not inadvertently initiate operation.

i) Repeat this test procedure four times for a total of five tests.

5.4.2.3 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1.

If an actual area EPS source is used, the area EPS source must remain within the undervoltage, overvoltage, underfrequency, and overfrequency trip limits defined by IEEE Std 1547.

Frequency should be set at nominal and maintained within ± 0.05 Hz.

The measurement system shall meet the requirements of 4.6.2.

5.4.2.4 Criteria

The testing shall demonstrate that the equipment complies with the requirements of IEEE Std 1547 for synchronizing performance. IEEE Std 1547 presumes that the voltage fluctuation requirement is met by successful completion of these tests.

Test results shall demonstrate that contacts will not close out of range during any test.

5.4.2.5 Comments

There are a large number of potential application issues that affect the performance of the synchronizing equipment. In particular, phase rotation of generator sets relative to the grid, phasing of potential transformers serving protection and control equipment, and many other factors. Therefore, it is critical that careful attention be paid to the manufacturer's installation instructions and system design drawings to avoid out-of-phase paralleling of the generator equipment to the area EPS.

5.4.3 Synchronization control function test for equipment with no synchronizing disable capability (Method 1, variation 3)

5.4.3.1 Purpose

The purpose of this test is to demonstrate that the EUT will synchronize to the area EPS across an open paralleling device, within allowable limits of voltage, frequency, and phase-angle difference before the paralleling device is allowed to close. The procedure is intended for equipment that automatically synchronizes when a reference voltage source is available, maintains synchronization prior to connecting with the area EPS, and does not include a means to disable or disconnect the synchronizing function.

5.4.3.2 Procedure

a) Install and adjust the EUT according to the manufacturer's recommendations and specifications.

b) Connect test equipment to monitor the paralleling device close command, the phase relationship between EUT output and area EPS sources, the frequency difference, voltage difference, and phase angle between the sources.

c) Set simulated area EPS source to operate at nominal voltage and frequency. Record applicable settings.

d) Disconnect the area EPS from the EUT.

e) Enable all monitoring equipment. Reapply the area EPS and record all required parameters (i.e., voltage, frequency, and phase-angle differences) during the paralleling operation.

f) Repeat this test procedure four times for a total of five tests.

5.4.3.3 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.4.3.4 Criteria

The testing shall demonstrate that the equipment complies with the requirements of IEEE Std 1547 for synchronization parameter limits.

5.4.4 Startup current measurement (Method 2)

5.4.4.1 Purpose

The purpose of these tests is to determine the maximum startup (in-rush) current drawn by an EUT (e.g., a line-excited induction generator) or by inverter equipment that does not produce output voltage at the time of connecting to the area EPS. The results of this test may be used along with information for the proposed location to verify that the EUT will not violate the synchronizing or flicker requirements of IEEE Std 1547 as installed.

5.4.4.2 Procedure

Induction generator equipment may be evaluated using NEMA MG-1. (Manufacturer's data are acceptable if available and directly applicable based on the application voltage level.)

Induction generator equipment or inverter equipment may be evaluated using the following procedure:

a) Set up the EUT according to the manufacturer's specifications connected to a simulated or actual area EPS.
b) The input power source to the EUT shall be capable of providing at least 120% of rated input power and any normal startup transients.
c) EUT startup shall follow the manufacturer's specified procedure.
d) Begin with the EUT shutdown.
e) Enable monitoring equipment to record area EPS voltages on all phases (line-to-line and line-to-neutral if it can be connected in that configuration) and to record EUT output current on all phases.
f) Initiate a normal EUT startup procedure.
g) Repeat the test nine times for a total of ten tests.[18]
h) For each test, calculate the startup current. The startup current is the maximum value of root-mean-square (rms) current calculated over any consecutive 5-cycle window during the startup process. The EUT maximum startup current is the maximum value of the startup current obtained on any phase in any of the ten tests.
i) Document the impedance of the source used on the test.[19]

5.4.4.3 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1.

The measurement system shall meet the requirements of 4.6.2. Voltage and current waveform measurements shall be recorded at a sample rate of at least 600 Hz per channel to provide at least 10 samples per cycle.

5.4.4.4 Criteria

This test determines the magnitude of current drawn (or sourced) by the EUT at startup so that voltage fluctuation (flicker) calculations can be completed for a specific site. This is a characterization test—there are no specific pass/fail criteria except as applied at a specific site.

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[18]The number of tests was selected to assure that a maximum value is obtained.

[19]The Thevenin impedance of the area EPS will have a significant effect on the value of the flicker. An infinite bus will create low flicker values while a high impedance system will result in high flicker values. Impedance of the source can be determined by calculations based on the Thevenin impedance (e.g., source transformer and wiring) or empirically determined by using a load large enough to cause a voltage drop.

The value reported for the EUT shall be the highest of the ten tests. A graphical representation of the time-current characteristic along with the calculated startup current shall be included in the test report.

5.5 Interconnection integrity

5.5.1 Protection from electromagnetic interference (EMI) test

5.5.1.1 Purpose

The purpose of these tests is to determine the EUT's protection from EMI and to confirm that the results are in compliance with IEEE Std 1547.

5.5.1.2 Procedure

The interconnection equipment of the EUT shall be tested in accordance with IEEE Std C37.90.2. This test shall be applied to one parameter and trip function representative of the EUT utility protective function measurement system.

5.5.1.3 Criteria

The influence of EMI shall not result in a change in state or misoperation of the interconnection functions of the EUT.

5.5.2 Surge withstand performance test

5.5.2.1 Purpose

The purpose of this test is to verify the level of surge withstand protection specified by the manufacturer of the EUT. The EUT shall be tested to verify the level of surge withstand protection as specified by the manufacturer and in accordance with IEEE Std C62.41.2 and/or IEEE Std C37.90.1, as applicable.

5.5.2.2 Procedure

The manufacturer shall specify the location category and exposure level of the tests required by IEEE Std C62.41.2 and/or IEEE Std C37.90.1.

a) Apply IEEE Std C37.90.1 to test appropriate EUT external signal and control circuits.

b) Apply IEEE Std C62.41.2 and IEEE Std C62.45 to test appropriate EUT power circuits.

   The EUT shall be tested in all normal operating modes in accordance with IEEE Std C62.45 for equipment rated less than or equal to 1000 V to confirm that the surge withstand capability is met by using the selected test level(s) from IEEE Std C62.41.2. The test should be conducted while the EUT is operating under nominal power unless it can be shown that the surge protection is not affected by its operational state. Equipment rated greater than 1000 V shall be tested in accordance with the applicable standards as designated by the manufacturer or system integrator.

5.5.2.3 Criteria

The results of these tests shall indicate the interconnection functions of the EUT did not fail, did not misoperate, and did not provide misinformation.

5.5.3 Dielectric test for paralleling device

The following test is for EUT that operate at 1000 V or less. For systems over 1000 V, the EUT shall be tested in accordance with the power frequency dielectric withstand rating specified in Table 4 of ANSI C37.06 and the procedures specified in 4.4.3.1 of IEEE Std C37.09.

5.5.3.1 Purpose

This test determines if the paralleling device of the EUT, while at normal operating temperature, can withstand for 1 min without breakdown the application of an ac rms test potential of 1000 V plus 220% of the nominal ac rms voltage.

5.5.3.2 Procedure

The unit is to be tested using a 500 VA or larger capacity transformer or dielectric tester, the output voltage of which is variable. The applied potential is to be increased from zero until the required test level is reached and is to be held at that level for 60 s. The increase in applied potential is to be at a substantially uniform rate as rapid as is consistent with correct indication of its value by a voltmeter.

- Exception 1: When a voltmeter is connected across the output circuit to directly indicate the test potential, the transformer is not required to be rated 500 VA or more.
- Exception 2: A dc test voltage of 220% of the nominal ac peak voltage plus 1400 V may be used for the dielectric test.

A low-voltage control circuit or a sensor circuit is not required to be connected during the test. Any circuit that is connected from input to output circuit shall remain connected during the test and provide proper isolation.

5.5.3.3 Criteria

The paralleling device of the EUT shall be capable of withstanding the applied test voltage for 60 s. There shall be no flashovers during the test, and no damage to the insulation shall be observed after the test.

5.5.3.4 Comments

This test should be applied only to the paralleling device as specified in IEEE Std 1547.

5.6 Limitation of dc injection for inverters without interconnection transformers

5.6.1 Purpose

The purpose of this test is to verify that an inverter that connects to the EPS complies with the dc injection limit specified in IEEE Std 1547. This test is conducted on inverters that connect to the EPS without the use of dc-isolation output transformers.

5.6.2 Procedure and data analysis

Operating power levels in this procedure have a tolerance of ± 5%.

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set all source parameters to the nominal operating conditions for the EUT.
c) Set (or verify) all EUT parameters to the nominal operating settings.
d) Record applicable settings.

e) Operate the EUT at 33% of its continuous rated output current[20] and at rated p.f. Allow the EUT to operate for at least 5 min prior to taking any test measurements (or until the EUT temperature stabilizes). The EUT shall operate at the specified current and p.f. for the duration of the test.

f) At the EUT output, measure the rms voltage, rms current, and dc component (frequency less than 1 Hz) of current on all phases. The averaging window for all measurements shall be not less than one cycle and not more than 60 cycles.

g) Record all measurements at a sampling rate of not less than the reciprocal of the selected averaging window[21] for a period of 5 min.

h) Repeat steps e) through g) with the DR operating at 66% and at a level as close to 100% of its rated output current as practical.

For all output current levels tested, the following data analysis is required:

a) Calculate average values of rms current and voltage on each phase. For each measurement, the average shall include every sample point recorded during the 5 min test period.

b) Verify that the average rms current on each phase is within 5% of the intended test point (33%, 66%, and 100%).

c) Verify that the average rms voltage on each phase is within 5% of the nominal voltage.

d) Calculate average values for the magnitude of the dc component of current on each phase. The average shall be taken of the absolute (unsigned) value of every sample point recorded during the 5 min test period.

e) For each phase, divide the average dc component magnitude value by the rated output current of the EUT and multiply the result by 100. Record the final calculated values as the percent dc injection current for each phase.

5.6.3 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1 and shall have negligible dc offset.

5.6.4 Criteria

The EUT shall be considered in compliance if all calculated percent dc injection currents are within the limit specified in IEEE Std 1547.

5.6.5 Comments

This test may be conducted as part of the harmonics test.

If a simulated area EPS is used, a dedicated isolation transformer should be used.

5.7 Unintentional islanding

The unintentional islanding test given in 5.7.1 is universally acceptable for all DR ICSs. ICSs intended for use solely with synchronous generators may alternatively use the procedures in 5.7.2. Reverse-power function used for detecting an unintentional island shall be tested in accordance with 5.8, instead of the test in this subclause.

[20]Use the grid-connected current rating for units that offer stand-alone and grid-connected mode.

[21]For block averaging or moving average filters, the averaging window is the period over which the averages are taken. For other filters, the averaging window is the reciprocal of the filter bandwidth in hertz.

This test addresses several EUT output power levels including EUT set power levels and levels limited by the DR input source.

5.7.1 Unintentional islanding test

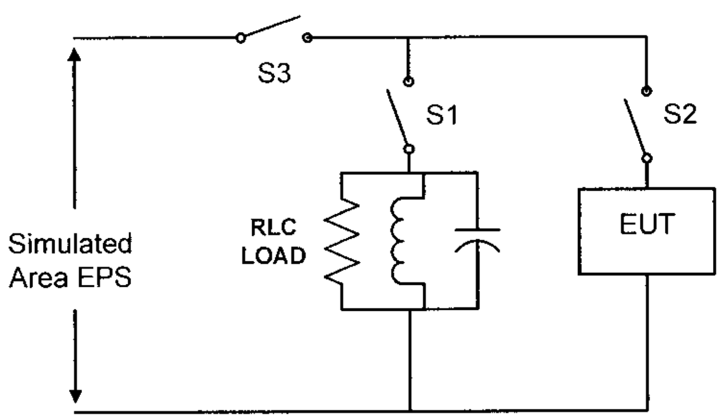
5.7.1.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 when an unintentional island condition is present. This test determines the trip time for the test conditions specified in 5.7.1.

5.7.1.2 Procedure

This test procedure is designed to be universally applicable to all DRs, regardless of output p.f. Any reactive power compensation by the EUT should remain on during the test.

Where the EUT manufacturer requires an external or separate transformer, the transformer is to be connected between the EUT and resistance, inductance, and capacitance (RLC) load specified in Figure 2[22] and is to be considered part of the product being tested.



NOTES

1—Switch S1 may be replaced with individual switches on each of the RLC load components.

2—Unless the EUT has a unity output p.f., the reactive power component of the EUT is considered to be a part of the islanding load circuit in the figure.

Figure 2—Unintentional islanding test configuration

a) For a single-phase EUT, the test circuit shall be configured as shown in Figure 2. The neutral connection (grounded conductor) of the RLC load, the simulated area EPS, and the EUT shall be unaffected by the operation of switch S3. For a multiphase EUT, the balanced load circuit shown in Figure 2 is to be applied between each phase to neutral for a four-wire configuration or between phases for a three-wire configuration. Switch S3, as shown in Figure 2, shall be gang-operated and multi-pole.
b) Connect the EUT according to the instructions and specifications provided by the manufacturer.
c) Set all EUT input source parameters to the nominal operating conditions for the EUT.

[22]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

d) Set (or verify) all EUT parameters to the nominal operating settings.

e) Set the EUT (including the input source as necessary) to provide 100% of its rated output power.[23]

f) Record all applicable settings.

g) Set the Simulated EPS to the EUT nominal voltage ± 2% and nominal frequency ± 0.1 Hz.

h) Adjust the islanding load circuit in Figure 2 to provide a quality factor Q_f of 1.0 ± 0.05 (when Q_f is equal to 1.0, the following applies: $P_{qL} = P_{qC} = 1.0 \times P$).[24] The value of Q_f is to be determined by using the following equations as appropriate:

$$Q_f = R\sqrt{\frac{C}{L}}$$

or

$$Q_f = \frac{\sqrt{P_{qL} \times P_{qC}}}{P}$$

where

Q_f is the quality factor of the parallel (RLC) resonant load,

R is the effective load resistance (Ω),

C is effective load capacitance (F),

L is effective load inductance (H),

P_{qL} is the reactive power per phase consumed by the inductive load component (VARS),

P_{qC} is the reactive power per phase consumed by the capacitive load component (VARS),

P is the real output power per phase of the unit (W),

f is frequency.

The inductance and capacitance are to be calculated using the following equations:

$$L = \frac{V^2}{2 \times \pi \times f \times P \times Q_f}$$

$$C = \frac{P \times Q_f}{2 \times \pi \times f \times V^2}$$

where

L is effective load inductance (H),

V is the nominal voltage across each phase of the RLC load (V) (for loads connected phase to phase, V is the nominal line voltage; for loads connected phase to neutral, V is the nominal phase voltage),

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[23]EUT provided with or intended for use with specific defined input sources that can not provide the input power range described in this test shall be tested within the limitations of the specified or supplied input source. Under these circumstances the test may be performed with the actual source or a simulated source. Test results will be applicable only to the combination of the EUT and specified source, and the test report should reflect this limitation.

[24]Based on the equation Q_f = Tan(ArcCos(d.p.f.)), where d.p.f is the displacement power factor, a Q_f of 2.5 is equivalent to an uncorrected load d.p.f of 0.37, a Q_f of 1.8, uncorrected load d.p.f. of 0.48, and a Q_f of 1, uncorrected load d.p.f. of 0.707. Area EPS circuits typically operate above 0.75 d.p.f. in steady-state conditions; therefore, $Q_f = 1$ (d.p.f.=0.707) is below the load d.p.f. that the DR is expected to be islanded with. For a point of comparison, the current draft of IEC 62116 [B4] uses a Q_f of 0.65 (d.p.f. of 0.84). A lower value of Q will allow DR manufacturers to use perturbation schemes that are potentially less detrimental to power quality.

P is the real output power per phase of the unit (W),

Q_f is the quality factor of the parallel (RLC) resonant load,

C is the effective load capacitance (F),

f is frequency.

The reactive load is balanced so that the resonant frequency f of the island circuit is within the underfrequency and overfrequency trip settings of the EUT and as close to nominal frequency as possible.

When tuning for the current balance in this step with a nonunity output p.f. EUT, there will be an imbalance between the L and C load components to account for the EUT reactive current. The EUT reactive output current shall be measured and algebraically added to the appropriate reactive load component when calculating Q_f.

i) Close switch S1, switch S2, and switch S3, and wait until the EUT produces the desired power level.

j) Adjust R, L, and C until the fundamental frequency current through switch S3 is less than 2% of the rated current of the EUT on a steady-state basis in each phase.[25]

k) Open switch S3 and record the time between the opening of switch S3 and when the EUT ceases to energize the RLC load.

l) The test is to be repeated with the reactive load (either capacitive or inductive) adjusted in 1% increments or alternatively with the reactive power output of the EUT adjusted in 1% increments from 95% to 105% of the initial balanced load component value. If unit shutdown times are still increasing at the 95% or 105% points, additional 1% increments shall be taken until trip times begin decreasing.

m) After reviewing the results of the previous step, the 1% load setting increments that yielded the three longest trip times shall be subjected to two additional test iterations. If the three longest trip times occur at nonconsecutive 1% load setting increments, the additional two iterations shall be run for all load settings in between.

n) Repeat steps d) through m) with the test input source adjusted to limit the EUT output power to 66%. This value is allowed to be between 50% and 95% of rated output power and is intended to evaluate the EUT at less than full power and under the condition where the available output is determined or limited by the input source. If the EUT does not provide this mode of operation, then set the EUT to control the output power to the specified level.

o) Repeat steps d) through m) with the EUT output power set via software or hardware to 33% of its nominal rating with the test input source capable of supplying at least 150% of the maximum input power rating of the EUT over the entire range of EUT input voltages. For units that are incapable of setting or commanding an output power level, the EUT output power shall be limited via the input power source. For units that are incapable of operating at 33%, the EUT shall be tested at the lowest output power the EUT will support. This step is intended to evaluate the EUT at low power and under the condition where the available output is determined or limited by the EUT control setting. If the EUT does not provide this mode of operation, then set the input source to meet the specified output power level.

5.7.1.3 Requirements

Where the EUT requires a separate test input source to conduct this test, that source shall be capable of supplying at least 150% of the maximum input power rating of the EUT over the entire range of EUT input voltages.

[25]Certain anti-islanding algorithms will sufficiently perturb the fundamental frequency current through switch S3 so that the 2% limit cannot be achieved on a continuous basis. Averaging of the rms current over a number of cycles in a manner that captures the quiescent magnitude of this current shall be utilized for determination of matched load during this quiescent period.

The RLC load shall be tuned so that the fundamental frequency current through switch S3 is less than 2% of the rated current of the unit under test on a steady-state basis in each phase.

The test and measurement equipment shall record each phase current and each phase-to-neutral or phase-to-phase voltage, as appropriate, to determine fundamental frequency real and reactive power flow over the duration of the test. Anti-aliasing filters and sampling frequencies appropriate to the measurement of the fundamental frequency component shall be applied. The minimum measurement accuracy shall be 1% or less of rated EUT nominal output voltage and 1% or less of rated EUT output current.

The equations for Q_f are based upon an ideal parallel RLC circuit. For this reason, noninductive resistors, low loss (high Q) inductors, and capacitors with low effective series resistance and effective series inductance shall be utilized in the test circuit. Real and reactive power should be instrumented in each of the R, L, and C legs of the load so that these parasitic parameters (and parasitics introduced by variacs or autotransformers) are properly accounted for when calculating Q_f. Iron core inductors, if used, shall not exceed a current THD of 2% when operated at nominal voltage. Power ratings of resistors should be conservatively chosen to minimize thermally induced drift in resistance values during the course of the test.

5.7.1.4 Criteria

A test is successful when the DR ceases to energize the test load within the timing requirements of IEEE Std 1547 after switch S3 is opened.

If any of these tests results in islanding for longer than the specified time, the unit fails the test.

The actual trip time for each test shall be recorded.

A single failure of any of these tests is considered a failure of the entire test sequence.

5.7.1.5 Comments

An area EPS source means any source capable of maintaining an island within the recommended voltage and frequency window. An engine-generator with voltage and frequency control and without islanding protection can be considered an area EPS source for the purpose of this test. However, because of the uncertainty associated with the need to sink both real and reactive power from the DR, this test can be performed most conveniently with an area EPS connection, rather than a simulated area EPS.

Harmonic currents flow between the area EPS, the capacitor, and the DR, complicating the situation by making it appear that current is flowing when the fundamental frequency component of current has been reduced to zero. Thus it is important, when adjusting inductive and capacitive reactance, to use instruments that can display only the fundamental frequency component of current and power.

It is often advantageous to adjust the inductance first because that measurement is low in harmonics. The capacitance is added second so that the voltage is stable when the resistance is added. The resistive parallel load is then added and adjusted. Note that this resistance will be in addition to the resistance that will inherently be part of the inductive load.

The maximum recorded trip times may prove useful in area EPS system protection coordination studies and should be presented with other EUT product literature.

5.7.2 Unintentional islanding test for synchronous generators

5.7.2.1 Purpose

The purpose of this test is to verify that a DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 when an unintentional island condition is present. This test is for applications where synchronous generators are connected to the EPS. This test determines the trip time for the test conditions specified in 5.7.2.

5.7.2.2 Procedure

a) For a single-phase EUT, the test circuit shall be configured as shown in Figure 3. For a three-phase EUT, the balanced load circuit shown in Figure 3 is to be applied between each phase to neutral for a four-wire configuration or between phases for a three-wire configuration. Switch S1, as shown in Figure 3, shall be gang-operated and three-pole. The grounding of the load and simulated area EPS side of the EUT shall be unaffected by the position of switch S1.

b) Connect the EUT according to the instructions and specifications provided by the manufacturer.

c) Set all source parameters to the nominal operating conditions for the EUT.

d) Set the islanding load circuit in Figure 3 to a real load of 5% (or minimum load as specified by the manufacturer) and unity 1.0 p.f.

e) Record all applicable settings.

f) Adjust the output of the synchronous generator to match the test load in power and p.f. until the fundamental frequency current through switch S1 is less than 2% of the rated current of the unit under test on a steady-state basis in each phase.

   NOTE—Certain anti-islanding algorithms will sufficiently perturb the fundamental frequency current through switch S1 so that the 2% limit cannot be achieved on a continuous basis. Averaging of the rms current over a number of cycles in a manner that captures the quiescent magnitude of this current shall be utilized for determination of matched load during this quiescent period.[26]

g) Open switch S1 and record the time between the opening of switch S1 and when the EUT ceases to energize the load.

h) Repeat test four times for a total of five times.

i) Repeat steps d) through h) for the following combinations:

   — Maximum real load at unity p.f.

   — Maximum real load at rated p.f. lagging

   — Maximum real load at rated p.f. leading

5.7.2.3 Requirements

The test and measurement equipment shall record each phase current and each phase-to-neutral or phase-to-phase voltage, as appropriate; to determine fundamental frequency real and reactive power flow over the duration of the test. Anti-aliasing filters and sampling frequencies appropriate to the measurement of the fundamental frequency component shall be applied. The minimum measurement accuracy shall be 1% of rated EUT nominal output voltage and 1% of rated EUT output current.

[26] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

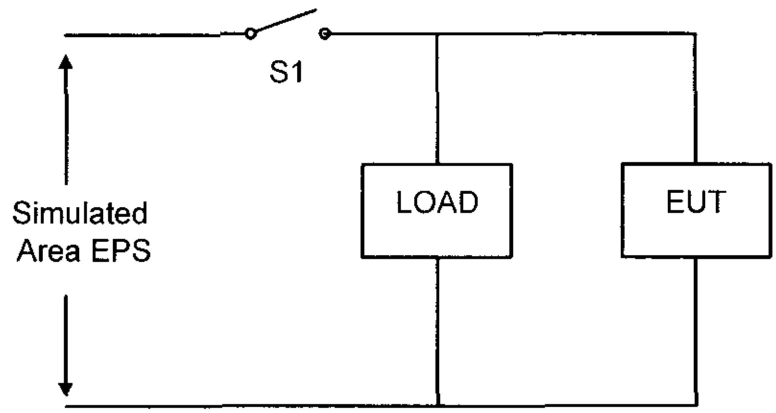

Figure 3—Unintentional islanding test configuration for synchronous generators

5.7.2.4 Criteria

A test is successful when the DR ceases to energize the test load within the timing requirements of IEEE Std 1547 after switch S1 is opened.

If any of these tests results in islanding for longer than the specified time, the unit fails the test.

The actual trip time for each test shall be recorded.

A single failure of any of these tests is considered a failure of the entire test sequence.

5.7.2.5 Comments

An area EPS source means any source capable of maintaining an island within the recommended voltage and frequency window. An engine-generator with voltage and frequency control and without islanding protection can be considered an area EPS source for the purpose of this test. However, because of the uncertainty associated with the need to sink both real and reactive power from the DR, this test can be performed most conveniently with an area EPS connection, rather than a simulated area EPS.

The maximum recorded trip times may prove useful in area EPS system protection coordination studies and should be presented with other EUT product literature.

A grid intertied synchronous generator will typically regulate real power (in kilowatts) irrespective of grid frequency, and it will regulate reactive power (in kilovars) or p.f. regardless of voltage level on the grid. The control systems inherent in synchronous machines may possibly maintain an unintentional island, but this condition depends on the load applied being closely matched to the synchronous generator output.

Note also that the change in kilowatts requires a change in the fuel rate to the engine, and the change in the kilovar load requires a change in the excitation rate in the synchronous generator. Because the excitation rate can be changed much faster than the fuel rate, the protection scheme for unintentional island detection should consider the characteristics required for proper operation in compliance with the requirements of IEEE Std 1547.

The synchronous machine can maintain ac output when islanded, but the frequency of the output is not related to the inductive and capacitive nature of the loads on the machine as it is in some inverter-based machines. Furthermore, the test load of Figure 3 needs reactive elements to achieve the p.f.s as required for step i) of the procedure in 5.7.2.2. Consequently, the testing procedure for unintentional island testing for synchronous machines is different from the procedure for other DR equipment.

It is possible that the synchronous machine may operate differently at one of its control limits from the way it operates at others. The test procedure for synchronous machines verifies that the unintentional islanding protection of the synchronous machine is effective over the operating range of the equipment for both the fuel and the excitation control.

5.8 Reverse power (for unintentional islanding)

IEEE Std 1547 requires DR units to cease to energize the area EPS during unintentional islanding conditions. One of the ways in which this requirement may be met is with reverse-power protection. The DR installation may contain reverse or minimum import power-flow protection, sensed between the point of DR connection and the PCC, which will disconnect or isolate the DR if power flow from the area EPS to the local EPS reverses or falls below a set threshold.

5.8.1 Reverse-power magnitude test

5.8.1.1 Purpose

This test is performed to characterize the accuracy of the reverse-power protection magnitude setting(s) of the EUT. The reverse-power protection accuracy of the EUT shall be specified prior to beginning the tests.

5.8.1.2 Procedures

a) Connect EUT according to the instructions and specifications provided by the manufacturer.

b) Set the source and DR voltages and the DR current(s) to the nominal operating conditions for the EUT.

c) Set (or verify) all EUT parameters to the nominal operating settings (refer to Appendix A for additional detail).

d) Record applicable settings.

e) Referring to the reverse-power magnitude test described in Annex A, adjust the current to starting point I_b. Initiate a phase-angle step function from 0° to 180°. The current shall be held at this magnitude and phase angle for period t_h.[27] At the end of this period, initiate the current ramp function.

f) Record the current magnitude when the EUT trips.[28]

g) Return the current to nominal magnitude I_N and phase angle $\theta = 0°$ (and reset the EUT as necessary).

h) Repeat steps e) through g) four times for a total of five tests.

i) For multiphase systems, repeat steps e) through h) for each phase individually and all phases simultaneously.

5.8.1.3 Criteria

The EUT is expected to trip within the specified accuracy for all tests. The test results may be used to characterize or verify the protection level accuracy relative to manufacturer specifications, interconnection standards, periodic verification of calibration, and so on.

[27] See Footnote 8.

[28] Because the source voltage is 1.0 per unit and the phase relationship between the source voltage and current is 180°, the reverse-power trip magnitude will be directly proportional to the current magnitude at the trip point.

5.8.2 Reverse-power time test

5.8.2.1 Purpose

This test is performed to characterize the accuracy of the reverse-power time-delay setting(s) of the EUT. The reverse-power protection time-delay accuracy of the EUT shall be specified prior to beginning the tests.

5.8.2.2 Procedures

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set the source and DR voltages and the DR current(s) to the nominal operating conditions for the EUT.
c) Set (or verify) all EUT parameters to the nominal operating settings (refer to Annex A for additional detail).
d) Record applicable settings.
e) Referring to the reverse-power time test described in Annex A, adjust the current to starting point I_b. Initiate a phase-angle step function from 0° to 180°. The current shall be held at this magnitude and phase angle for period t_h.[29] At the end of this period, initiate the current step function.
f) Record the time between the initiation of the step function and the occurrence of the EUT's expected response.
g) Return the current to nominal magnitude I_N and phase angle $\theta = 0°$ (and reset the EUT as necessary).
h) Repeat steps e) through g) four times for a total of five tests.
i) For multiphase systems, repeat steps e) through h) for each phase individually and all phases simultaneously.

5.8.2.3 Criteria

The EUT is expected to respond within the specified accuracy for all tests. The test results may be used to characterize or verify the protection level accuracy relative to manufacturer specifications, interconnection standards, periodic verification of calibration, and so on.

5.9 Open phase[30]

5.9.1 Purpose

The purpose of this test is to verify that the ICS ceases to energize the area EPS upon loss of an individual phase at the PCC or at the point of DR connection.

5.9.2 Procedure

Single-phase two-wire ICSs shall be subjected to steps a) through e) only. Multiphase and single-phase three-wire ICSs shall be subjected to steps a) through f). If the EUT requires the use of an isolation transformer, it will be tested with the isolation transformer.

a) Connect the EUT in accordance with the instructions and specifications provided by the manufacturer through individual phase conductor disconnects on each ungrounded phase to a simulated area EPS.
b) Set DR and simulated area EPS source parameters to the nominal operating conditions for the EUT.

[29] See Footnote 8.

[30] This test is intended to demonstrate compliance with the individual phase requirement of the cease-to-energize functionality test of IEEE Std 1547. It is noted that loss of a phase is a common area EPS occurrence.

c) Open one phase conductor disconnect while the EUT is operating at the greater of
   — 5% of rated output current or
   — The EUT's minimum output current.
d) Record the clearing time.
e) Repeat steps c) through d) four times for a total of five tests.[31]
f) Repeat steps c) through e) for all remaining phase conductor disconnects.

5.9.3 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.9.4 Criteria

After the disconnect is opened, the EUT shall cease to energize all output terminals connected to the simulated area EPS within the timing requirement of IEEE Std 1547 for unintentional islanding.

5.9.5 Comments

CAUTION

With multiphase EUT, it is advisable to predetermine if opening one phase at a time could cause a ferroresonant overvoltage. Where the EUT is connected to the simulated area EPS through an isolation transformer, opening one or two phases between the transformer and the simulated area EPS, and the subsequent cease-to-energize response by the EUT, will result in the transformer being energized by only one or two phases, one of several necessary conditions for ferroresonance. Ferroresonant overvoltages can be several times greater than nominal voltage and should be avoided.

5.10 Reconnect following abnormal condition disconnect

5.10.1 Purpose

The purpose of this test is to verify the functionality of the DR interconnection component or system reconnect timer, which delays the DR reconnection to the area EPS following a trip event.

5.10.2 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer to a simulated area EPS. Set all input source parameters and EPS parameters to the nominal operating conditions for the EUT.
b) With the EUT operating inside the normal EPS voltage and frequency operating range of the unit, step-change the simulated area EPS voltage to 5% beyond one of the voltage trip limits.[32] Confirm that the EUT ceases to energize the simulated area EPS.
c) Adjust the voltage so that it is beyond the reconnect voltage by twice the manufacturer's stated tolerance. The simulated area EPS voltage source shall maintain the abnormal voltage for two times the reconnect time delay. Verify that the EUT does not reenergize the simulated area EPS.

[31]The reconnect time may be adjusted for testing convenience. The reconnect time test is given in 5.10.

[32]A voltage trip was picked for illustration. The protective functions listed in step h) can be tested in any order.

d) Step-change or change the voltage to be within 1 s, back into the product's nominal operating voltage range. Measure the reconnect time between when nominal operating voltage is restored and when the product initiates the exportation of current.

e) The EUT shall not reconnect to the simulated area EPS source for at least the manufacturer's reconnect time delay within the manufacturer's stated tolerance.

f) The EUT shall not reconnect to the simulated area EPS source unless the area EPS voltage and frequency have been restored to the voltage and frequency ranges specified in IEEE Std 1547 and have remained within those ranges for the full specified reconnect time period.

g) To verify that the timer resets for additional voltage excursions within the reconnect time, retest with an abnormal voltage step-change event that is introduced during the reconnect countdown period. While the unit is counting down to reconnect, step the voltage to a value 5% outside of the manufacturer's specified normal operating voltage for the trip time setting plus twice the manufacturer's stated timer accuracy, and then return to the normal operating voltage. The unit shall restart its reconnect timer and not reconnect until the grid voltage has been within the specified range for the specified reconnect time.

h) The tests shall be conducted to confirm that both voltage and frequency are within the requirements of IEEE Std 1547.

i) The tests shall be conducted for voltage and frequency, both over and under.

5.10.3 Requirements

If used, the simulated area EPS shall meet the requirements of 4.6.1. The measurement system shall meet the requirements of 4.6.2.

5.10.4 Criteria

The reconnect time delay shall meet the requirements of IEEE Std 1547 within the manufacturer's stated accuracy.

5.10.5 Comments

This test may be performed in conjunction with the overvoltage, undervoltage, overfrequency, and underfrequency tests.

5.11 Harmonics

The purpose of this test is to measure the individual current harmonics and total rated-current distortion (TRD) of the DR interconnection component or system under normal operating conditions. The results shall comply with the requirements of IEEE Std 1547. Self-excited induction generators shall be tested using the procedure for synchronous generators.

5.11.1 Harmonics test for inverters

This test is for an inverter-based ICS. If the EUT requires the use of an isolation transformer, it will be tested with the isolation transformer. The harmonics measurement point will be at the isolation transformer connection to the area EPS source.

A resistive load equal to the output power of the EUT may be placed between the EUT and the simulated area EPS.

5.11.1.1 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer to a simulated area EPS. Set all input source parameters and EPS parameters to the nominal operating conditions for the EUT.

b) Operate the EUT at 33% of output rated current.

c) With the EUT operating at normal operating temperature and inside the normal EPS voltage and frequency operating range of the unit, for each phase measure the individual current harmonics and output current TRD through the first 40 harmonics. When the EUT has a harmonic spectrum that is varying in time, the harmonic calculation shall use an averaging window of sufficient length to accurately represent the average level of harmonic current.

d) Repeat for an output load current I_L of 66% and at a level as close to 100% of the rated output current as practical. Operating power levels in this procedure have a tolerance of ± 5%.

5.11.1.2 Requirements

The measurement equipment shall be capable of capturing and processing the data in a manner to ensure that the results are representative of the average TRD over a period of time that is a multiple of any periodic or repetitive output waveform transient.

The DR shall be operated in parallel with a predominantly inductive voltage source with a short-circuit current capacity I_{SC} of not less than 20 times the DR rated output current at fundamental frequency as specified in IEEE Std 1547.

When an EUT's input power source voltage and frequency parameters affect the output power quality, the tests are to be performed with the least favorable input parameters.

The simulated area EPS shall not exhibit dependence upon the product being tested or use algorithms to cancel or correct the simulated area EPS waveform in response to the harmonics generated by the product being tested.

5.11.1.3 Criteria

The individual current harmonics and TRD shall not exceed the limits specified in IEEE Std 1547.

For multiphase EUT, each of the phases shall comply with the specified limits.

5.11.1.4 Comments

Steps may be necessary to ensure that measured harmonics exceeding the allowable levels in IEEE Std 1547 are not caused by characteristics of the simulated area EPS.

5.11.2 Harmonics test for synchronous generators

Synchronous generator harmonics can be verified either by the voltage harmonics test presented in this subclause or by the current harmonics test in 5.11.3.

5.11.2.1 Procedure

a) Connect the synchronous generator EUT to a rotating source capable of operating the machine at a steady-state frequency within ± 0.25% of nominal conditions. Set the voltage and frequency to the nominal operating levels for the facility under question.

b) Connect a resistive load bank to the synchronous generator. Verify that the load bank provides a balanced resistive load to the synchronous generator. The load bank shall be capable of operating continuously at the full load rating of the EUT.

c) With the EUT operating at nominal voltage and frequency and at full load, for each phase measure the individual voltage harmonics through the first 40 harmonics. If the EUT has a harmonic spectrum that is varying in time, the harmonic calculation shall use an averaging window of sufficient length to accurately represent the average level of harmonic voltage.

d) Measure harmonics from line to neutral on machines operated as three-phase/four-wire sources and line to line for machines operated as three-phase/three-wire sources.

5.11.2.2 Requirements

The measurement equipment shall be capable of capturing and processing the data in a manner to ensure that the results are representative of the average THD over a period of time that is a multiple of any periodic or repetitive output waveform transient.

5.11.2.3 Criteria

The test shall demonstrate that the individual harmonic voltage levels and the total harmonic voltage produced by the generator set are within the requirements of IEEE Std 1547.

5.11.2.4 Comments

The synchronous generator is tested at 100% of the full load rating because this is considered the worse-case condition.

5.11.3 Harmonics test for induction generators

5.11.3.1 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer to a simulated area EPS. Set all input source parameters and EPS parameters to the nominal operating conditions for the EUT.

b) Operate the EUT at 100% of the rated output current.

c) With the EUT operating at nominal voltage and frequency and at full load, for each phase measure the individual current harmonics and output current TRD through the first 40 harmonics. When the EUT has a harmonic spectrum that is varying in time, the harmonic calculation shall use an averaging window of sufficient length to accurately represent the average level of harmonic current.

5.11.3.2 Requirements

The measurement equipment shall be capable of capturing and processing the data in a manner to ensure that the results are representative of the average TRD over a period of time that is a multiple of any periodic or repetitive output waveform transient.

The DR shall be operated in parallel with a predominantly inductive voltage source with a short-circuit current capacity I_{SC} of not less than 20 times the DR rated output current at fundamental frequency.

The simulated area EPS shall not exhibit dependence upon the product being tested or use algorithms to cancel or correct the simulated area EPS waveform in response to the harmonics generated by the product being tested.

5.11.3.3 Criteria

The individual current harmonics and TRD shall not exceed the limits specified in IEEE Std 1547.

For a multiphase unit, each of the phases shall comply with the specified limits.

5.11.3.4 Comments

Steps may be necessary to ensure that measured harmonics exceeding the allowable levels in IEEE Std 1547 are not caused by characteristics of the simulated area EPS.

A resistive load equal to the output power of the EUT may be placed between the EUT and the simulated area EPS.

The induction generator is tested at 100% of the full load rating because this is considered the worse-case condition.

5.12 Flicker

Given the site dependence of flicker, there are no type tests available to determine if a given DR will meet the flicker requirements. The synchronization test procedure provided in 5.4.3 is intended to characterize the maximum current flow to or from the DR under a nonfaulted condition. The results of that test can be used, along with local line impedance information, to determine if a DR might present a flicker nuisance (i.e., in a "flicker calc"). Mitigating action must be taken if measurements show that DR-induced voltage fluctuations exceed those allowed in IEEE Std 1547.

6. Production tests

Production tests verify the operability of every unit of interconnect equipment manufactured for customer use. These tests assume that the equipment has met the applicable requirements of Clause 5 and may be conducted as a factory test or performed as part of a commissioning test. Tests are performed to verify manufacturers' settings rather than specific requirements in IEEE Std 1547 since that standard allows adjustability of set points and it is of value to have the unit factory set and tested at specific settings. If any tests from Clause 5 have not been previously completed, they may be included in the production test regimen.

For any of the tests to be conducted in this clause, function settings need be recorded only once. The report shall provide a list of final settings.

At the discretion of the manufacturers, production tests may use the corresponding tests from Clause 5 in place of the procedures listed in this clause.

For the purposes of this standard, multiphase ICSs include single-phase three-wire ICSs.

ICSs with adjustable set points shall be tested at a single set of set points as specified by the manufacturer. Production tests shall include the following as applicable:

- Response to abnormal voltage (see 6.1)
- Response to abnormal frequency (see 6.2)
- Synchronization (see 6.3)

6.1 Response to abnormal voltage

6.1.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system responds to abnormal voltage conditions as required. Trip setting shall be as specified by the manufacturer.

6.1.2 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Verify all simulated area EPS parameters are at nominal operating conditions for the EUT.

c) Set the EUT to the manufacturer's trip voltage and time settings as applicable. Verify that all of the other EUT settings are at their factory set points.

d) Record applicable settings.

e) Select one of the undervoltage or overvoltage protective functions for test.[33]

f) Adjust the voltage to a point at least twice the manufacturer's stated accuracy outside the abnormal voltage trip setting.[34] Record the rms voltage magnitude and trip time.

g) For multiphase units perform this test on each phase, adjusting one phase at a time.

h) Repeat steps e) through g) for all of the undervoltage and overvoltage protective functions.

6.1.3 Criteria

The test results are acceptable if the EUT trips in the ranges specified by the manufacturer.

6.2 Response to abnormal frequency

6.2.1 Purpose

The purpose of this test is to verify that the DR interconnection component or system responds to abnormal frequency conditions as required. Trip setting shall be as specified by the manufacturer.

6.2.2 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Verify all simulated area EPS parameters are at nominal operating conditions for the EUT.

c) Set the EUT to the manufacturer's trip frequency and time settings as applicable. Verify that all of the other EUT settings are at their factory set points.

d) Record applicable settings.

e) Select one of the underfrequency or overfrequency protective functions for test.[35]

f) Adjust the frequency to a point at least twice the manufacturer's stated accuracy outside the abnormal frequency trip setting.[36] Record the frequency and trip time.

g) Repeat steps e) through f) for all of the underfrequency and overfrequency protective functions.

[33]The EUT may have one or more undervoltage protective functions and/or one or more overvoltage protective functions.

[34]The test shall be designed so that the EUT trips due to the selected abnormal voltage protective function and not due to another protective function of the EUT. The test design should include selection of appropriate voltage level. The trip magnitude and time settings may be verified using a single test waveform in one test or using different test waveforms in two separate tests.

[35]The EUT may have one or more underfrequency protective functions and/or one or more overfrequency protective functions.

[36]The test shall be designed so that the EUT trips due to the selected abnormal frequency protective function and not due to another protective function of the EUT. The test design should include selection of appropriate frequency level. The trip magnitude and time settings may be verified using a single test waveform in one test or using different test waveforms in two separate tests.

6.2.3 Criteria

The test results are acceptable if the EUT trips in the ranges specified by the manufacturer.

6.3 Synchronization

The purpose of this test is to verify that the DR interconnection component or system will connect the DR only when the voltage, frequency, and phase-angle differences are acceptable or will not induce flicker on the area EPS. Equipment that is using the startup (in-rush) current method is exempt from this production test. Two procedures are offered: one for equipment that does not include provisions for switching off the synchronizing function and another for equipment that can be manipulated to control the synchronization process.

Settings shall be as specified by the manufacturer and shall be within the requirements of IEEE Std 1547.

6.3.1 Synchronization production test

6.3.1.1 Procedure

a) Install and adjust the EUT per the manufacturer's recommendations and specifications.
b) Connect the test equipment to monitor the paralleling device close command, the phase-angle relationship between EUT output and area EPS sources, the frequency difference, and voltage difference.
c) Set the simulated area EPS source to operate at nominal voltage and frequency. Record applicable settings.
d) Verify that the EUT is operating properly when connected to the simulated area EPS.
e) Disconnect the area EPS from the EUT.
f) Enable all monitoring equipment. Reapply the area EPS and record all required parameters (i.e., voltage, frequency, and phase-angle differences) during the paralleling operation.

6.3.1.2 Criteria

The test results are acceptable if the EUT operates in the ranges specified by the manufacturer and within the requirements of IEEE Std 1547.

6.3.2 Optional test for equipment with synchronizing disable function

6.3.2.1 Procedure

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.
b) Set the parameters of the two sources to nominal operating conditions, but with the voltage and frequency differences outside of the acceptable range for synchronism.
c) Set the voltage difference, frequency difference, and phase-angle difference of the EUT as specified by the manufacturer. Verify that all of the other EUT settings are at their factory set points.
d) Record applicable settings.
e) Verify synchronizing performance with respect to frequency difference
    1) Adjust the voltage difference of the sources to within the acceptable range for synchronism.
    2) Adjust the frequency difference to a point at least twice the manufacturer's stated accuracy outside the acceptable frequency difference.
    3) Wait for at least two passes through synchronism.

4) Step the frequency difference to a point at least twice the manufacturer's stated accuracy within the acceptable range for synchronism.

5) Record the voltage, frequency, and phase-angle differences at the time of DR connection (for complete interconnect systems) or at the initiation of the EUT output device signal (for ICS components).

f) Set the parameters of the two sources to nominal operating conditions, but with the voltage and frequency differences outside of the acceptable range for synchronism.

g) Verify synchronizing performance with respect to voltage difference

1) Adjust frequency difference of the sources to within the acceptable range for synchronism.

2) Adjust the voltage difference to a point at least twice the manufacturer's stated accuracy outside the acceptable voltage difference. Wait for two passes through synchronism.

3) Step the voltage to a point at least twice the manufacturer's stated accuracy within the acceptable range for synchronism.

4) Record the voltage, frequency, and phase-angle differences at the time of DR connection (for complete interconnect systems) or at the initiation of the EUT output device signal (for ICS components).

6.3.2.2 Criteria

The test results are acceptable if the EUT operates in the ranges specified by the manufacturer and within the requirements of IEEE Std 1547.

6.4 Documentation

The production test documentation shall include the manufacturer's model number, serial number, functional software and firmware versions (where applicable), testing date, test settings, manufacturer's stated accuracies, and production test results. This information shall be provided with the equipment.

7. Commissioning test

7.1 General

The commissioning test shall be conducted after the ICS is installed and is ready for operation. An individual qualified in testing protective equipment (e.g., professional engineer, factory-certified technician, licensed electrician with experience in testing protective equipment) should perform or directly supervise commissioning tests. Where the operation of the ICS is integrated with and dependent upon the operation of the area EPS, the commissioning test should be coordinated with and agreed to by the area EPS operator. The area EPS operator may require that he or she witness the commissioning test as described in this clause or may require documentation from the equipment owner describing which tests were performed and their results.

A commissioning test report shall be produced and shall contain the results of all tests and a listing of the final ICS settings. Once complete and accepted, the commissioning test will not have to be repeated.

For the purposes of this standard, multiphase ICSs include single-phase three-wire ICSs.

7.1.1 Purpose

The commissioning test shall be performed to verify that the completed and installed ICS meets the requirements of IEEE Std 1547.

7.1.2 Procedure

All tests shall be performed based on written procedures. Test procedures are commonly provided by equipment manufacturers or system integrators and approved by the equipment owner and area EPS operator. The written commissioning test procedure shall include the following:

- Verification and inspections (see 7.2)
- Field-conducted type and production tests (see 7.3)
- Unintentional islanding functionality test (see 7.4)
- Cease-to-energize functionality test (see 7.5)
- Revised settings (see 7.6)

7.2 Verifications and inspections

a) Confirm that the equipment and its installation comply with the interconnection installation evaluation in IEEE Std 1547.

b) Record applicable settings.

c) Visually inspect system grounding implementation according to the requirements of IEEE Std 1547.

d) Visually inspect and verify operability of isolation device, if required.

e) Verify that polarities, burdens, and ratios of field-wired CTs and VTs are correct and in accordance with the design.

f) Through visual inspection, continuity test, or insulation resistance test, verify that field-installed power and control wiring is in compliance with drawings and manufacturer requirements.

g) Interconnection protective devices that have not previously been tested as part of the ICS with their associated interrupting devices (e.g., contactor or circuit breaker) shall be tested to verify that the associated interrupting devices open when the protective devices operate. Interlocking circuits between protective and interrupting devices shall be similarly tested unless they have been tested during production tests.

h) On three-phase systems, check the phase rotation of both area EPS and DR and verify that they are compatible as installed.

i) Verify functionality of all monitoring provisions required by IEEE Std 1547.

7.3 Field-conducted type and production tests

Determine which type and production tests as required in Clause 5 and Clause 6 have not been conducted and if any type testing is required due to changes in software, firmware, or hardware. Conduct these tests in accordance with the procedures given in Clause 5 and Clause 6.

7.4 Unintentional islanding functionality test

7.4.1 Reverse-power or minimum power test

If a reverse-power or minimum power function is used as a method to prevent unintentional islanding, it shall be tested by signal injection test methods, by adjusting the DR output and local loads, or by other suitable methods to verify that the function is met and that the DR ceases to energize.

7.4.2 Non-islanding functionality test

An ICS certified to 5.7 is considered non-islanding and need be tested only to 7.5.

Figure A.2 is a graphical representation of a ramp function used for a high-magnitude parameter test of the PUT (e.g., overvoltage, overfrequency). In the figure, p represents the magnitude of the PUT, t represents time, P_N is the nominal condition of the PUT, P_T is the trip magnitude of the PUT, t_0 is the start time of the ramp, and t_s is the start of the hold time[40] t_h for the test signal at starting point P_b.

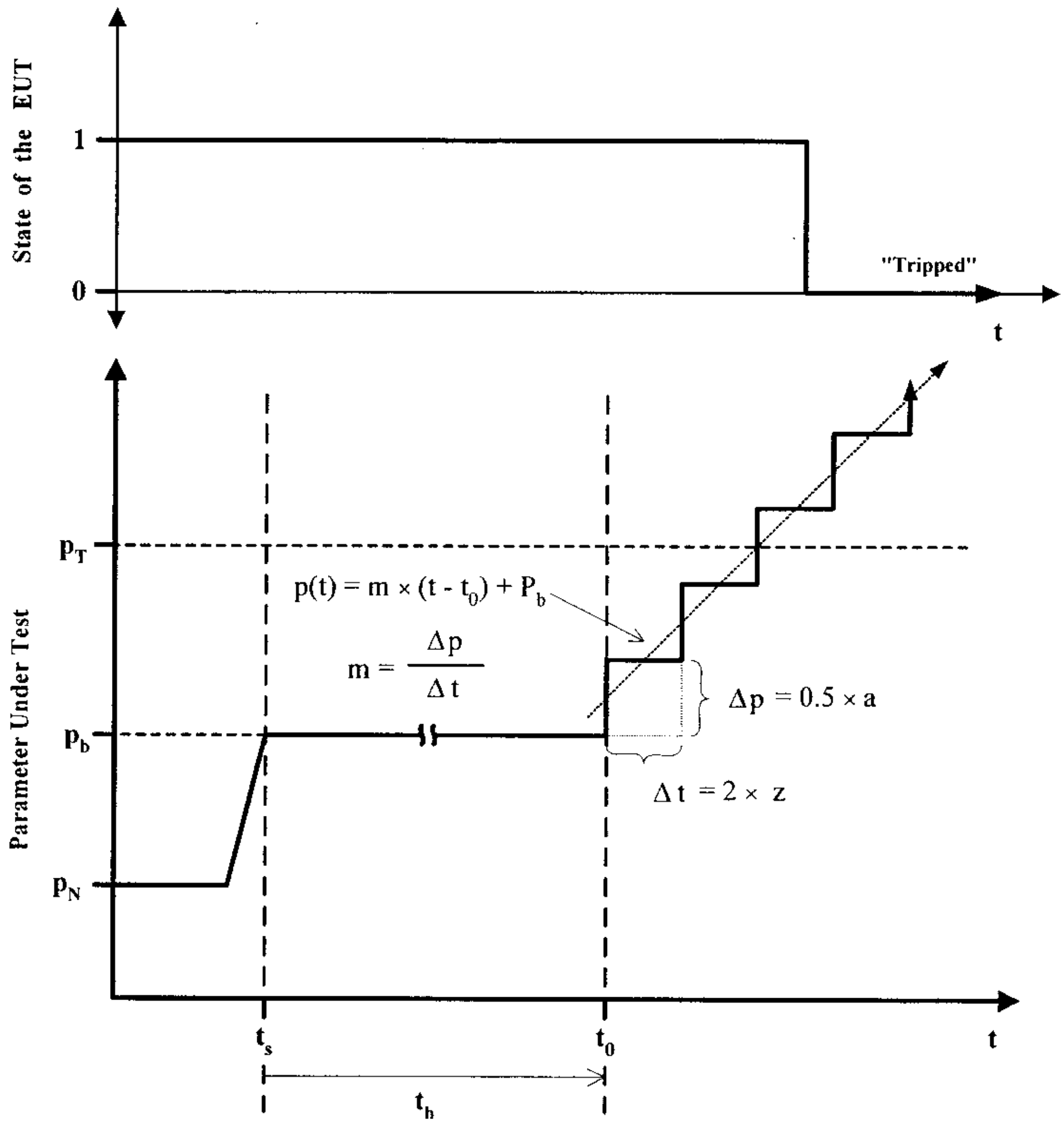

Figure A.2—Graphical representation of magnitude test using ramp function for PUT

When the ramp function conflicts with a design characteristic or settings of the EUT, an alternative method that is agreeable to the manufacturer and the testing agency may be used.

[40]The hold time t_h is at least two times the time-delay setting of the PUT. This number may be adjusted to avoid conflict with other trip points.

14 AC Output Connections

Section 14 effective November 7, 2000

14.1 Stand-alone inverters

14.1.1 The ac output of a stand-alone inverter shall be provided with (a) or (b), or both:

a) Receptacles which comply with 14.1.2.

b) Provision for connection of a fixed wiring system in accordance with Supply Connections, Section 16.

14.1.2 An inverter provided with an ac output receptacle shall comply with the following:

a) The receptacle shall be of the grounding type,

b) The ac output conductor that is connected to the white or silver terminal of the receptacle shall be bonded to ground in accordance with 19.1, 19.3, and 19.5,

c) An equipment-grounding connection as described in Equipment Grounding, Section 18, shall be provided. Grounding of the receptacle shall not rely on mounting means only. The ground terminal provided as part of the receptacle shall be employed, and

d) Receptacles installed in raised covers shall not be secured solely by a single screw.

14.1.3 A ground-fault circuit-interrupter shall comply with the Standard for Ground-Fault Circuit-Interrupters, UL 943.

14.2 Utility-interactive inverters

14.2.1 A utility-interactive inverter shall have provision for connection of a wiring system complying with Supply Connections, Section 16.

14.2.2 A general-use ac output receptacle shall not be provided on a utility-interactive inverter unless it is internal to the unit and accessible for service personnel use only.

14.2.3 An inverter with an ac output shall comply with the following:

a) The installation instructions shall comply with 65.2, and

b) The output circuit shall not be bonded to the enclosure. See also 19.2.

15 Receptacles

15.1 A general-use receptacle in an inverter shall be of the grounding type.

15.1 effective November 7, 2000

15.2 A receptacle supplied from the output ac circuit of an inverter shall comply with the following:

a) The white or silver terminal of the receptacle shall be grounded, see AC Output Circuit Grounded Conductor, Section 19,

b) The equipment-grounding terminal of the receptacle shall be conductively connected to the equipment-grounding means in accordance with Internal Bonding for Grounding, Section 20, and

c) A receptacle installed in a raised cover shall be in accordance with Section 410.56(i) of the National Electrical Code, ANSI/NFPA 70.

15.2 revised January 17, 2001

16 Supply Connections

16.1 General

16.1.1 A unit shall have provision for connection of a wiring system consisting of:

a) Wiring terminals as specified in 16.1.3 – 16.2.10 or wiring leads as specified in 16.1.3 and 16.3.1 – 16.3.6, and

b) A means for connection of cable or conduit as specified in 16.5.1.

Exception No. 1: The requirements described in 16.1.3 – 16.4.3 do not apply to the means for connection to isolated accessible signal circuits complying with the requirements specified in Isolated Accessible Signal Circuits, Section 28.

Exception No. 2: This requirement does not apply to ac output power circuit of an inverter consisting of receptacles complying with the requirements specified in Receptacles, Section 15.

16.1.1 effective November 7, 2000

16.1.2 The requirement in 16.1.1 applies to the wiring connection means for ac and dc input and output power circuits of a unit intended to be made in the field when the unit is installed.

16.1.2 effective November 7, 2000

16.1.3 A wiring terminal or lead shall be rated and sized for connection to a field wiring conductor having an ampacity based on Table 310.16 of the National Electrical Code, ANSI/NFPA 70, of no less than 125 percent of the RMS or dc current that the circuit carries during rated conditions. For determining the appropriate column in Table 310.16, see 66.4 (L) and (M).

16.1.3 revised January 17, 2001

16.2 Wiring terminals

Section 16.2 effective November 7, 2000

16.2.1 A wiring terminal shall comply with the requirement in 16.1.3 for a wire of each metal for which it is marked. See 63.11.

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16.2.2 A wiring terminal shall be provided with a factory-installed pressure terminal connector that is securely fastened in place – for example, firmly bolted or held by a screw.

Exception No. 1: A field-installed pressure terminal connector in accordance with 16.2.4 meets the intent of this requirement.

Exception No. 2: A wire-binding screw employed at a wiring terminal intended for connection of a No. 10 AWG (5.3 mm^2) or smaller conductor and having upturned lugs, a cupped washer, or the equivalent to hold the wire in position meets the intent of this requirement.

16.2.3 A wiring terminal shall be secured in position, by a means other than friction between surfaces, so that it does not turn or shift. This is able to be accomplished by two screws or rivets; by square shoulders or mortises; by a dowel pin, lug, or offset; by a connecting strap or clip fitted into an adjacent part; or by an equivalent method.

Exception: A pressure terminal connector used in accordance with 16.2.4 is able to turn when the spacing complies with Spacings, Section 24, when the connector is oriented in the position resulting in the least spacing between adjacent terminals and also between terminals and dead metal parts.

16.2.4 With reference to Exception No. 1 to 16.2.2, a pressure terminal connector is not required to be factory installed when the conditions in (a) – (e) are met:

a) One or more component terminal assemblies shall be available from the unit manufacturer or others and specified in the instruction manual. See 66.4(B) and (C).

b) The fastening hardware such as a stud, nut, bolt, spring, or flat washer, and similar hardware, as required for an effective installation, shall be:

1) Provided as part of the terminal assembly,

2) Mounted on or separately packaged with the unit, or

3) Specified in the instruction manual.

c) The installation of the terminal assembly shall not involve the loosening or disassembly of parts other than a cover or other part giving access to the terminal location. The means for securing the terminal connector shall be readily accessible for tightening before and after installation of conductors.

d) When the pressure terminal connector provided in a terminal assembly requires the use of other than a common tool for securing the conductor, identification of the tool and any additional instructions shall be included in the assembly package or with the unit. See 66.4(D).

e) Installation of the pressure terminal connector in the intended manner shall result in a unit complying with the requirements of this Standard.

16.2.5 A terminal block or insulating base for support of a pressure terminal connector shall comply with the Standard for Terminal Blocks, UL 1059.

16.2.6 A wire-binding screw at a field-wiring terminal shall not be smaller than No. 10 (4.8 mm diameter).

Exception No. 1: A No. 8 (4.2 mm diameter) screw is usable at a terminal intended only for the connection of:

a) No. 14 AWG (2.1 mm^2) conductor, or

b) No. 16 or 18 AWG (1.3 or 0.82 mm^2) control-circuit conductor.

Exception No. 2: A No. 6 (3.5 mm diameter) screw is usable for the connection of a No. 16 or 18 AWG (1.3 or 0.82 mm^2) control-circuit conductor.

16.2.7 A wire-binding screw shall thread into metal.

16.2.8 A terminal plate tapped for a wire-binding screw shall be of metal not less than 1.27 mm (0.050 inch) thick.

Exception: A terminal plate of metal less than 1.27 mm (0.050 inch) thick complies where used in a low-voltage, limited-energy (LVLE) circuit or limited energy (LE) circuit (see 2.23 and 2.25) and the tapped threads are capable of withstanding the tightening torque specified in Table 16.1 without stripping.

Table 16.1
Tightening torque for wire-binding screws

Size of terminal screw, No.	(diameter, mm)	Wire sizes to be tested, AWG (mm^2)	Tightening torque Newton meters	(Pound-inch)
6	(3.5)	Stranded 16 – 18 (1.3 – 0.82)	1.4	(12)
8	(4.2)	Solid 14 (2.1) and Stranded 16 – 18	1.8	(16)
10	(4.8)	Solid 10 – 14 (4.8 – 2.1) and Stranded 16 – 18	2.3	(20)

16.2.9 There shall be two or more full threads in the metal of a terminal plate. The metal is to be extruded at the tapped hole to provide at least two full threads.

Exception: Two full threads are not required for a terminal in a low-voltage, limited-energy (LVLE) circuit or limited-energy (LE) circuit, see 2.23 and 2.25, when a lesser number of threads results in a secure connection in which the threads do not strip when subjected to the tightening torque specified in Table 16.1.

16.2.10 A terminal for connection of a grounded conductor of an ac circuit shall be identified as described in 63.15.

16.3 Wiring leads

Section 16.3 effective November 7, 2000

16.3.1 A field-wiring lead shall not be more than two wire sizes smaller than the copper conductor to which it is to be connected, and shall not be smaller than No. 18 AWG (0.82 mm^2). For example, a No. 10 AWG (5.3 mm^2) or larger field-wiring lead is required for connection to a No. 6 AWG (13.3 mm^2) field-provided conductor. A field-wiring lead shall not be less than 152.4 mm (6 inches) long.

Exception: A lead is able to be more than two wire sizes smaller than the field-provided copper conductor to which it is to be connected, and be not smaller than No. 18 AWG (0.82 mm^2), when more than one factory-provided copper lead is intended for connection to the same field-provided lead, and the construction complies with the following:

a) A wire connector for connection of the field-provided wire is factory-installed as part of the unit or remote-control assembly, and the wire connector is rated for the combination of wires that are to be spliced,

b) The factory-provided leads are bunched or otherwise arranged so that stress does not result on an individual lead, and

c) Instructions are provided in accordance with 66.4(E).

16.3.2 A field-wiring lead shall consist of general building wire, or of other wiring having an insulation of:

a) At least 0.8-mm (1/32-inch) thick thermoplastic material,

b) At least 0.4-mm (1/64-inch) thick rubber plus a braid cover for applications of 300 volts or less, or

c) At least 0.8-mm thick rubber plus a braid cover for applications between 301 and 600 volts.

16.3.3 A field-wiring lead shall comply with Strain Relief Test, Section 50.

16.3.4 A field-wiring lead provided for connection to an external line-voltage circuit shall not be connected to a wire-binding screw or pressure terminal connector located in the same compartment as the free end of the wiring lead unless the screw or connector is rendered unusable for field-wiring connection or:

a) The lead is insulated at the unconnected end, and

b) A marking is provided on the unit in accordance with 63.23.

16.3.5 The free end of a field-wiring lead that is not used in every installation, such as a lead for a tap of a multivoltage transformer, shall be insulated. For an equipment-grounding lead, see 18.1.7.

16.3.6 A field-wiring lead for connection of a grounded conductor of an ac circuit shall be identified as described in 63.15.

16.4 Wiring compartments

Section 16.4 effective November 7, 2000

16.4.1 A wiring compartment for a unit shall be located so that wire connections therein are accessible for inspection, without disturbing factory or field connected wiring, after the unit is installed in the intended manner.

16.4.2 A wiring compartment, raceway, or similar device, for routing and stowage of conductors connected in the field shall not contain rough, sharp, or moving parts that are capable of damaging conductor insulation.

16.4.3 A wiring compartment shall not have a volume less than specified in Table 16.2. The volume is to be determined in accordance with the Standard for Metallic Outlet Boxes, UL 514A, or the Standard for Nonmetallic Outlet Boxes, Flush-Device Boxes and Covers, UL 514C, as applicable. No compartment enclosure dimension shall be less than 19.1 mm (3/4 inch).

Table 16.2
Wiring compartment volume

Size of conductor,		Free space for each conductor	
AWG	(mm^2)	Cubic centimeter	(Cubic inches)
18	(0.82)	24.60	(1.50)
16	(1.3)	28.70	(1.75)
14	(2.1)	32.80	(2.00)
12	(3.3)	36.90	(2.25)
10	(5.3)	40.00	(2.50)
8	(8.4)	49.20	(3.00)
6	(13.3)	82.00	(5.00)

16.5 Openings for conduit or cable connection

Section 16.5 effective November 7, 2000

16.5.1 For a fixed unit, an opening or knockout complying with the requirements specified in 5.7.1 – 5.7.7 shall be provided for connection of conduit or a cable wiring system.

Exception: A unit complying with 5.7.6 is not required to be provided with an opening or a knockout.

A.2 Time test (step function)—general

The test signal described in this subclause is used to characterize the accuracy of the time-delay setting for relevant protection parameters.

Vary the PUT according to the magnitude step function defined herein. Only the PUT shall be varied. Therefore, all other parameters shall be held at nominal values. The time test signal shall take the form described in Equation (A.3).

$$p(t) = A \times u(t - t_i) + P_b \quad \text{(A.3)}$$

where

- p is the magnitude of the PUT,
- t is time (s),
- A is a scaling factor,[41]
- $u(t)$ is the unit step function,[42]
- P_b is the starting point of the step function (in units of the PUT).[43]

Figure A.3 is a graphical representation of the function used for a time test of the PUT. In the figure, p represents the magnitude of the PUT, t represents time, t_t is the trip time, P_N is the nominal condition for the PUT, P_T is the trip magnitude of the PUT, P_U is the final value of the step function, t_i is the start of the step function, t_0 is the start time used for calculating the trip time, t_r is the rise time of the test signal from $(t_0 - t_i)$,[44] and t_s is the start of the hold time[45] t_h for the test signal at starting point P_b.

When the step function conflicts with a design characteristic or settings of the EUT, an alternative method that is agreeable to the manufacturer and the testing agency may be used.

A.3 Reverse-power magnitude test (ramp function)

The test signal described in this subclause is used to characterize the accuracy of the reverse-power magnitude protection setting.

Vary the current test signals (i.e., magnitude and phase angle) according to the ramp function defined in this subclause. Only the current test signals shall be varied. Therefore, the voltage test signal shall be held at nominal values. The current test signal magnitude i and phase angle θ shall take the form described in Equation (A.4) and Equation (A.6).

$$i(t) = m(t - t_0) + I_b \quad \text{(A.4)}$$

where

- i is the current magnitude,
- m is the slope of the ramp function,
- t is time (s),

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[41] The scaling factor A shall be chosen so that P_U is at least 110% (90% for under value tests) of P_T. Exception: for frequency tests, the scaling factor A shall be chosen so that P_U is at least 101% (99% for under value tests) of P_T.

[42] $u = 0$ for $t < 0$ and $u = 1$ for $t > 0$

[43] See Footnote 39.

[44] The rise time t_r shall be less than the larger of 1 cycle or 1% of the time-delay setting of the PUT.

[45] See Footnote 40.

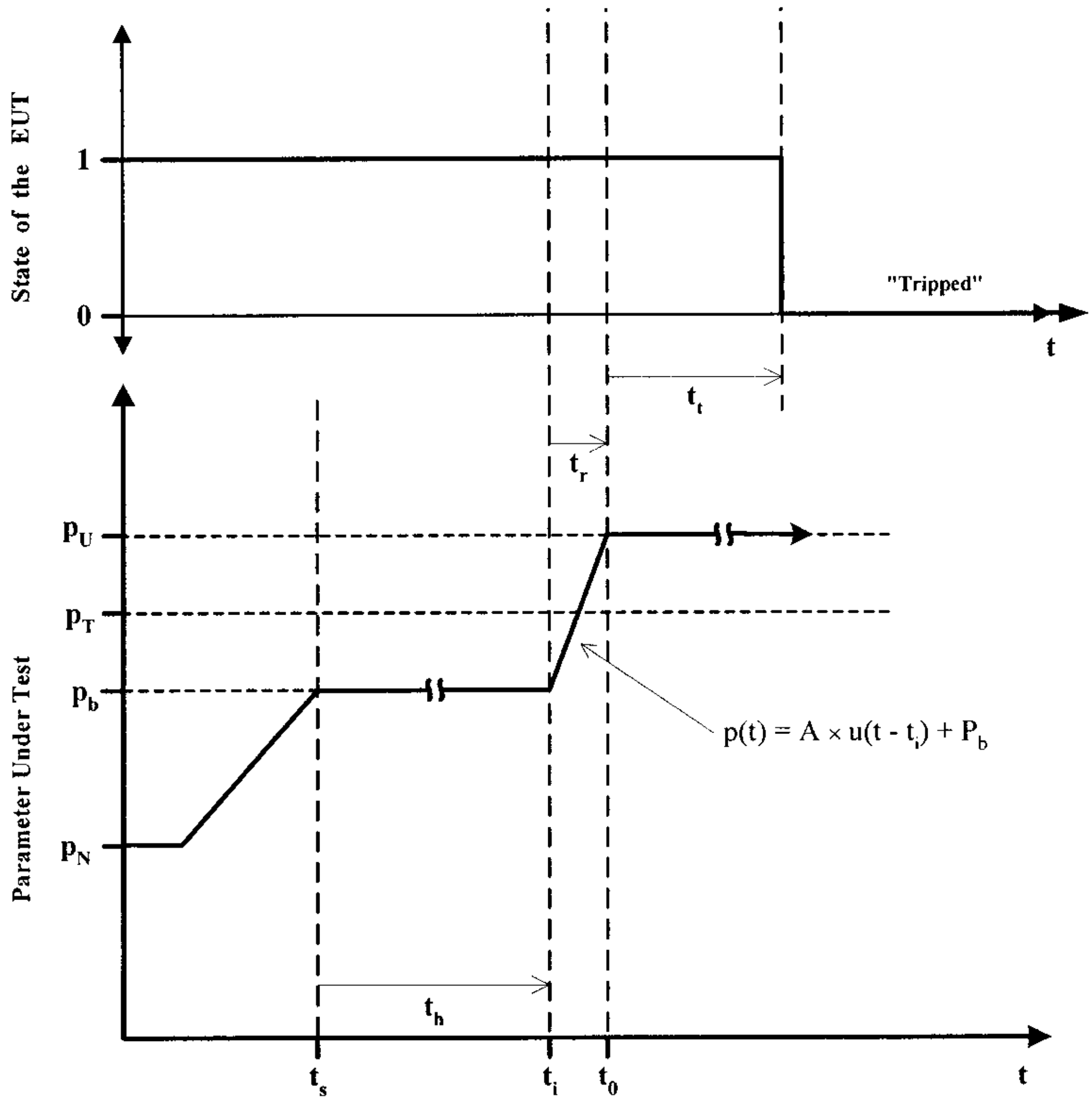

Figure A.3—Graphical representation of time test using step function for PUT

t_0 is the start time of the ramp,

I_b is the starting point of the ramp function.[46]

The slope m is defined by Equation (A.5).

$$m = \frac{(0.5 \times a)}{(2 \times z)} \tag{A.5}$$

where

z is the time-delay setting (s) for the reverse-power protection parameter plus the manufacturer's stated detection time (s),

a is the manufacturer's stated accuracy of the reverse-power protection parameter.

[46]The starting point I_b shall be within 10% of, but not exceed, the trip point magnitude. At low settings, I_b may be zero.

The current phase angle θ defined as the phase difference between the voltage and current test signals shall be varied according to Equation (A.6).

$$\theta(t) = -180 \times u(t - t_s) \tag{A.6}$$

where

θ is the current phase angle,

t_s is the time when the phase-angle change occurs,

t is time (s).

Figure A.4 is a graphical representation of a reverse-power magnitude test using the current magnitude ramp function coupled with a current phase-angle step function. In the figure, i represents the current magnitude, θ represents the phase angle of the current test signal, t represents time, I_N is the nominal current condition, I_T is the trip magnitude,[47] t_0 is the start time of the ramp, and t_s is the instant when the phase transition occurs and the hold time[48] t_h for the test signal starts at starting point I_b.

When the ramp function conflicts with a design characteristic or settings of the EUT, an alternative method that is agreeable to the manufacturer and the testing agency may be used.

A.4 Reverse-power time test (step function)

The test signal described in this subclause is used to characterize the accuracy of the time-delay setting for reverse-power protection parameter.

Vary the current test signals (i.e., magnitude and phase angle) according to the test function defined in this subclause. Therefore, the voltage test signal shall be held at nominal values. The current test signal magnitude i and phase angle θ shall take the form described in Equation (A.7) and Equation (A.8).

$$i = A \times u(t - t_i) + I_b \tag{A.7}$$

where

i is the current test signal magnitude,

t is time (s),

A is a scaling factor,[49]

I_b is the starting point of the step function.[50]

$$\theta(t) = -180 \times u(t - t_s) \tag{A.8}$$

where

θ is the current phase angle,

t_s is the time when the phase-angle change occurs,

t is time (s).

[47] For the reverse-power magnitude test, the reverse-power trip magnitude will be a function of the magnitude of the current test signal because the voltage magnitude is at nominal and the phase difference between the voltage and current test signals, θ, is 180°. Where the accuracy of the measurement is affected by p.f., design of the test regimen shall accommodate various power factors.

[48] See Footnote 40

[49] The scaling factor A shall be chosen so that I_u is at least 110% of I_T.

[50] See Footnote 39.

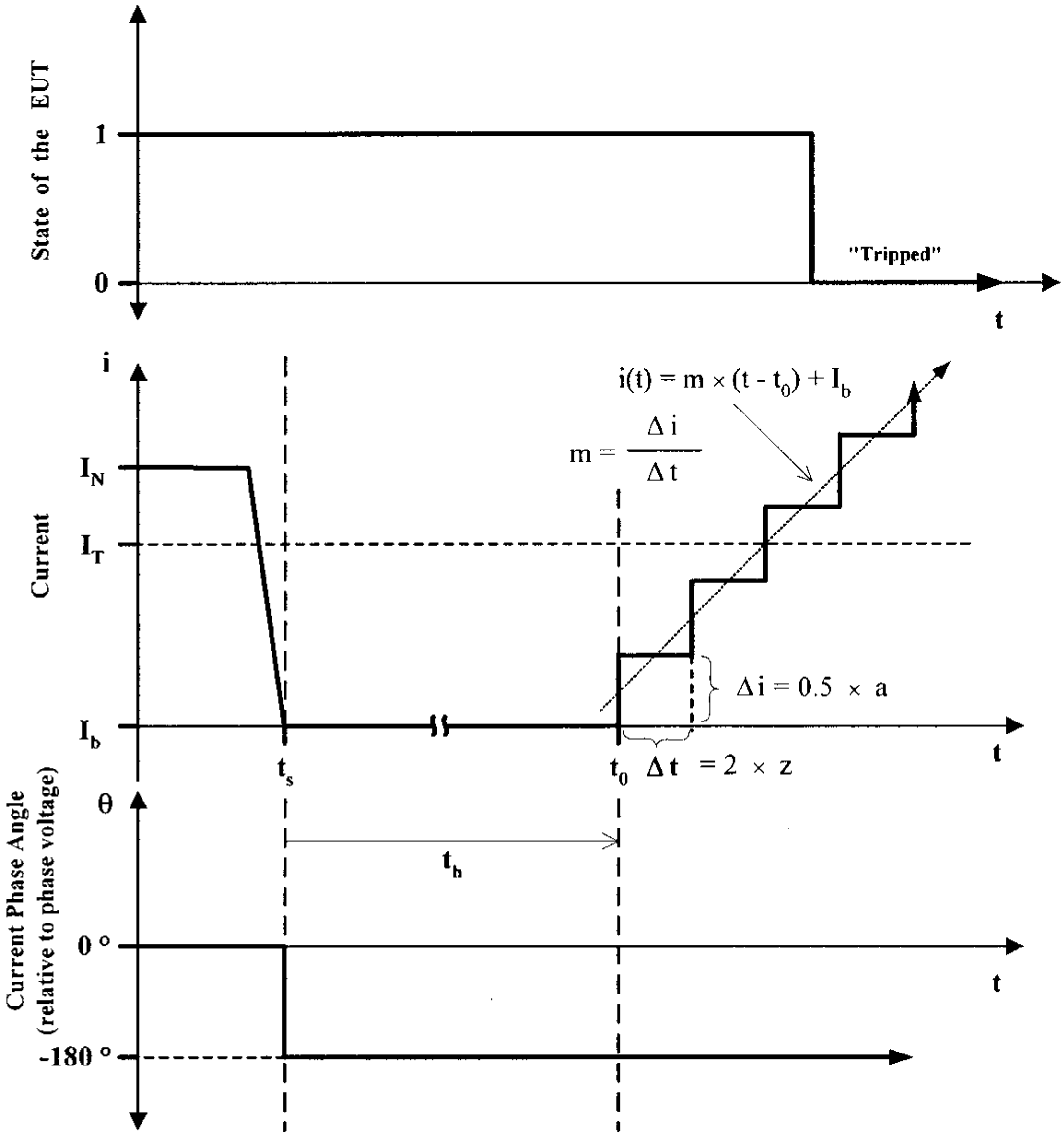

Figure A.4—Graphical representation of reverse-power magnitude test using current magnitude ramp function coupled with current phase-angle step function

Figure A.5 is a graphical representation of the functions used for a reverse-power time test. In the figure, i represents the current test signal, θ represents the phase angle of the current test signal, t represents time, t_t is the trip time, I_N is the nominal current magnitude, I_T is the trip magnitude,[51] I_b is the starting point of the current-magnitude step function, I_U is the final value of the current-magnitude step function, t_0 is the start time used for calculating the trip time, t_i is the start of the current-magnitude step function, t_r is the rise time

[51]For the reverse-power time test, the reverse-power trip magnitude will be a function of the magnitude of the current test signal, because the voltage magnitude is at nominal and the phase difference between the voltage and current test signals, θ, is 180°.

of the test signal from (t_0 - t_i),[52] t_s is the instant when the phase transition occurs and the hold time[53] t_h for the test signal starts at I_b.

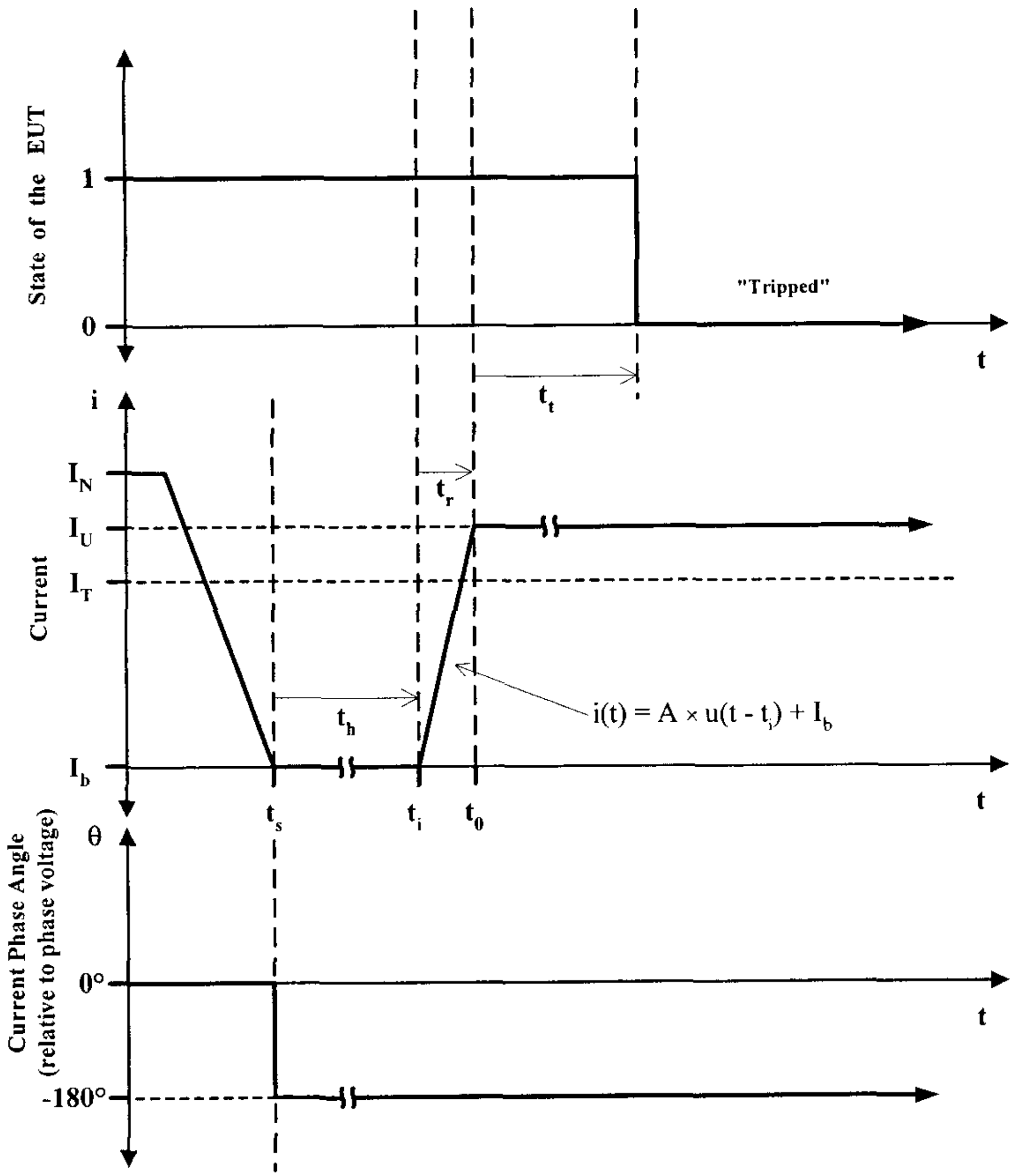

Figure A.5—Graphical representation of reverse-power time test using current magnitude step function coupled with current phase-angle step function

When the step functions conflict with a design characteristic or settings of the EUT, an alternative method that is agreeable to the manufacturer and the testing agency may be used.

[52]The rise time t_r shall be less than the larger of 1 cycle or 1% of the time-delay setting of the PUT.

[53]See Footnote 40.

Annex B

(informative)

Bibliography

The specifications refer to provisions that do not constitute provisions of this standard. They are listed to provide additional useful information. At the time of publication, the editions indicated were valid. All standards and specifications are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the references listed below.

[B1] IEC TR3 61000-3-7, Electromagnetic Compatibility (EMC)—Part 3: Limits—Section 7: Assessment of Emission Limits for Fluctuating Loads in MV and HV Power Systems—Basic EMC Publication.[54]

[B2] IEC 61000-4-15, Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 15: Flickermeter—Functional and Design Specifications.

[B3] IEC 61400-21, Wind Turbine Generator Systems—Part 21: Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines.

[B4] IEC 62116, Testing Procedure of Islanding Prevention Measures for Utility Interactive Photovoltaic Inverters.

[B5] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition, New York, Institute of Electrical and Electronics Engineers, Inc.[55]

[B6] IEEE P1547.2™, Draft Application Guide for IEEE Std 1547, Interconnecting Distributed Resources with Electric Power Systems.[56]

[B7] IEEE P1547.3™, Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems.

[B8] IEEE P1547.4™, Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.

[B9] IEEE P1547.5™, Draft Technical Guidelines for Interconnection of Electric Power Sources Greater Than 10 MVA to the Power Transmission Grid.

[B10] IEEE P1547.6™, Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks.

[B11] IEEE Std C37.108™, IEEE Guide for the Protection of Network Transformers.

[B12] IEEE Std C57.12.44™, IEEE Standard Requirements for Secondary Network Protectors.

[B13] IEEE Std 120™, IEEE Master Test Guide for Electrical Measurements in Power Circuits.

[54]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[55]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[56]The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[B14] IEEE Std 519™, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

[B15] IEEE Std 929™, IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems.

[B16] IEEE Std 1001™, IEEE Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems.

[B17] IEEE Std 1453™, IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems.

[B18] UL 1741, Static Inverters and Change Controllers for Use in Photovoltaic Power Systems.[57]

[57]UL standards are available from *Global Engineering Documents*, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

