UL 2231-2

STANDARD FOR SAFETY

Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems

UL Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems, UL 2231-2

Second Edition, Dated September 7, 2012

Summary of Topics

This revision to ANSI/UL 2231-2 dated December 15, 2020 includes revising requirements for Isolated Circuit Systems – Capacitor Switching Transient Test and Harmonic Distortion Immunity Test; 24.1.3A, 24.2.1 and 24.9.2

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated May 15, 2020.

No Text on This Page

Association of Standardization and Certification
NMX-J-668-2-ANCE
Second Edition

CSA Group
CAN/CSA C22.2 No. 281.2-12
First Edition

Underwriters Laboratories Inc.
UL 2231-2
Second Edition

Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems

September 7, 2012

(Title Page Reprinted: December 15, 2020)

ANSI/UL 2231-2-2020

Commitment for Amendments

This standard is issued jointly by the Association of Standardization and Certification (ANCE), the Canadian Standards Association (operating as "CSA Group"), and Underwriters Laboratories Inc. (UL). Comments or proposals for revisions on any part of the standard may be submitted to ANCE, CSA Group, or UL at any time. Revisions to this standard will be made only after processing according to the standards development procedures of ANCE, CSA Group, and UL. CSA Group and UL will issue revisions to this standard by means of a new edition or revised or additional pages bearing their date of issue. ANCE will incorporate the same revisions into a new edition of the standard bearing the same date of issue as the CSA Group and UL pages.

ISBN 978-1-55491-815-7 © 2012 Canadian Standards Association

This Standard is subject to review within five years from the date of publication, and suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to inquiries@csagroup. org and include "Proposal for change" in the subject line: Standard designation (number); relevant clause, table, and/or figure number; wording of the proposed change; and rationale for the change.

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This ANSI/UL Standard for Safety consists of the Second Edition including revisions through December 15, 2020. The most recent designation of ANSI/UL 2231-2 as an American National Standard (ANSI) occurred on December 15, 2020. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page (front and back), or the Preface.

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PREFACE

This is the harmonized ANCE, CSA Group, and UL Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems. It is the Second edition of NMX-J-668-2-ANCE, the First edition of CAN/CSA-C22.2 No. 281.2, and the Second edition of UL 2231-2. This harmonized standard has been jointly revised on December 15, 2020. For this purpose, CSA Group and UL are issuing revision pages dated December 15, 2020, and ANCE is issuing a new edition dated December 15, 2020.

This harmonized standard was prepared by the Association of Standardization and Certification (ANCE), CSA Group, and Underwriters Laboratories Inc. (UL). The efforts and support of the Technical Harmonization Working Group for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits are gratefully acknowledged.

This Standard is considered suitable for use for conformity assessment within the stated scope of the Standard.

The present Mexican Standard was reviewed and approved by the Comité de Normalización de la Asociación de Normalización y Certificación, A.C., CONANCE.

This standard was reviewed by the CSA Subcommittee on Electric Vehicle – Personal Protection Systems for Supply Circuits, under the jurisdiction of the CSA Technical Committee on Industrial Products and the CSA Strategic Steering Committee on Requirements for Electrical Safety, and has been formally approved by the CSA Technical Committee. This standard has been developed in compliance with Standards Council of Canada requirements for National Standards of Canada. It has been published as a National Standard of Canada by CSA Group.

Application of Standard

Where reference is made to a specific number of specimens to be tested, the specified number is to be considered a minimum quantity.

Note: Although the intended primary application of this standard is stated in its scope, it is important to note that it remains the responsibility of the users of the standard to judge its suitability for their particular purpose.

Level of harmonization

This standard uses the IEC format but is not based on, nor is considered equivalent to, an IEC standard.

This standard is published as an equivalent standard for ANCE, CSA Group, and UL.

An equivalent standard is a standard that is substantially the same in technical content, except as follows: Technical national differences are allowed for codes and governmental regulations as well as those recognized as being in accordance with NAFTA Article 905, for example, because of fundamental climatic, geographical, technological, or infrastructural factors, scientific justification, or the level of protection that the country considers appropriate. Presentation is word for word except for editorial changes.

Reasons for differences from IEC

This standard provides particular requirements for personnel protection systems for electric vehicle supply circuits for use in accordance with the electrical installation codes of Canada, Mexico, and the United States. At present there is no IEC standard for these products for use in accordance with these codes. Therefore, this standard does not employ any IEC standard for base requirements.

Interpretations

The interpretation by the standards development organization of an identical or equivalent standard is based on the literal text to determine compliance with the standard in accordance with the procedural rules of the standards development organization. If more than one interpretation of the literal text has been identified, a revision is to be proposed as soon as possible to each of the standards development organizations to more accurately reflect the intent.

Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems

INTRODUCTION

1 Scope

1.1 This Standard is intended to be used in conjunction with the general requirements of Annex A, Ref. No. 1. The requirements of Annex A, Ref. No. 1 apply unless modified by this Standard.

2 General

2.1 This Part contains the construction and performance requirements that are applied to a device that is intended to become an integral part of an overall device or charging system.

2.2 Annex A, Ref. No. 1 contains an outline of the features required to provide protection based on voltage and grounding or isolation of the system or part of the system under consideration.

3 Components

3.1 Except as indicated in 3.2, a component of a product covered by this standard shall comply with the requirements for that component.

3.2 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.

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

3.4 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.

4 Units of Measurement

4.1 The values given in SI (metric) units shall be normative. Any other values given shall be for information purposes only.

5 Normative References

5.1 Where reference is made to any Standards, such reference shall be considered to refer to the latest editions and revisions thereto available at the time of printing, unless otherwise specified.

5.2 Products covered by this standard shall comply with the referenced installation codes and standards noted in Annex A as appropriate for the country where the product is to be used. When the product is intended for use in more than one country, the product shall comply with the installation codes and standards for all countries where it is intended to be used.

CONSTRUCTION

6 General

6.1 The design, workmanship, and degree of production uniformity shall be such that the reliability of the device to perform the functions evaluated by the requirements is high.

7 Grounding

Note: In Canada, equipment grounding conductors are referred to as bonding conductors.

7.1 A grounding circuit shall comply with Annex A, Ref. No. 2 with respect to the size of the grounding conductors.

7.2 All accessible parts of a device that are likely to become energized when arc-over, insulation failure, or the similar conditions occur, shall be connected together and to the terminals intended for an equipment grounding conductor.

7.3 Except as described in 7.4 the equipment grounding conductor shall be sized in accordance with Annex A, Ref. No. 2.

7.4 When a charging circuit interrupting device is intended for use in a circuit where the voltage to ground is greater than 300 Vrms, the impedance of the grounding circuit shall not be higher than that value which limits the voltage to 150 Vrms on accessible parts with respect to earth at the site of the fault during a low impedance fault.

7.5 The accessible parts of a device intended for use on an isolated supply with not more than 150 Vrms between conductors are not required to be grounded.

7.6 In a portable product, accessible parts that are double insulated from energized parts shall not be grounded unless the grounding path is monitored by use of a ground/monitor interrupter.

7.7 Except as indicated in 16.3, a portable device shall be provided with an equipment grounding conductor that extends to the vehicle connector. On the supply side of the interrupting contacts of the CCID, the equipment grounding conductor shall not be connected to accessible conductive parts. On the load side of the CCID interrupting contacts, the equipment grounding conductor shall be connected to the vehicle connector and shall not be connected to accessible metal unless permitted by the construction and potentials involved. See Table 2 of Annex A, Ref. No. 1.

8 Insulation and Protective Features

8.1 An interrupting device such as a charging circuit interrupting device, a grounding monitor/interrupter or an isolation monitor/interrupter, shall have insulation and features or accessories that are required for the voltage rating and type of system where use is intended. See Protective Systems, Section 6, of Annex A, Ref. No. 1 for insulation requirements and features.

8.2 Double insulation or reinforced insulation shall be provided in that part of a grounded circuit between the connections to the supply and the interrupting contacts of the charging circuit interrupting device.

8.3 A device that is required to be double insulated and is rated 120 or 127 or 120/240 Vrms or less shall comply with Annex A, Ref. No. 3.

8.4 A device that is required to be double insulated and is rated more than 120 or 127 or 120/240 Vrms shall comply with the intent of Annex A, Ref. No. 3.

9 Double or Reinforced Insulation Bridged By Components

9.1 Any electrical component that bridges double or reinforced insulation shall comply with 9.2 through 9.4 as applicable.

9.2 Capacitors that bridge double or reinforced insulation shall consist of two capacitors in series, each complying with Subclass Y1 of Annex A, Ref. No. 4. They shall each be rated for the total working voltage across the pair and shall have the same nominal capacitance valve.

9.3 Resistors that bridge double or reinforced insulation shall be comprised of two resistors in series. They shall each comply with the requirements of Spacings, Section 12, or Clearances and Creepage Distances, Section 13, between their terminations based on the total voltage across the pair and shall have the same nominal resistance value.

9.4 Where accessible conductive parts or circuits are separated from other parts by double or reinforced insulation that is bridged by components in accordance with 9.1 through 9.3, the accessible parts shall comply with the requirements in Section 38.

10 Accessibility of Energized Parts

10.1 Parts of a device that are capable of being energized during normal operation shall not be accessible.

10.2 In determining compliance with the provisions of 10.1:

a) A part is determined to be accessible when it is capable of being touched by any part of the articulated probe, see Figure 1, under normal conditions,

b) A permanently connected device shall be mounted as intended,

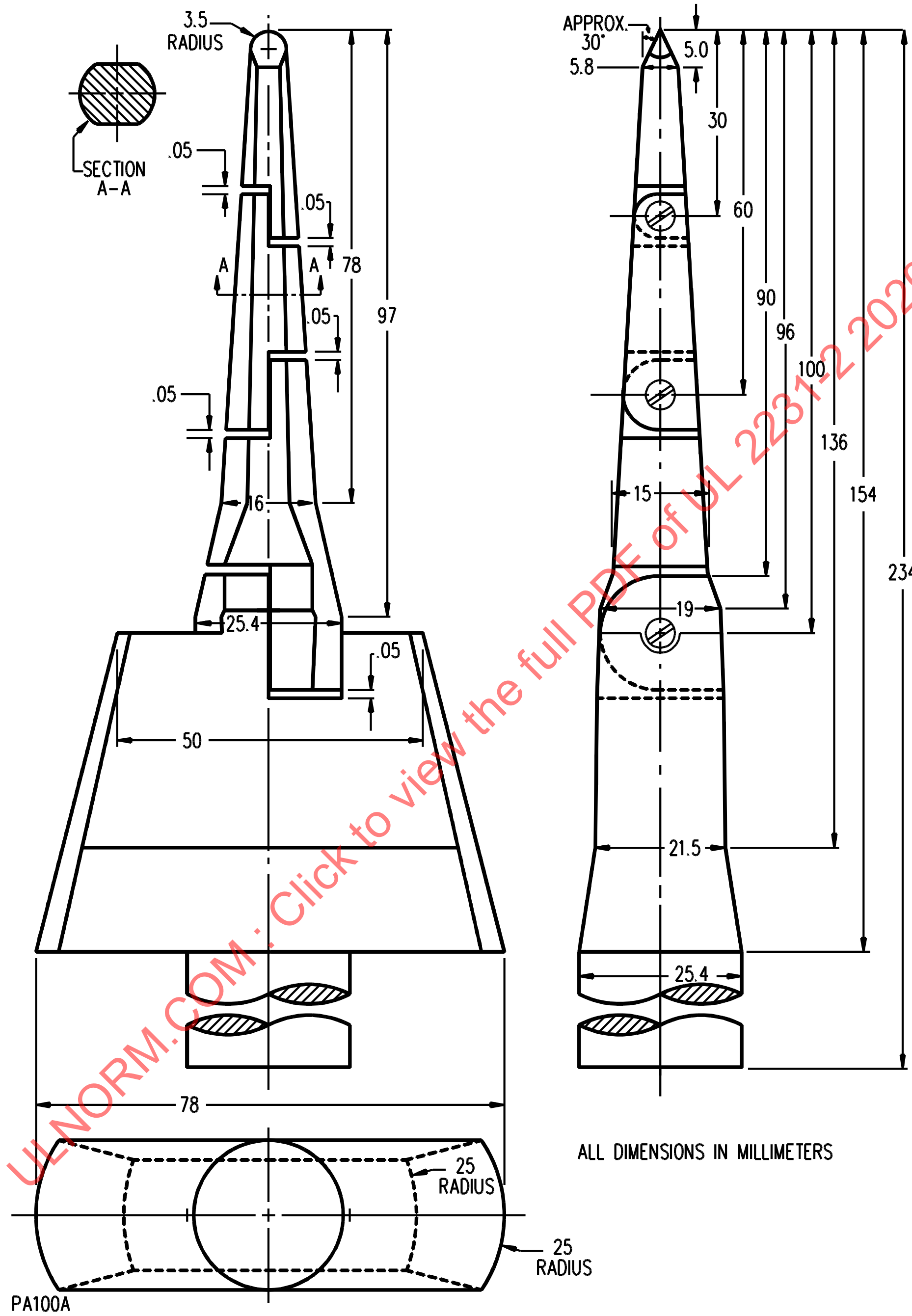
c) A door or cover that is capable of being opened or removed without the use of a separate tool shall be open or removed,

d) A door or cover that must be opened or removed in order to use a device shall be opened or removed, and

e) Material that is not accepted as insulation is evaluated as conductive.

Figure 1

Articulated probe



[a] The probe shall be used only as a gauge and inserted with minimal force. The probe shall be rotated with the moveable sections straight or in any possible position resulting from bending one or more sections in the same direction.

11 Internal Wiring

11.1 The gauge and insulation of wires shall withstand the mechanical and electrical stresses of service. Particular consideration should be given to the effect of vibration and user servicing where wire smaller than 0.205 mm^2 (24 AWG) is employed.

11.2 In a double-insulated device, there shall be at least one independent means provided at a wire termination or splice, which alone prevents the conductor from becoming free to bridge supplementary or reinforced insulation in the event that the wire breaks at the termination or splice. A wire-binding screw or nut, such as one with a spring-type lock washer or equivalent, shall be suitably prevented from loosening under conditions where such loosening allows the attached conductor to become free to bridge supplementary or reinforced insulation.

11.3 Electrical splices and terminations shall provide effective, continuous conductivity.

11.4 In determining compliance of a clamped splice or termination with the provisions of 11.3, consideration shall be given to the risk of permanent deformation under mechanical load (creep).

12 Spacings

12.1 Except as described in 12.2, the spacings of a device shall be evaluated in accordance with:

a) Spacings, Section 12, and Table 1, or

b) Clearances and Creepage Distances, Section 13.

Table 1
Through-air and over-surface spacings

Parts separated by	Operating potential between parts											
	70 V peak or less				71 – 200 V peak				201 – 400 V peak			
	Through air		Over surface		Through air		Over surface		Through air		Over surface	
	Open[a] mm (inch)	Closed-in[b] mm (inch)	Open[a] mm (inch)	Closed-in[b] mm (inch)	Open[a] mm (inch)	Closed-in[b] mm (inch)	Open[a] mm (inch)	Closed-in[b] mm (inch)	Open[a] mm (inch)	Closed-in[b] mm (inch)	Open[a] mm (inch)	Closed-in[b] mm (inch)
Functional insulation[c]	1.6[d] (1/16)	1.6[d] (1/16)	1.6[d] (1/16)	1.6[d] (1/16)	3.2 (1/8)	1.6[d] (1/16)	6.4 (1/4)	1.6 (1/16)	6.4 (1/4)	3.2 (1/8)	9.5 (3/8)	3.2 (1/8)
Supple-mentary insulation	3.2 (1/8)	1.6 (1/16)	6.4 (1/4)	1.6 (1/16)	3.2 (1/8)	1.6 (1/16)	6.4 (1/4)	3.2 (1/8)	6.4 (1/4)	1.6 (1/16)	9.5 (3/8)	3.2 (1/8)
Double or reinforced insulation	6.4 (1/4)	3.2 (1/8)	12.7 (1/2)	3.2 (1/8)	6.4 (1/4)	3.2 (1/8)	12.7 (1/2)	6.4 (1/4)	12.7 (1/2)	6.4 (1/4)	19 (3/4)	6.4 (1/4)

[a] A space that is not specially protected from deposition of dirt.

[b] A space that is specially protected from deposition of dirt such that the construction complies with the requirements of the Dust Test of 41.

[c] Smaller spacings may be acceptable where they are inherent in a suitable component.

[d] Shall not be less than 0.8 mm (1/32 inch) at a printed wiring board without conformal coating.

12.2 When a device is an integral part of a charging system, the spacings of the device shall be evaluated in accordance with Annex A, Ref. No. 5.

12.3 Except as indicated below, the through-air and over-surface spacings between conductive parts shall not be less than the values shown in Table 1.

a) At field-wiring terminals, spacings shall not be less than the values shown in Table 2.

b) For printed wiring boards with suitable conformal coating which has been determined to comply with the requirements for conformal coatings in Annex A, Ref. No. 6, spacings are able to be reduced to 0.8 mm (1/32 inch), and are able to be further reduced when the coating is determined to be suitable and a special dielectric withstand test is performed between the conductors.

Table 2
Field wiring terminals spacings

Voltage (RMS)	Spacing distance (over surface or through air)	
	Opposite polarity mm (inch)	To ground mm (inch)
0 – 150	6.4 (1/4)	12.7 (1/2)
151 – 300	9.5 (3/8)	12.7 (1/2)
301 – 600	12.7 (1/2)	12.7 (1/2)
601 – 1000	25.4 (1)	25.4 (1)

12.4 Except as permitted in note c to Table 1, when a groove or a slot in insulating material is less than 0.4 mm (1/64 inch) wide, the contour of the slot or groove shall be disregarded in measuring spacings over the surface.

12.5 Spacings measured along the boundary of insulating materials that have been joined together are regarded as over surface spacings unless it is shown that the dielectric strength of the boundary is not less than that of any of the materials joined.

12.6 In determining compliance with the provisions of Spacings, Section 12, or Clearances and Creepage Distances, Section 13, parts not locked in position, parts subject to random orientation (such as non-circular heads of screws), adjustable parts of terminal connectors, and similar parts, shall be moved to the most adverse position.

12.7 In determining spacings through openings in a housing of insulating material, the use of metal foil is permitted to bridge the opening but shall not be pressed into the opening.

12.8 Film-coated magnet wire is regarded as uninsulated in determining spacings.

13 Clearances and Creepage Distances

13.1 As an alternative to the spacings requirements specified in Spacings, Section 12, and other than as noted in 13.2 and 13.3, clearances and creepage distances may be evaluated in accordance with the requirements in Annex A, Ref. No. 7, as described in 13.4.

13.2 Clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable, shall be as noted in this Clause. The clearances shall be determined by physical measurement.

13.3 The clearance and creepage distance at field wiring terminals shall be in accordance with the requirements in Spacings, Section 12.

13.4 In conducting evaluations in accordance with the requirements in Annex A, Ref. No. 7, the following guidelines shall be used:

a) Unless specified elsewhere in this standard, the pollution degree shall be regarded as pollution degree 3;

b) Equipment which operates in the direct line of the source of power to the load equipment shall be regarded as Overvoltage Category II. Other equipment covered under this Standard shall be regarded as Overvoltage Category III;

c) Pollution degree 2 is regarded as existing on a printed wiring board between adjacent conductive material that 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) Any printed-wiring board which complies with the requirements in Annex A, Ref. No. 8, shall be identified as providing a Comparative Tracking Index (CTI) of 100, and if it further complies with the requirements for Direct Support in Annex A, Ref. No. 8, then it shall be identified as providing a CTI of 175;

e) For the purposes of compliance with the requirements for coatings of printed-wiring boards used to achieve pollution degree 1 in accordance with Annex A, Ref. No. 7, a coating which complies with the requirements for Conformal Coatings in Annex A, Ref. No. 6, meets the intent of the requirement;

f) Pollution degree 1 is also capable of being achieved at a specific printed-wiring board location by application of at least a 0.8-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) Evaluation of only clearances to determine equivalence with current through air spacings requirements is capable of being be conducted in accordance with Clearance A (Equivalency), of Annex A, Ref. No. 7. An impulse test potential having a value as determined in Annex A, Ref. No. 7 shall be applied across the same points of the device as is required for the Dielectric Voltage-Withstand Test, Section 26;

h) Evaluation of clearances and creepage distances shall be conducted in accordance with the requirements in Annex A, Ref. No. 7, for Clearance B (Controlled Overvoltage) and Creepage Distances;

i) The voltage used in the determination of clearances shall be the equipment phase-to-ground rated supply voltage, or the voltage measured in the circuit under consideration, 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 capable of being interpolated with interpolation continued across the table for the rated impulse voltage peak and clearance; and

j) Determination of the dimensions of clearances and creepage distances shall be conducted in accordance with the requirements for Measurement of Clearances and Creepage Distances of Annex A, Ref. No. 7.

14 Operating Mechanism

14.1 Compliance with the provisions of System Operational Test Requirements, Section 23, shall not be prevented by manipulation or restraint of accessible control levers, knobs, and similar parts, of a device.

14.2 Except as indicated in 14.3 or 14.4, a device that has tripped in accordance with the provisions of the System Operational Test Requirements, Section 23, shall not be capable of automatic reset function.

14.3 A device with an automatic supervisory circuit that performs a self-test prior to each reclosure shall be permitted to have an automatic reset function which permits operation following an acceptable self-test. If the automatic supervisory circuit is used there shall be a minimum of 15 seconds between the tripping function with no maximum number of resets. The automatic supervisory test system shall comply with 17.7 and 17.8 as applicable.

14.4 A device shall be permitted to have an automatic reset function provided the automatic reset function complies with the following requirements:

a) There shall be a minimum delay of 15 minutes between the activation of the tripping function and the automatic reset,

b) The device shall not reset more than 4 times for any given charge sequence,

c) A device having an automatic reset function utilizing solid state circuitry shall comply with the requirements in Annex A, Ref. No. 9, and

d) A device having an automatic reset function utilizing programmable components shall comply with the requirements in 18A.1 and 18A.2.

A manual intervention may override both the time delay to the automatic reset and the maximum number of resets. See 43.4.

14.5 A device that trips immediately due to closing onto a fault shall not automatically reset.

14.6 Except as indicated in 14.6.1 and 14.6.2, when a device that is providing power output opens because of a loss of power on the line side, it shall automatically restore power output when line side power is restored.

14.6.1 Compliance with the power output restoration requirement of 14.6 shall not be required for devices that incorporate a point of sale or user authentication feature. It shall be acceptable for such devices to return to a standby mode that requires a manual action to initiate resumption of power output.

14.6.2 Compliance with the power output restoration requirement of 14.6 shall not be required for devices that do not allow automatic resumption of power. It shall be acceptable for such devices to return to a standby mode that requires a manual action to initiate resumption of power output.

14.7 In a permanently-connected device that is not capable of tripping without power from the line, the grounded circuit conductor shall be electrically continuous during normal operation of the device.

14.8 A 120/240 Vrms or polyphase device shall function to provide protection with one or more ungrounded line terminals energized.

14.9 The requirement in 14.8 does not apply if the device is able to automatically disconnect the load when one or more ungrounded line terminals become de-energized, when that is capable of leading to a condition that results in the risk of injury to persons.

15 Isolation Monitor/Interrupter

15.1 An isolation monitor/interrupter shall monitor the resistance of the insulation that provides electrical isolation from ground of an isolated circuit. When the resistance from any ungrounded conductor to ground is less than 100 ohms/volt, based on nominal system voltage, the device shall not allow the load circuit to be energized.

15.2 The AC internal resistance of the monitor shall be at least 250 ohms/volt of nominal system voltage. The DC internal resistance of the measuring device shall be at least 30 ohms/volt of nominal system voltage and shall limit the measuring output current to 5mA.

15.3 An isolation monitor that has an adjustable trip setting shall also have a means to prevent tampering with the setting.

15.4 An isolation monitor shall have a built-in test circuit or means to connect circuitry to verify correct operation of the monitor.

15.5 When the circuit is intended to operate as an isolated circuit throughout the entire charging cycle, then the isolation monitor/interrupter shall continue to monitor the circuit during charging and shall open the circuit when the resistance to ground from any ungrounded conductor is less than 100 ohms/volt.

15.6 An isolation monitor intended to be used on systems where the voltage between conductors is greater than 150 Vrms and where only basic insulation is provided shall have an automatic self-test feature that:

a) Tests the monitor to determine whether or not it is functioning within intended limits, and

b) Does not permit energizing the circuitry connected to the load terminals under the condition that the isolation monitor is not functioning properly.

15.7 The test mentioned in 15.6 shall be performed prior to each charging cycle or at regular intervals. If testing is performed at regular intervals, the test shall be performed at least once each hour.

15.8 To demonstrate that an isolation monitor/interrupter meets the requirements of 15.1 – 15.5 tests as described in System Operational Test Requirements, Section 23, shall be performed.

16 Grounding Circuit

16.1 Grounding monitor/interrupter

16.1.1 A device intended to monitor equipment grounding continuity in a charging system shall prevent the charger circuitry from becoming energized under conditions where the grounding is not available and shall interrupt the circuit under conditions where the grounding is lost during operation.

16.1.2 To demonstrate that a grounding monitor/interrupter meets the requirements of 16.1.1, tests as described in System Operational Test Requirements, Section 23, shall be performed.

16.2 Grounding circuit impedance

16.2.1 The impedance of the grounding circuit shall be limited to a value that does not permit a potential of more than 150 Vrms to be impressed on a person who is in a fault path. The grounding circuit is assumed to be intact and the person is in parallel with the grounding circuit. The potential available at the fault depends upon the location of the fault in the circuit.

16.2.2 In a circuit with a supply greater than 300 Vrms, the limit shall be accomplished by reducing the impedance of the grounding path to a value less than the impedance of the ungrounded conductors by an amount that limits the voltage available at a fault.

16.2.3 The impedance shall be verified by measurement.

16.3 Grounding circuit employing a switched equipment grounding conductor

16.3.1 In Mexico and the US, it shall be permissible for a CCID to employ a switching device in the equipment grounding conductor that extends to the vehicle connector provided the construction complies with the following:

a) The device is intended for use on a supply circuit not exceeding 150 V to ground,

b) A grounding monitor interrupter (GM/I) is provided integrally with the CCID,

c) The switching device in the equipment grounding conductor shall close before the line switching contacts when the output is energized,

d) The switching device in the equipment grounding conductor shall open after the line switching contacts when the output is deenergized, and

e) The construction shall comply with Section 39.

In Canada, this requirement does not apply.

17 Supervisory Circuit

17.1 A device intended to be used on a grounded system shall be provided with a supervisory circuit that complies with at least one of the following:

a) Allows for periodic manual, convenient testing of the ability of the device to trip by way of a simulated ground-fault,

b) Automatically tests the system at least once for each use and at power up, or

c) Automatically tests the system periodically. The automatic test shall be repeated at least every three hours.

17.2 The tests shall include the entire interrupting device including the interrupting contacts or:

a) Employ a contactor position monitor that continuously verifies the contacts are open when operated to be open and closed when operated to be closed, or

b) Employ an interrupting device that utilizes redundant components in the control path, including the interrupting contacts.

17.3 When it is necessary to employ a separate tool in order to manually operate the supervisory circuit, operation is regarded as inconvenient within the intent of these requirements.

17.4 The simulated fault current shall be of the same polarity as an anticipated actual fault.

17.5 The results of the test shall be made known by means of an evident indication. If the device is an EVSE employing an electric vehicle communication signal and the supervisory circuit test conditions of 17.2 are not met, the device shall indicate that charging is not available.

17.6 The current employed by the supervisory circuit shall cause tripping at 85 percent of rated voltage. At rated voltage the current shall not exceed 150 percent of the nominal rated tripping current.

17.7 An automatic supervisory test system utilizing solid state circuitry shall comply with the requirements in Annex A, Ref. No. 9, and there shall be a minimum delay of 15 seconds between the tripping function and the reset.

17.8 An automatic supervisory test system utilizing programmable components shall comply with the requirements in 18A.3 and 18A.4.

18 Leakage Cancellation

18.1 It is expected that some electric vehicle supply equipment will be used in locations where a Class A GFCI is required to be installed in accordance with Annex A, Ref. No. 11. In order to prevent unwanted tripping of a Class A GFCI due to leakage currents that exceed the Class A GFCI trip threshold, it shall be permissible for a cord connected CCID20 to employ leakage cancellation provided the construction complies with the following:

a) The device is intended for use on a supply circuit not exceeding 150 V to ground,

b) The device is provided with an attachment plug rated 15 or 20 amperes,

c) A grounding monitor interrupter (GM/I) is provided integrally with the CCID, and

d) The construction shall comply with Section 40.

18A Programmable Components

18A.1 If a programmable component is employed in a device with an automatic reset function as mentioned in 14.4, the device shall be evaluated to the requirements of Annex A, Ref. No. 10, as defined in 18A.2.

18A.2 The risks to be considered in the evaluation mentioned in 18A.1 shall include the following scenarios as applicable:

a) Failure to trip under conditions where tripping should occur;

b) Tripping at the wrong trip threshold value;

c) Failure of a supervisory circuit to complete evaluation; and

d) Unwanted tripping.

18A.3 If a programmable component is employed in a device employing an automatic supervisory test system, as mentioned in 14.3 and 17.8, the applicable portion of the device shall be evaluated in accordance with the requirements of Annex A, Ref. No. 10, as defined in 18A.4.

18A.4 The risks to be considered in the evaluation mentioned in 18A.3 shall include the following scenarios as applicable:

a) Failure of supervisory circuit to complete evaluation; and

b) Failure of the supervisory circuit to indicate an unacceptable test result.

PERFORMANCE

19 General

19.1 The representative device or devices being evaluated shall be subjected to the tests shown in Table 3 in the order shown. At the manufacturer's discretion, a representative device can be subjected to more than one test sequence.

Table 3
Test sequence for representative devices

Test	Reference	Test sequence													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Humidity Conditioning	Section 20	X	X	X											
Leakage Current Test[a]	Section 21	X	X	X											
Conditioning Tests	Section 22	X	X	X	X										
Ground-Fault Trip Threshold	Subsection 23.2	X													
Interrupting Time	Subsection 23.3	X													
High-Resistance Ground Fault Test	Subsection 23.4	X													
Second Neutral Ground	Subsection 23.5	X													
Test for Isolation Monitor/Interrupters	Subsection 23.6		X												
Tests for Ground Monitor/Interrupters	Subsection 23.7			X											
Normal Temperature Test	Section 25				X										
Overload Test	Section 27					X									
Endurance Test	Section 28					X									
Low-Resistance Ground Fault Test	Section 29						X								
Abnormal Operations Test	Section 31							X							
Extra-Low-Resistance Ground Fault Test	Section 32								X						
Short Circuit Test	Section 33									X					
Dielectric Voltage-Withstand Test	Section 26	X	X	X	X	X	X	X	X	X					
Terminal Lead Strain-Relief Test	Section 34										X				
Power Supply Cord Strain-Relief Test	Section 35										X				
Mechanical Tests	Section 36										X				

Table 3 Continued on Next Page

Table 3 Continued

Test	Reference	Test sequence													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Accessible Conductive Parts With Double Or Reinforced Insulation Bridged By Components	Section 38											X			
Switched Equipment Grounding Conductor Tests – Contact Switching Sequence	Subsection 39.1												X		
Switched Equipment Grounding Conductor Tests – Mechanical Endurance Test	Subsection 39.2												X		
Switched Equipment Grounding Conductor Tests – Ground Fault Test	Subsection 39.3													X	
Leakage Cancellation Tests	Section 40														X
[a] Cord-connected devices only.															

19.2 The tests in Sequences A, B, and C shall be performed in the sequence shown, except that the Conditioning Tests is permitted to precede Humidity Conditioning.

19.3 A device that is double insulated shall also comply with the performance requirements of Annex A, Ref. No. 12.

19.4 A device that meets the requirements of 17.2 a) or 17.2 b) and 17.5 shall not be required to comply with the Dielectric Voltage-Withstand Test between line and load terminals with the device open or tripped, Section 26, after the Extra-Low-Resistance Ground Fault Test, Section 32, or after the Short Circuit Test, Section 33, provided the device complies with all of the following:

a) Line side and load side grounding monitor/interrupter (GM/I) is provided for both permanently connected and cord connected EVSE.

b) Circuitry is provided that monitors the isolation between each input and output pole and verifies that the contacts are open when operated to be open and closed when operated to be closed prior to initiation of a charge in accordance with Section 17.

c) In the event of a loss of isolation or incorrect operation of the interrupting contacts, the communication to the vehicle is disabled, including disabling of the pilot signal if provided.

d) A visual or audible indication that the device is no longer functional, such as a fault light or alarm, shall be provided. The instructions provided with the device shall explain the meaning of the visual indication or alarm, noting that a device with such indications is no longer functional and should not be used.

e) The reliability of solid state components used to implement the functions identified in (b – d) above shall be evaluated to Annex A, Ref. No. 9. Programmable components used to implement the functions identified in (b – d) above shall be investigated using Annex A, Ref. No. 10.

20 Humidity Conditioning

20.1 A representative device that is to be subjected to Test Sequence A, B, or C from Table 3 shall be conditioned in an atmosphere as described in 20.2.

20.2 The conditioning mentioned in 20.1 and 21.9 is exposure to air at a relative humidity of 93 ±2 percent at a temperature of 32.0 ±2.0°C (89.6 ±3.6°F). The device shall be exposed to ambient air at a temperature of at least 30°C (86°F) until thermal equilibrium is attained before placed in the test chamber. A device shall be kept in the chamber for 168 hours.

21 Leakage Current Test

21.1 Except as described in 21.2 or 21.3, the leakage current of a cord-connected device shall not be more than 0.5 MIU-RR when tested in accordance with 21.4 – 21.10.

21.2 The leakage current from any part to ground is permitted to exceed 0.5 MIU when the device complies with all of the following conditions:

a) The leakage current from one accessible part to another accessible part shall not exceed 0.5 MIU,

b) The leakage current shall not exceed 3.5 MIU when another leakage current measurement is made using the measurement instrument shown in Figure 5,

c) An EMI filter is required in the product to meet FCC and Canadian regulations,

d) The product is provided with a grounding type supply cord and plug,

e) The parts of the product from which the high leakage current is available are not readily contacted by persons,

f) Persons in the vicinity of the product are usually insulated from ground so that they do not conduct the high-leakage current when they touch a high-leakage part, and

g) The consequences of touching a high-leakage part are not severe. For example, a person is not injured by involuntarily reacting to the current and contacting active machinery.

21.3 The leakage current of a device that incorporates a ground monitor/interrupter shall not exceed 5 MIU when tested using the measurement instrument shown in Figure 5 with the ground monitor/interrupter intentionally disabled.

21.4 All accessible conductive surfaces shall be tested for leakage currents to determine compliance with 21.1.Where surfaces are simultaneously accessible, they shall be tested:

a) Individually,

b) Collectively (connected together) with the combined current measured to ground, and

c) Point-to-point on the device for leakage current between the simultaneously accessible surfaces.

Surfaces shall be regarded as simultaneously accessible when they are capable of being touched by one or both hands of a person at the same time. Accessible parts within a 100 mm by 200 mm (4 inch by 8 inch) rectangle are considered simultaneously accessible to one hand. The rectangle is able to be flexed or bent to closely conform to the surface of the device. Accessible parts that are capable of being touched at the same time by the ends of a string 1.8 m (6 ft) in length are considered to be simultaneously accessible to both hands. The grounding pin, blade, or contact of an attachment plug is considered an accessible part.

21.5 When a surface other than metal is used for the enclosure or part of the enclosure, the leakage current shall be measured using metal foil with an area of 100 mm by 200 mm in contact with the surface. Where the surface is less than 100 mm by 200 mm, the metal foil shall be the same size as the surface. The metal foil shall not be pressed into openings and shall not remain in place long enough to affect the temperature of the representative device.

21.6 Typical measurement circuits for leakage current with the ground connection open are illustrated in Figure 2 and Figure 3. The measurement instrument is defined in Figure 4. Over the frequency range of 20 Hz to 1 MHz with sinusoidal currents, the performance of the instrument shall be as follows:

a) The measured ratio V1/I1 with sinusoidal voltages shall be as close as feasible to the ratio V1/I1 calculated with the resistance and capacitance values of the measurement instrument shown in Figure 4.

b) The measured ratio V3/I1 with sinusoidal voltages shall be as close as feasible to the ratio V3/I1 calculated with the resistance and capacitance values of the measurement instrument shown in Figure 4. V3 shall be measured by the meter M in the measuring circuit. The reading of meter M in RMS volts is converted to MIU by dividing the reading by 500 ohms and then multiplying the quotient by 1000. The mathematic equivalent is to multiply the RMS voltage reading by 2.

Figure 2

Leakage current measurement circuit used for devices intended for connection to 120 Vrms or 127 Vrms circuits

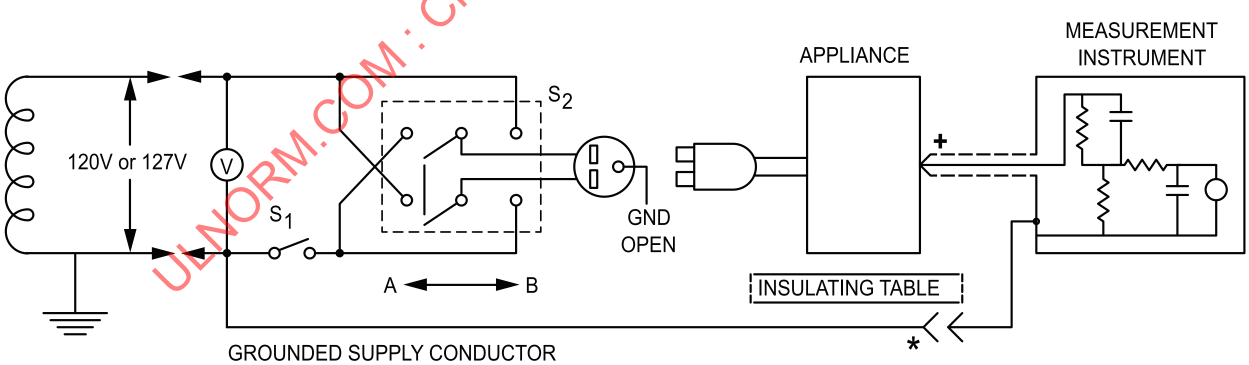


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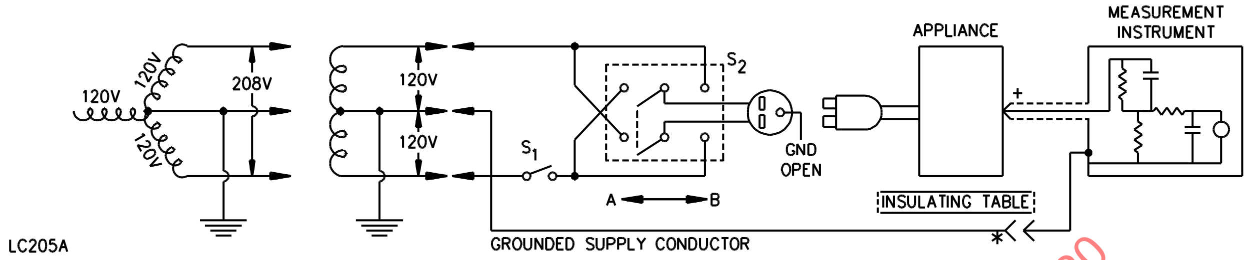
Figure 3

Leakage current measurement circuit used for grounded or ungrounded 208 Vrms or 240 Vrms devices intended for connection to 3-wire neutral grounded circuits



*Separated and used as clip when measuring currents from one part of the device to another.

+Probe with shielded lead.

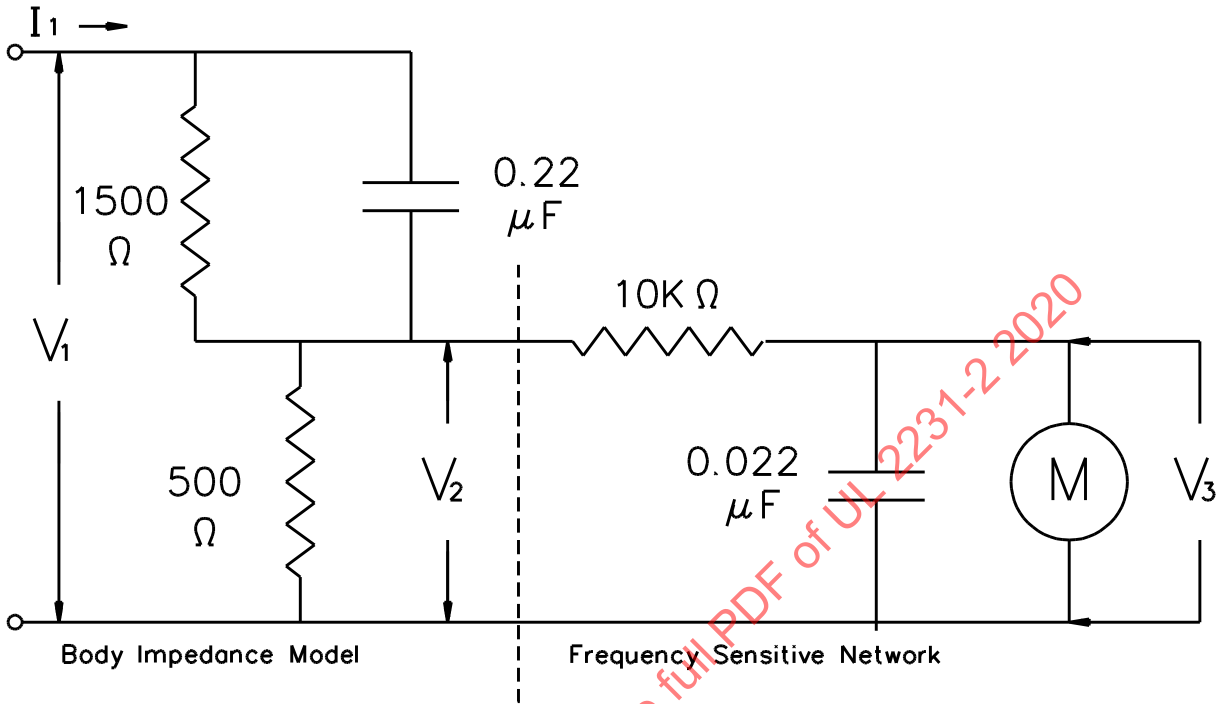
NOTES –

1) All voltages shown in Figure 2 and Figure 3 are nominal.

2) When it is not feasible to isolate the device from ground, the supply circuit shall be isolated from ground. It is possible that it will also be necessary to reverse the leads of the measurement instrument.

Figure 4

Measurement instrument for reaction



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21.7 Unless the meter is being used to measure leakage from one part of the representative device to another, the meter shall be connected between the accessible parts and the supply conductor which shall be connected to ground.

21.8 When there is no grounded conductor connected to the product under test, then the instrument return lead is capable of being connected to either the grounded or grounding conductor of the supply.

21.9 A representative device shall be tested for leakage current after the conditioning described in Humidity Conditioning, Section 20. When removed from the humidity chamber, the testing shall start within one minute after its removal. The grounding conductor of a cord-connected device shall be open at the supply receptacle. The supply voltage shall be adjusted to 110 percent of the rated voltage.

21.10 The test sequence, with reference to the measuring circuits in Figure 2 and Figure 3, is as follows:

a) With switch S1 open, the representative device shall be connected to the measurement circuit. The leakage current shall be measured using both positions of switch S2 and with the representative switching devices in all their positions.

b) Switch S1 shall then be closed, energizing the representative device, and within a period of five seconds, the leakage current shall be measured using both positions of switch S2 and with the control settings varied throughout the operating range.

c) Leakage current shall be monitored at intervals necessary to determine the maximum leakage current, with additional measurements being taken until such time as thermal equilibrium is attained. Both positions of switch S2 shall be used in determining this measurement.

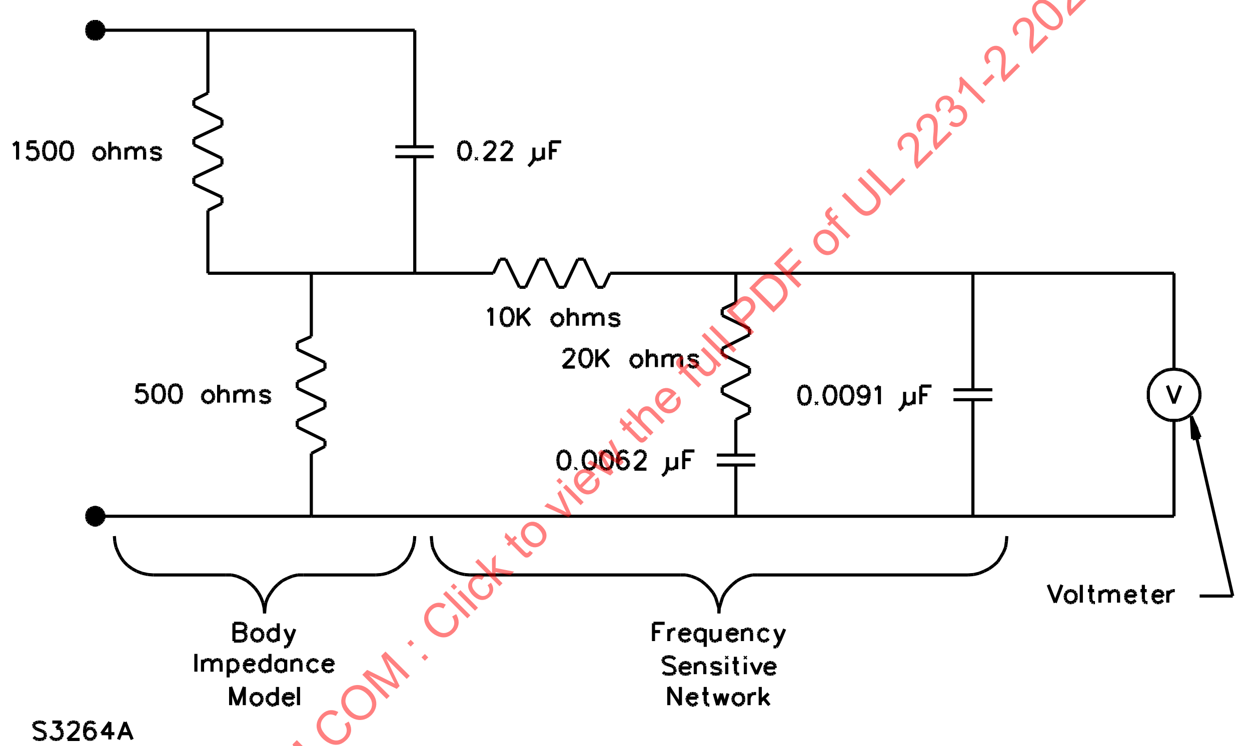
d) The leakage current shall also be monitored with switch S1 open while the product is at operating temperature and while cooling.

21.11 Normally a representative device is subjected to the entire Leakage Current Test, as specified in 21.10, without interruption for other tests. With the concurrence of those concerned, the Leakage Current Test is capable of being interrupted, or performed in conjunction with other tests.

21.12 *Deleted*

Figure 5

Measuring instrument circuit for let-go



22 Conditioning Tests

22.1 General

22.1.1 A device shall continue to function in a normal manner, as determined by performance of the tests described in Section 23, after having been subjected to the conditioning described in this section.

22.2 Impact tests

22.2.1 A representative permanently-connected device shall be subjected to an externally applied impact of 6.8 J (5 ft-lbs) applied by way of a solid, smooth, steel sphere 50.8 mm (2 inches) in diameter.

22.2.2 The sphere mentioned in 22.2.1 shall be allowed to fall freely from rest through the distance required to cause the specified impact upon the surface under test. For surfaces other than horizontal, the sphere shall be suspended by a cord and allowed to fall as a pendulum through the required distance. The device shall be placed against a vertical wall with the surface to be tested in the same vertical plane as the point of support of the pendulum.

22.2.3 The surfaces mentioned in 22.2.2 are those exposed during normal service, including operating handles, pushbuttons, and similar surfaces. Doors that are hinged or sliding or otherwise captive, and covers that are unable to be removed without tools, shall be closed. Other doors or covers shall be opened or removed. A representative device that has been struck is not required to withstand another blow. However, when more than one blow is applied to a single representative device, a failure after the first blow shall be disregarded. The same surface shall withstand a blow on another representative device. When a device fails during the first test, the device is determined to have failed.

22.3 Drop tests

22.3.1 A representative portable device shall be allowed to fall from a height of 0.91 m (3 ft) such that a different part strikes a hardwood surface in each of three drops. Doors or covers shall be moved to any position likely in normal service provided that a captive door or cover is not forced to remain in any position by some means not part of the device.

22.3.2 The hardwood surface mentioned in 22.3.1 shall consist of a layer of nominal 25.4 mm (1 inch) tongue-and-groove oak flooring mounted on two layers of 19-mm (3/4-inch) plywood. The surface shall be a square 1.2 m (4 ft) on a side. The assembly shall rest on a concrete floor or the equivalent.

22.4 Shock and vibration test

22.4.1 A representative device that is intended to be installed on, or likely to be routinely transported aboard a vehicle, shall be subjected to the tests described in 22.4.2 – 22.4.8.

22.4.2 The representative device shall be mounted on a table that is capable of being moved in such a manner as to subject the representative device to the forces described in 22.4.3 – 22.4.6. A cable or other hardware that is provided with the device or required to be connected to it for proper operation shall be used with the control during this test.

22.4.3 The representative device shall be subjected to the applied motion in each of the three primary axes, for a period of 1 hour in each axis.

22.4.4 The applied motion shall be sinusoidal and result in the fixing points of the device moving in phase and in straight parallel lines. The motion shall have a maximum displacement amplitude of 0.75 mm (0.03 in) as frequency is increased from 10 Hz until a crossover point at 60 Hz is reached which is where the maximum acceleration of 10 g is attained. The maximum acceleration level of 10 g shall then be maintained as frequency is increased to the upper limit of 100 Hz. The maximum acceleration level is then to be maintained until the frequency is reduced through the crossover point. The motion shall again have the specified maximum displacement amplitude as frequency is reduced to 10 Hz.

22.4.5 The frequency shall be varied from 10 to 100 Hz by continuously sweeping over the specified range at a rate of one octave per minute ±10 percent. The tolerance for the frequency shall be ±1 percent up to 50 Hz and ±2 percent above 50 Hz. The vibration amplitude tolerance in the observed direction shall be ±15 percent.

22.4.6 For these tests, amplitude is defined as the maximum displacement of sinusoidal motion from a position of rest or one-half of the total table displacement.

22.4.7 To verify continued acceptable operation following this exposure, the representative device shall be subjected to the tests described in 22.4.8 and Normal Temperature Test, Section 25.

22.4.8 The representative device shall be connected to a rated voltage source and caused to operate by depressing the "TEST" switch or by otherwise verifying that the intended functions meet the requirements of this standard.

23 System Operational Test Requirements

23.1 General

23.1.1 System components, that is a charging circuit interrupting device, an isolation monitor/interrupter or a ground monitor/interrupter, shall be subjected to the tests in 23.2 – 23.7 as appropriate for that component.

23.1.2 A charging circuit interrupting device (CCID) shall act to interrupt the circuit when the current, I, reaches or exceeds the threshold current specified in 23.2 within the time specified in 23.3. See 23.4 and 23.5.

23.1.3 An isolation monitor/interrupter shall act to interrupt the circuit when the resistance to ground through a single fault is reduced to less than the predetermined value. See 23.6.

23.1.4 A ground monitor/interrupter shall monitor the grounding path and act to open the circuit when the grounding path impedance increases to an unacceptable level. See 23.7.

23.2 Ground-fault trip threshold

23.2.1 A charging circuit interrupting device intended to be used on a grounded system shall act to interrupt the electrical circuit when the ground-fault current reaches a value as described in 23.2.2 – 23.2.10.

23.2.2 A charging circuit interrupting device designated as Type CCID5 shall act to interrupt the circuit when the fault current to ground, I, reaches the applicable threshold as shown in Table 4. The values shown are RMS milliamperes.

Table 4
Required trip threshold for Type CCID5 devices

Type of source for fault-current	Ground fault threshold – I (rms mA) or (MIU)
60 Hz	5 ±1
DC	30
DC + AC	5 minimum. See 23.2.4 and Figure 6
AC > 60 Hz	5 x FF but not greater than 70. See 23.2.5 and Figure 7.
Multiple frequencies	5 x FF but not greater than 70. See 23.2.7 and Figure 9.
FF – is the Frequency Factor from Figure 7.	

23.2.3 A charging circuit interrupting device that is designated as a Type CCID20 device shall act to interrupt the circuit when the current to ground reaches the threshold as shown in Table 5.

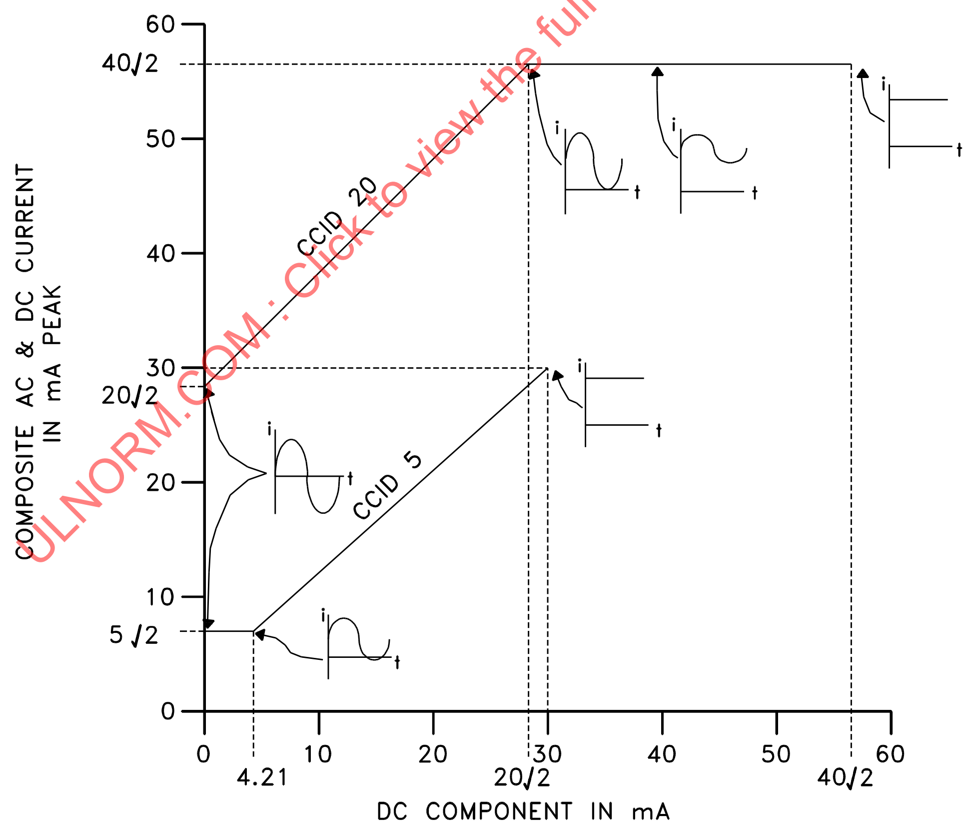
Table 5
Required trip threshold for Type CCID20 devices

Type of source for fault current	Ground fault threshold – I (rms mA) or (MIU)
60 Hz	15 – 20
DC	40 x 1.414
DC + AC	20 min. See 23.2.4 and Figure 6.
AC > 60 Hz	20 x Ratio in accordance with 23.2.6 and Figure 8.
Multiple frequencies	20 x Ratio in accordance with 23.2.8 and Figure 9.

23.2.4 The permitted trip threshold for a CCID intended to be used with a known supply that includes both AC and DC shall be determined using Figure 6. When the AC content is not known, the trip level shall be 5 ±1 MIU for a Type CCID5 and 15 – 20 MIU for a Type CCID20.

Figure 6

Trip threshold for a CCID



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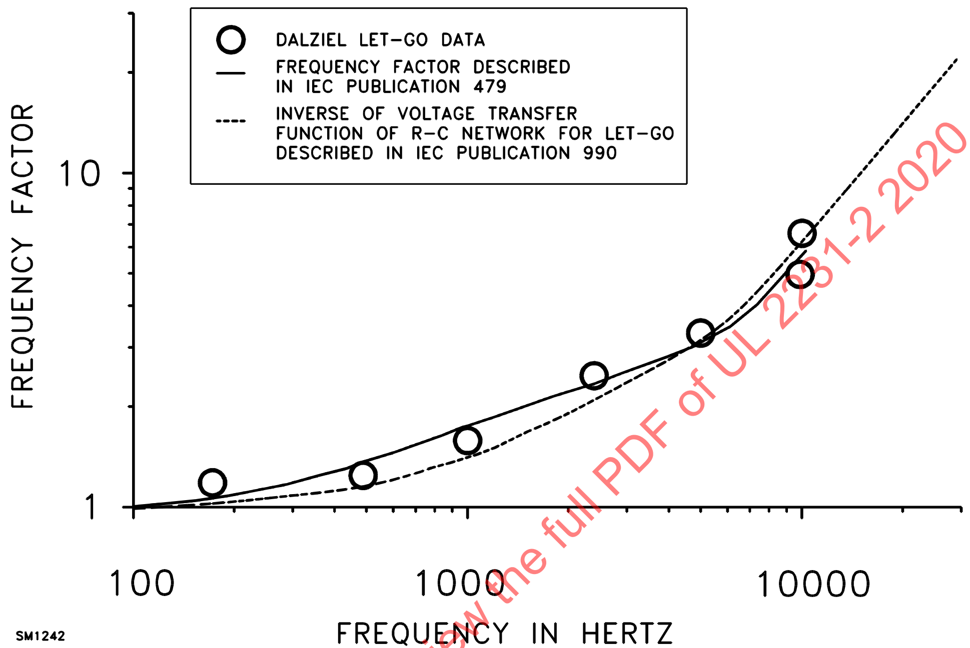
23.2.5 When a Type CCID5 device is intended to operate on a circuit whose rated frequency is greater than 60 Hz, the permitted trip threshold is equal to 5 times the Frequency Factor (FF) as shown in Figure 7.

Figure 7

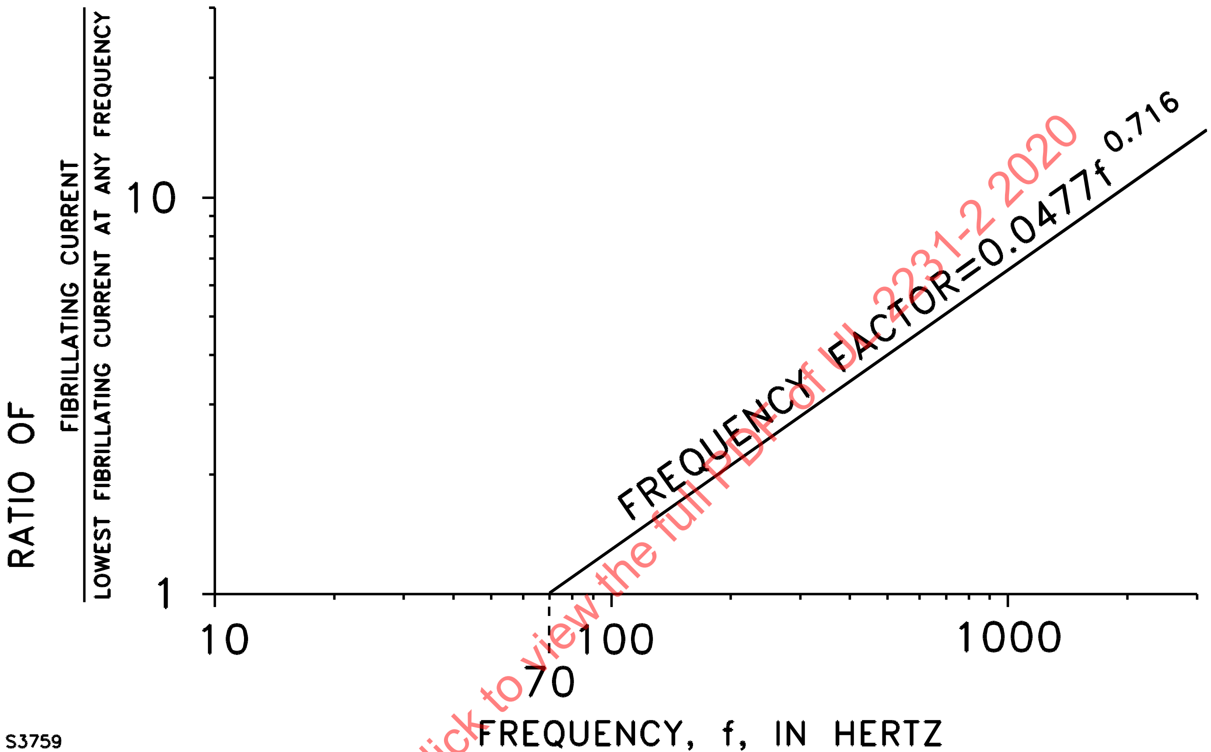
Frequency factor for Type CCID5 devices



23.2.6 When a Type CCID20 device is intended to operate on a circuit whose rated frequency is greater than 60 Hz, the permitted trip threshold is equal to 20 times the value determined from Figure 8, but no more than 70 mA.

Figure 8

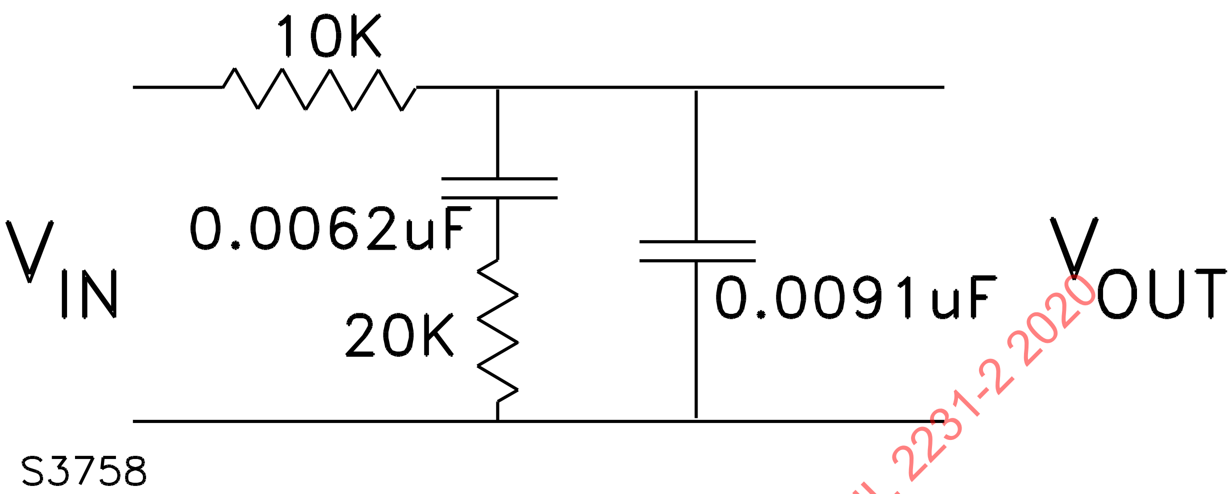
Frequency factor for Type CCID20 devices



23.2.7 The permitted trip level for a Type CCID5 device intended for use on a circuit with a supply where multiple frequencies are present, shall be determined by applying the supply to the circuit shown in Figure 9. The Frequency Factor is determined by dividing the V-IN value by the measured V-OUT value. The permitted threshold value, in milliamperes, for tests is determined by multiplying the Frequency Factor by 5.

Figure 9

Trip threshold frequency factor network



23.2.8 The permitted trip level for a Type CCID20 device intended for use on a circuit with multiple frequencies shall be determined as described in 23.2.7 except that the Frequency Factor is multiplied by 20. The trip threshold shall not exceed 70 mA.

23.2.9 A CCID intended for use on a circuit with multiple frequencies shall be tested with the specific supply or at a sufficient number of frequencies to determine whether operation with any intended supply is assured.

23.2.10 A CCID that is rated for operation with more than one type of supply, that is 60 Hz and higher frequencies or other combinations, shall be tested using each type of supply or a variety of supplies sufficient to cover the claimed range of supplies.

23.3 Interrupting time

23.3.1 A CCID shall be capable of interrupting the electric circuit to the load when the fault current to ground, I, is within the range of the trip threshold, as specified in Table 4 or Table 5, to the value related to 500 ohms (the minimum equivalent for the body) determined by using the equations shown below, within the time interval T in accordance with the relationships in Table 6, except that the time to trip is not required to be less than 20 ms.

$$I = \frac{1.1V}{500}$$

in which:

I is the fault current, and

V is the RMS system voltage.

Table 6
Interrupting time

Type of source for fault current	Maximum allowable opening time (sec)
All except pure DC	$T = (20/I)^{(1.43)}$ for values of I that equal or exceed the maximum permitted trip threshold
Direct current (No AC content)	$T = (40 \times 1.414/I)^{4}$ for values of I > 30 ≤ 100.6 mA $T = (20/I)^{(1.43)}$ for values of I greater than 100.6 mA
in which T is expressed in seconds and I is expressed in milliamperes.	

23.3.2 A portable device shall comply with the provisions of 23.2 and 23.3 with and without one or more of the following conditions in its power-supply cord:

a) The ungrounded and grounded conductors transposed at the attachment plug terminals.

b) An open circuit in the grounding conductor.

c) An open circuit in any one power conductor.

d) Except when normal operation of the supervisory circuit provides an indication of trouble, the ungrounded and grounding conductors of the power-supply cord transposed at the attachment plug terminals.

23.3A Environmental sequence

23.3A.1 A device shall comply with all of the applicable tests in 23.4 – 23.7, while operating in ambient air at 25°C (77°F). Except as indicated in 23.3A.2 – 23.3A.10, the device shall also be tested while in ambient air at 66°C (150.8°F), -35°C (-31°F), and 25°C (77°F) by following the sequence of steps shown in Table 8, and the requirements of this section. The ambient air temperature shall be changed to each value without intentional delay.

23.3A.2 When conducting the applicable tests described in 23.4 – 23.7, it shall be acceptable for only the assemblies providing the protective functions being tested to be subjected to the test sequence shown in Table 8. The assemblies shall include those providing power for the protective function to operate, as well as the interruption function.

23.3A.3 When conducting the test of Step 3 of Table 8 at 66°C (150.8°F), in the event a device is self-protecting such that it trips at this ambient temperature, lower values of load current shall be employed, until the device just continues to operate at this temperature. This value of load current shall also be used for step 4 if applicable for the most adverse operating condition.

23.3A.4 When the test of Step 3 of Table 8 is conducted at rated load current, the tests of Steps 5 and 6 shall not be performed.

23.3A.5 If a device is not intended to operate at a temperature greater than 40°C (104°F), it shall be tested in accordance with Steps 5 and 6 of Table 8 instead of Steps 3 and 4.

23.3A.6 If a device is intended to operate at a temperature greater than 66°C (150.8°F), the test of Steps 3 and 4 of Table 8 shall be conducted at the intended temperature.

23.3A.7 If a device employs a thermal limiting function that intentionally prevents operation above a specific ambient temperature, the test of Steps 3 and 4 of Table 8 shall be conducted at the maximum permissible temperature.

23.3A.8 If a device is not intended to operate at a temperature lower than -5°C (23°F), it shall be tested in accordance with Steps 10 and 11 of Table 8 instead of Steps 8 and 9.

23.3A.9 If a device is intended to operate at a temperature lower than -35°C (-31°F), the test of Steps 8 and 9 of Table 8 shall be conducted at the intended temperature.

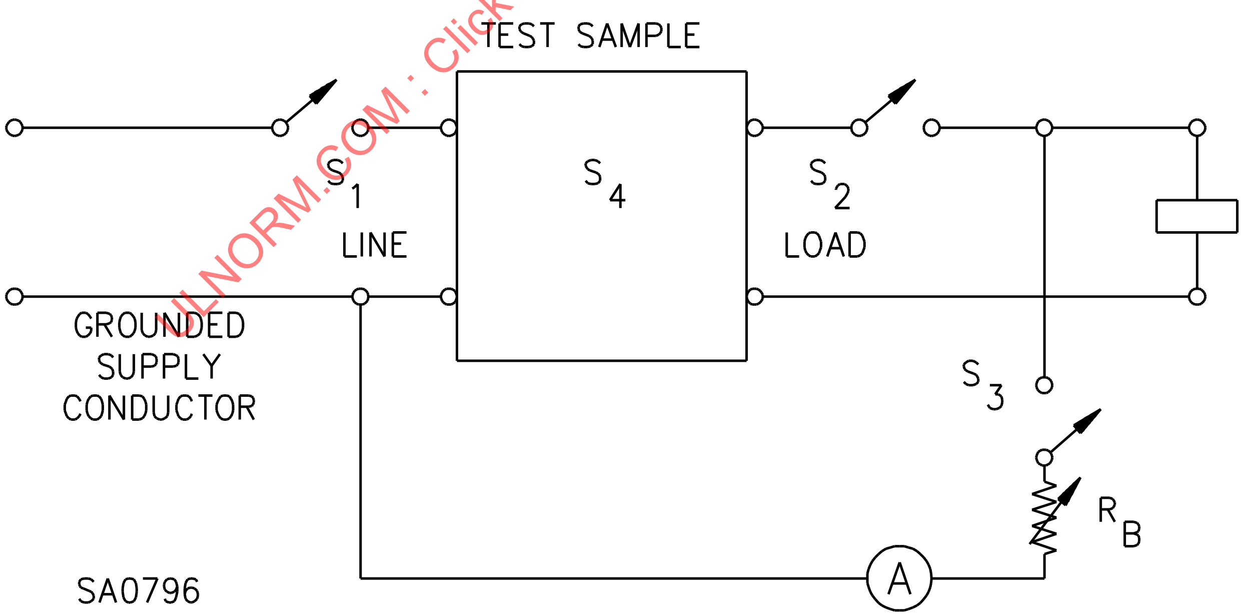
23.3A.10 If a device employs a thermal limiting function that intentionally prevents operation below a specific ambient temperature, the test of Steps 8 and 9 of Table 8 shall be conducted at the lowest allowable temperature.

23.4 High-resistance ground fault test

23.4.1 To determine compliance with the provisions of 23.1 – 23.3 a device intended for use on a grounded system shall be connected as shown in Figure 10 and tested as described in 23.4.2 – 23.4.4 in the sequence described in Section 23.3A.

Figure 10

High-resistance ground-fault test circuit



S4 – Integral on-off or other operating switch (not test switch)

23.4.2 In performing the test mentioned in 23.4.1, the resistance R_B shall be varied to obtain the test values of current to be indicated by meter A. The sum of R_B and the resistance of meter A shall be not less than 500 ohms. The test values of current shall include the minimum specified (threshold) and the maximum possible (500 ohms) and one or two additional values as determined necessary to assure compliance with the provisions of 23.2 and 23.3. Ten measurements of current duration shall be made for each mode of operation described and for each value of test current selected. The average of each group of ten shall not exceed the time allowed in Table 6. Individual measurements are capable of exceeding the time allowed in Table 6 provided that such measurements do not exceed 125 percent of the time allowed in Table 6. The modes of operation noted in Table 7 shall be performed. For devices intended to be used on multi-wire or multi-phase circuits, the resistance shall be connected between each ungrounded load terminal, in turn, and the grounded conductor of the supply.

23.4.3 To determine that a device trips at the required level, in addition to the tests described under 23.2, a representative device shall be connected to a supply adjusted to rated voltage and a variable resistor connected as a ground fault (see Figure 10). The resistance shall be decreased until the device operates. The value of current that caused tripping shall be no greater than the value from Table 4 or Table 5, as appropriate. The test shall be repeated for values of voltage equal to 85 percent and 110 percent of rated voltage. The test shall be performed at each step in the sequence described in Section 23.3A that requires testing.

Table 7
Modes of operation

Precondition of circuit[a]		Action that starts ground-fault current
A	Switch S1 closed Switch S2 closed Switch S3 closed Switch S4 open	Switch S4 shall be moved (1) in one continuous motion to its extreme position, and (2) to the position at which current just starts, and the operating handle held in that position.
B	Switch S1 open Switch S2 closed Switch S3 closed Switch S4 closed	Switch S1 shall be closed
C	Switch S1 closed Switch S2 open Switch S3 closed Switch S4 closed	Switch S2 shall be closed
D	Switch S1 closed Switch S2 closed Switch S3 open Switch S4 closed	Switch S3 shall be closed[b]

[a] See Figure 10

[b] In obtaining the minimum value of current specified for the rated class, R_B shall be decreased gradually until tripping occurs, and preset for the desired value.

23.4.4 In the event that it is necessary to prevent tripping of the device under test while adjusting for various values of current in resistance R_B, care shall then be taken to assure that components that are not continuously energized in normal operation are not caused to be continuously energized during the adjustment procedure. Attempts to bypass one or more poles of the device usually produce the condition described.

23.4.5 In determining the "most adverse" conditions mentioned in Section 23.3A and Table 8, each of the operating parameters described in (1) – (5) of item (b) below shall be varied so as to obtain a combination, if any, determined to be most adverse to the tested function of the device, at room-temperature ambient. The "most adverse" condition of an operating parameter shall be learned from:

a) A study of the design, and

b) When necessary, from operating the representative device, provided that when it is necessary to operate the representative device it is not required to be subjected to any of the tests described in these requirements:

1) LINE VOLTAGE – The closed-circuit line voltage shall be adjusted within the range of 85 – 110 percent of rated voltage, at rated load, with the cover(s), if any, of the device closed, and with the device supported in its marked mounting position. When no mounting position is marked on the device, any one position that is determined to be normal for the device shall be arbitrarily selected. The line voltage to the device shall be obtained from a source having sinusoidal wave-form and free from any measurable transient voltage rises or dips.

2) MOUNTING POSITION – Except for a permanently-connected device marked to specify a mounting position, the device shall be placed in different positions. The mounting position of a permanently-connected device that is marked to specify a mounting position shall be varied from the marked mounting position by no more than 10 degrees (for a total range of 20 degrees). Rated load shall be connected and the cover(s), if any, of the device shall be closed.

3) COVER POSITION – Any cover or door normally moved or removed during operation or functioning of the device, or that is capable of being moved or removed without the use of a tool, is able to be so moved or removed. Rated load shall be connected.

4) LOAD – The load is capable of having any value of current, frequency or DC, or a mix of frequencies for which the device is claimed to offer protection up to rated and shall be resistive.

5) GROUNDING – A cord-connected device, and a permanently-connected device not required by method of operation to be grounded, shall be either grounded or ungrounded, whichever is more adverse.

Table 8
Environmental sequence

Ambient air temperature		Opening parameters	Remarks
1.	25.0 ±5.0°C (77 ±9°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
2.	25.0 ±2.0°C (77 ±3.6°F)	Most adverse	Test in accordance with 23.4 and 23.5 or 23.6 or 23.7 as soon as possible to minimize self-heating.
3.	66.0 ±2.0°C (150.8 ±3.6°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.
4.	66.0 ±2.0°C (150.8 ±3.6°F)	Most adverse	Test in accordance with 23.4 and 23.5 or 23.6 or 23.7.
5.	40.0 ±2.0°C (104 ±3.6°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.

Table 8 Continued on Next Page

Table 8 Continued

Ambient air temperature	Opening parameters	Remarks
6. 40.0 ±2.0°C (104 ±3.6°F)	Most adverse	Test in accordance with 23.4 and 23.5 or 23.6 or 23.7
7. 25.0 ±5.0°C (77 ±9°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
8. −35.0 ±2.0°C (−31 ±3.6°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
9. −35.0 ±2.0°C (−31 ±3.6°F)	Most adverse	Test in accordance with 23.4 and 23.5 or 23.6 or 23.7 as soon as possible to minimize self-heating.
10. −5.0 ±2.0°C (23 ±3.6°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
11. −5.0 ±2.0°C (23 ±3.6°F)	Most adverse	Test in accordance with 23.4 and 23.5 or 23.6 or 23.7 as soon as possible to minimize self-heating.
12. 25.0 ±5.0°C (77 ±9°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.
13. 25.0 ±5.0°C (77 ±9°F)	Most adverse	Test in accordance with 23.4 and 23.5 or 23.6 or 23.7

23.5 Second neutral ground

23.5.1 A charging circuit interrupting device that is intended for use with a grounded supply shall comply with the provisions of 23.2 and 23.3 when the circuit conductor that is normally grounded at the service only, is also grounded at a point in the load circuit of the device.

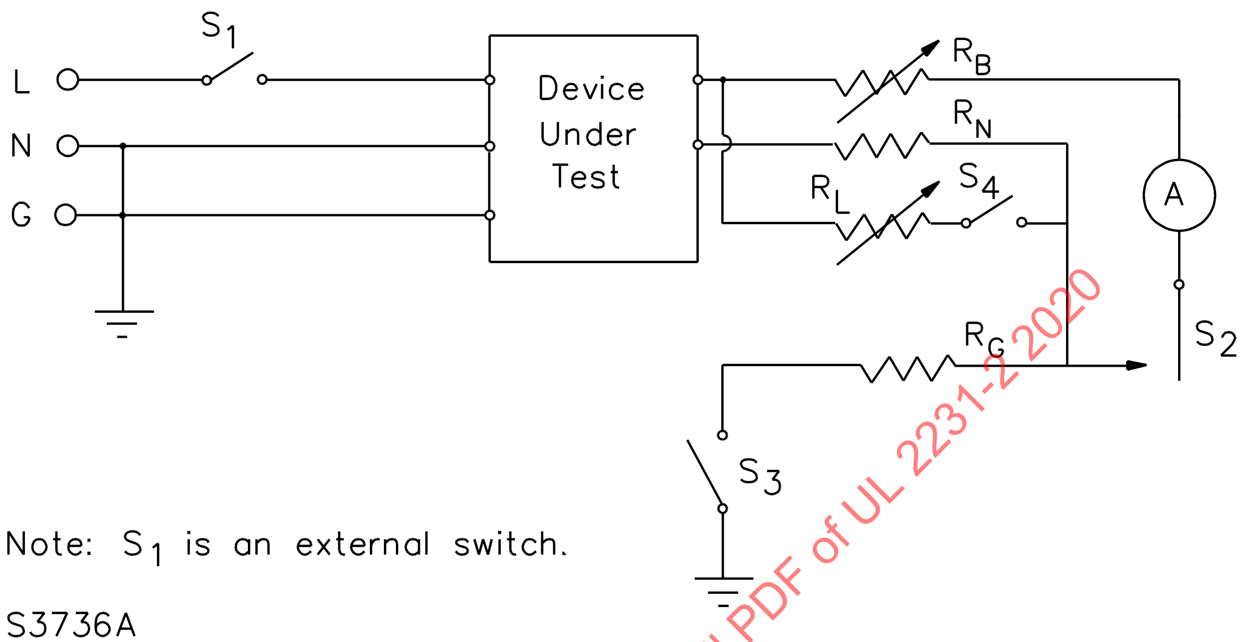
23.5.2 Compliance with 23.5.1 is not required for a system where the output is not permitted unless a load is connected. Compliance is met by a demonstration of that feature which suppresses the output until a load of sufficient value is present if tripping occurs when a second connection between the grounded and grounding conductors is present.

23.5.3 Systems that include an isolation monitor/interrupter or ground monitor/interrupter that detects the condition and opens the circuit in the time required in this Standard are not required to comply with 23.5.1.

23.5.4 In determining compliance with the provisions of 23.5, the representative device shall be connected as shown in Figure 11 and tested in the sequence of steps described in Section 23.3A, as described in 23.5.6 for the highest and lowest combination of R_N and R_G as indicated in Table 9. The tests shall be conducted both with R_L open and with R_L adjusted for rated current. The test voltage shall be the most adverse as determined in 23.4.5.

Figure 11

Supplementary high-resistance test circuit



23.5.5 When testing as described in 23.5.6, additional values of current indicated by meter A and in resistance R_L and other values of resistances R_N and R_G are capable of being employed when necessary to determine compliance with the provisions of 23.5.1. Such other values shall be in accordance with the rating of the product and the cable constructions represented in Table 9. For conductor sizes not shown in Table 9 the values of R_N and R_G shall be calculated based on the impedance of the conductor used in the system under investigation. Values corresponding to 1.5 m (5 ft) and 30.5 mm (100 ft) shall be used for combination 1 and 6 respectively. The product shall trip within the time interval prescribed in 23.3.

23.5.6 The representative device shall be tested following the procedure indicated in (a) – (h).

a) Select the combination of R_G and R_N from Table 9 as required.

b) Open S_3 and S_4. Close S_1 and S_2.

c) Using ammeter (A), set the current to 6.0 mA for a CCID 5 or 20 mA for a CCID 20 by adjusting R_B.

d) With S_2 and S_4 open and S_3 closed, close S_1. If the device trips, trip time need not be recorded. If the device does not trip, close S_2 and record trip time. Repeat 10 times.

e) Repeat step (d) with S_2 closed, S_3 closed, and close S_1 and record trip time.

f) With S_2 and S_4 open and S_1 closed, close S_3 and if the device trips, trip time need not be recorded. If the device does not trip, close S_2 and record trip time. Repeat 10 times.

g) Repeat procedure (a) – (f) for the combinations of resistors from Table 9 which apply.

h) Repeat procedure (a) – (g) with S_4 closed (which would switch on the load) and with R_L = to rated load current.

Table 9
Resistance in ohms[a]

Combination	mm² (AWG) copper wire size for field wiring			
	2.08 (14) and 3.31 (12)		5.26 (10)	
	R_N	R_G	R_N	R_G
1	0.008	0.008	0.005	0.005
2	0.08	0.20	0.05	0.13
3	0.4	1.0	0.25	0.65
4	0.008	0.032	0.005	0.028
5	0.08	0.32	0.05	0.28
6	0.4	1.6	0.25	1.4

[a] The combinations shown represent discrete lengths and constructions of cable or flexible cord. Resistances R_N and R_G represent respectively the resistance of the grounded and the grounding conductors of the cable or cord.

23.6 Tests for isolation monitor/interrupters

23.6.1 An isolation monitor/interrupter system for use on an ungrounded system shall disconnect the electric circuit when the resistance to ground from any ungrounded conductor is less than 100 ohms/volt, as determined from the rated voltage of the charger.

23.6.2 To demonstrate that the isolation monitor/interrupter operates as intended, a representative isolation monitor/interrupter shall be connected as shown in Figure 12 and when required, at rated control voltage, and tested as described in 23.6.3, in the sequence described in Section 23.3A.

23.6.3 In performing the test mentioned in 23.6.2 the resistance R_F shall be:

a) Preset to 200% of the set point and introduced into the circuit by means of switch S, and

b) Reduced with switch S closed to the point that the monitor has responded.

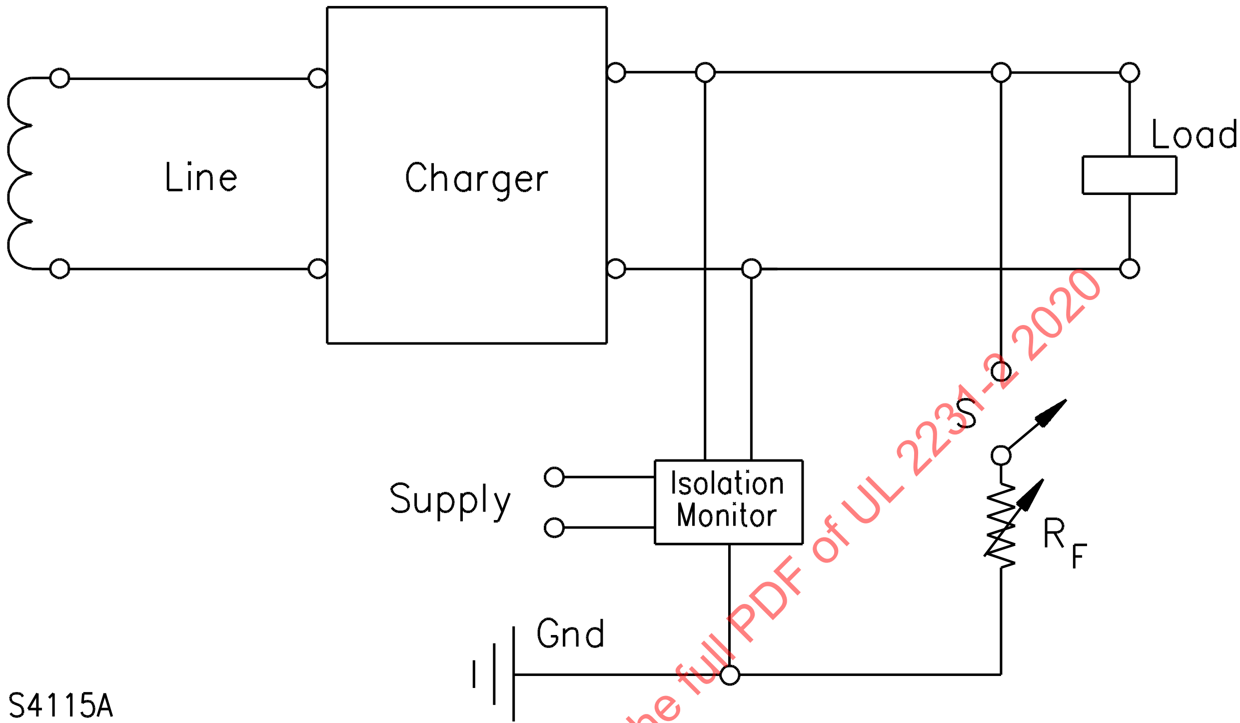
23.6.4 The isolation monitor/interrupter shall be operated ten times for each method described in 23.6.3 in each of the modes described in 23.6.3. For part (a) the time to disconnect shall not exceed 10 s. For part (b) the resistor value R at tripping shall be greater than 85 ohms/volt.

23.6.5 The test described in 23.6.2 shall be performed with the adjustable resistance connected to each ungrounded load conductor, in turn.

23.6.6 When the isolation monitor/interrupter requires a control voltage supply, the test described in 23.6.2 shall be repeated with the control voltage set to 85 percent and 110 percent of rated voltage, in turn.

Figure 12

Isolation monitor test circuit



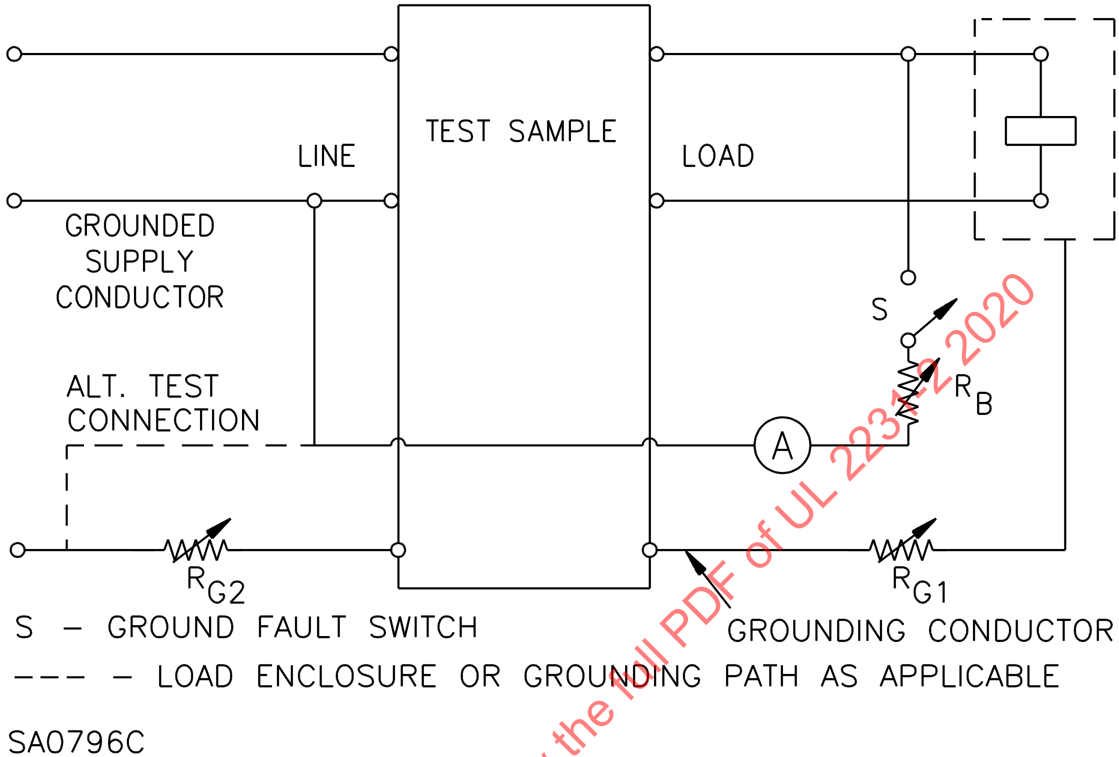
23.7 Tests for ground monitor/interrupter

23.7.1 A device intended to provide the ground monitor/interrupter function of a system shall be capable of detecting an unacceptable impedance in the grounding circuit and causing interruption of the power circuit.

23.7.2 To demonstrate that the device operates as intended, a representative device shall be connected to a circuit as shown in Figure 13 and tested as described in 23.7.3 – 23.7.8, in the sequence described in Section 23.3A.

Figure 13

Ground monitor test circuit



23.7.3 With no ground fault present (switch S open), beginning with a low resistance, the resistance of the grounding path shall be increased using resistance R_{G1} to a value which causes interruption.

23.7.4 With no ground fault present (switch S open), beginning with a low resistance, the resistance of the grounding path shall be increased using resistance R_{G2} to a value which causes interruption.

23.7.5 With no ground fault present (switch S open), beginning with a high resistance in the load circuit ground path (R_{G1}), the circuit shall be energized. The device shall act to prevent operation, that is, the load shall not be energized.

23.7.6 With no ground fault present (switch S open), beginning with a high resistance in the line circuit ground path (R_{G2}), the circuit shall be energized. The device shall act to prevent operation, that is, the load shall not be energized.

23.7.7 The tests described in 23.7.3 – 23.7.6 shall each be repeated until 10 operations have been performed.

23.7.8 The tests described in 23.7.3 – 23.7.7 shall be repeated with a ground-fault current equal to the trip current minus one milliampere (switch S closed).

23.7.9 *Deleted*

24 Resistance to Environmental Noise Test

24.1 General

24.1.1 A protective device, including a CCID, ground monitor/interrupter or an isolation monitor/interrupter, shall function as intended after exposure to the conditions described in 24.2 – 24.10. Additionally, where indicated in the individual tests described in 24.2 – 24.10, the protective device shall function as intended during the exposure.

24.1.2 Except as indicated in 24.1.3, a protective device, including a CCID, ground monitor/interrupter or an isolation monitor/interrupter, shall not interrupt power to the load when exposed to each of the conditions described in 24.2 – 24.10.

24.1.3 It shall be acceptable for a protective device including a CCID, ground monitor/interrupter or an isolation monitor/interrupter, to interrupt power to the load under any of the following conditions:

a) Where permitted in the individual test conditions described in 24.2 – 24.10

b) For the Electrostatic Discharge Immunity Test of 24.3, and the Electrical Fast Transient Immunity Test of 24.6, power to the load may be interrupted once as a result of each exposure. However, except as indicated in (1) and (2) below, the protective device shall automatically restore power output following the exposure.

1) Compliance with the power output restoration requirement of 24.1.3 (b) shall not be required for devices that incorporate a point of sale or user authentication feature. It shall be acceptable for such devices to return to a standby mode that requires a manual action to initiate resumption of the power output.

2) Compliance with the power output restoration requirement of 24.1.3 (b) shall not be required for devices that do not allow automatic resumption of power. It shall be acceptable for such devices to return to a standby mode that requires a manual action to initiate resumption of the power output.

c) If the device utilizes an automatic restart feature that complies with the Standard for Software in Programmable Components, UL 1998, provided the device employs a CCID self-test prior to restart.

24.1.3A An Electric Vehicle Supply or Charging Equipment monitored by an Isolation Monitor Interrupter (IM/I) shall be subjected to the following tests under the following conditions:

a) For Harmonic Distortion Immunity test of 24.2 tested at any output load within its rated operating range to activate the equipment output.

b) For Capacitor Switching Transient test of 24.9 tested at any output load within its rated operating range to activate the equipment output.

24.1.4 The same representative device shall be tested for all of the tests in 24.2 – 24.10.

24.2 Harmonic distortion immunity

24.2.1 Annex A, Ref. No. 13 shall be used as the basis for requirements. The unit shall function correctly during exposure to 10 percent harmonic distortion between the 2nd and the 5th harmonics, and 2 percent harmonic distortion between the 6th and the 30th harmonics. Harmonic distortion shall be injected on the input power lines at full rated load and no-load conditions.

24.3 Electrostatic discharge immunity

24.3.1 Annex A, Ref. No. 14 shall be used as the reference for testing and measurement techniques. The test limits are:

a) 8 kV, positive and negative polarity, for direct contact discharge, and

b) 15 kV, positive and negative polarity, for air discharge.

24.4 Radiated electromagnetic field immunity

24.4.1 Annex A, Ref. No. 15 shall be used as the basis for requirements. These requirements state that the unit shall function correctly during exposure to 20 V/m. Annex A, Ref. No. 16 shall be the test measurement reference. The frequency range shall be 80 – 1000 MHz. The protective device shall have the ability to recognize and respond to a fault while exposed to selected frequencies. The frequencies to be used encompass the standard broadcast frequency ranges for commercial and "ham" radio and television. The step size for the test frequency ranges shall be 1 percent of fundamental.

24.4.2 Annex A, Ref. No. 17 shall be used as the basis for requirements for tests using bursts of radiation (as can be emitted by digital phones and other digital devices). The test requirements state that the unit shall function correctly during exposure to 20 V/m at a 200 Hz digital modulation, 50 percent duty cycle, between 895 MHz and 905 MHz. Other frequencies ranges shall be considered.

24.5 Immunity to conducted disturbances, induced by RF fields

24.5.1 The test method described in Annex A, Ref. No. 18 shall be followed. The representative product shall be subjected to a conducted disturbance at 20 V over a frequency range of 150 KHz to 80 MHz.

24.6 Electrical fast transient immunity

24.6.1 Annex A, Ref. No. 19 shall be used as the basis of requirements. Annex A, Ref. No. 20 shall be the standard for testing methods and to specify multiple levels of limits based on installation environment. Level 3 (2 kV transients on power lines) shall be the generic test limit.

24.7 Voltage dips, short interruptions and voltage variations immunity

24.7.1 Annex A, Ref. No. 21 shall be used as the basis for requirements. Annex A, Ref. No. 22 shall be the standard for testing methods. The protective aspects of the device shall not be compromised under the following power line conditions:

a) 100 percent voltage dip for 10 ms,

b) 60 percent voltage dip for 200 ms, or

c) 30 percent voltage dip for 1 s.

See also 24.7.2.

24.7.2 The protective device is permitted to turn OFF during the disturbances specified in 24.7.1 as long as:

a) This removes the power to the protected unit, and

b) Except as indicated in (1) and (2) below, the power output is automatically restored when input power is restored to at least 85 percent of rated voltage.

1) Compliance with the power output restoration requirement of 24.7.2 (b) shall not be required for devices that incorporate a point of sale or user authentication feature. It shall be acceptable for such devices to return to a standby mode that requires a manual action to initiate resumption of the power output.

2) Compliance with the power output restoration requirement of 24.7.2 (b) shall not be required for devices that do not allow automatic resumption of power. It shall be acceptable for such devices to return to a standby mode that requires a manual action to initiate resumption of power output.

24.8 Magnetic field immunity

24.8.1 Annex A, Ref. No. 23 shall be used as the basis for requirements. The device shall operate correctly when exposed to a field of 30 A/m at the fundamental frequency.

24.9 Capacitor switching transient test

24.9.1 A device shall not trip when exposed to a variable ringing wave.

24.9.2 The device shall be connected to a source of rated supply and at full rated load. The ringing wave described in 24.9.3 shall be directly injected onto the input power line using a coupling-decoupling network (CDN) or equivalent.

24.9.3 The peak amplitude of the ringing wave shall be 40 ±2 percent of the peak amplitude of the fundamental (60 Hz) and shall decay exponentially with a time constant of 1.6 ms. The ringing wave test frequencies are 1, 2, 3, 4, and 5 kHz. Each ringing wave frequency shall be applied 5 times randomly at to the input power line, with each application lasting for 8 ms.

24.10 Voltage surge test

24.10.1 The representative device shall be capable of withstanding voltage impulses as specified in 24.10.2, using a full-wave 1.2 x 50 µs impulse in accordance with Annex A, Ref. No. 24, and having a crest value in accordance with 24.10.2. The surge generator shall have a surge impedance of 2 ohms.

24.10.2 The representative device shall be tested such that each terminal intended to be connected to an ungrounded circuit conductor is subjected to the following surge voltage impulses in the order given:

a) Three applications of a positive impulse voltage with a 6 kV crest and three of a negative impulse voltage with a 6 kV crest. Each of the specified impulses shall be superimposed on the AC power with the device energized and applied phase angles of 90 and 270 electrical degrees for a total of 12 impulses. The follow current shall be a minimum of 3 kA available. When flash-over is noted on any of a group of three, an additional nine impulses of the type which had flash-over shall be applied. Any flash-over during the additional impulses is unacceptable.

Tripping or denial of power by the device following any applied impulse shall be permitted provided the device can be reset prior to the next surge application.

b) Three applications of a positive impulse voltage with a 3 kV crest and three of a negative impulse voltage with a 3 kV crest. Each of the specified impulses shall be superimposed on the AC power with the device energized and applied phase angles of 90 and 270 electrical degrees for a total of 12 impulses. Any tripping or denial of power by the device as a result of the impulses is unacceptable.

25 Normal Temperature Test

25.1 When carrying rated current and with rated voltage applied, a device shall not attain a temperature at any point that is sufficiently high to:

a) Constitute a risk of fire,

b) Affect injuriously any materials used in the device, or

c) Exhibit greater rises in temperature at specific points than indicated in Table 10, based on an assumed average ambient temperature in normal service of 25°C (77°F).

The representative device shall be connected to a supply adjusted to rated voltage. Loads shall be connected to the load terminals to cause the load conductors to carry rated current. Devices shall be tested with rated voltage or with rated current in the load circuits and rated voltage to the control circuit, including the ground-fault circuitry.

Table 10
Maximum temperature rises

Insulating materials	Temperature rise	
	°C	°F
Wire-wound coils		
Class 105 insulation:		
Thermocouple method	65	117
Resistance method	85	153
Class 130 insulation:		
Thermocouple method	85	153
Resistance method	105	189
Wire insulation or insulation tubing	35	63
Electrical tape	55	99
Varnish-cloth insulation	60	108
Fiber employed as electrical insulation	65	117
Phenolic composition or melamine[a]	110	198
Urea composition[a]	60	108
Other insulating materials[a]	–	–

[a] The acceptability of insulating materials shall be determined with respect to properties – such as flammability, arc resistance, and similar properties – based on a temperature rise plus 40°C (104°F).

25.2 In performing the test described in 25.1, parts and circuits that are heated only when there is ground-fault current shall be continuously heated by providing a value of ground-fault current just low enough not to cause tripping.

25.3 Coil or winding temperatures shall be measured by thermocouples unless access is unable to be gained for mounting a thermocouple (for example, a coil enclosed in sealing compound) or unless the coil wrap includes thermal insulation or more than two layers (0.8 mm or 1/32 inch maximum) of cotton, paper, rayon, or similar insulating material.

25.4 Except at coils, temperature readings shall be obtained by means of thermocouples consisting of wires not larger than 0.205 mm^2 (24 AWG), and a temperature is determined to be constant when three successive readings, taken at intervals of 10 percent of the previously elapsed duration of the test, but not less than 5-minute intervals, indicate no change. When thermocouples are used in the determination of temperatures in connection with the heating of electrical devices, it is common practice to employ thermocouples consisting of 0.05 mm^2 (30 AWG) iron and constantan wires and a potentiometer type of indicating instrument. Such equipment shall be used whenever referee temperature measurements by thermocouples are necessary.

25.5 Ambient air shall be at any convenient temperature within the range of 20 – 30°C (68 – 86°F).

25.6 The thermocouples and related instruments shall be accurate and calibrated in accordance with accepted laboratory practice. The thermocouple wire shall conform with the requirements specified in Annex A, Ref. No. 25.

26 Dielectric Voltage-Withstand Test

26.1 In a device, except as described in 26.3, the insulation and spacings between:

a) Line-connected circuits, and

b) Other circuits and accessible parts

shall withstand without breakdown the test potentials shown in Table 11. The tests of line connected circuits shall include a test between the line terminals and load terminals of the power circuit. The basic insulation and spacings of other circuits too shall withstand without breakdown the test potentials shown in Table 11, except that where the potential does not exceed 70 V peak in normal service, the test potential shall be 500 Vrms. See Table 3.

Table 11
Dielectric voltage-withstand

Insulation tested	Potential (volts)
Basic	1000 + twice the rated voltage
Supplementary	2000 + twice the rated voltage
Reinforced	3500 + twice the rated voltage

26.2 The test voltage across the dielectric of a capacitor shall be 900 volts.

26.3 Basic insulation and spacings inherent in a component is not required to withstand the test potentials mentioned in 26.1 when the component in question complies with the requirements applicable to the component.

26.4 In order to determine compliance with the provisions of 26.1, the insulation and spacings shall be subjected to 60 Hz essentially sinusoidal potentials increased from zero to the values specified and maintained for a period of one minute. The increase in the applied potential shall be at a substantially uniform rate and as rapid as is consistent with the value of the applied potential being correctly indicated by the voltmeter.

26.5 Where the construction of the device is such that access to the insulation to be tested is denied, suitable subassemblies are capable of being employed.

26.6 In the application of test potentials to insulating surfaces, metal foil is able to be used when care is taken to avoid flash-over at the edge of the insulation.

26.7 The measuring circuit of an isolation monitor and any other components in parallel with the applied potential shall be permitted to be disconnected before performing the dielectric voltage withstand test.

27 Overload Test

27.1 A device shall have the necessary interrupting capacity.

27.2 In order to determine compliance with the provisions of 27.1, a device that is able to open a load circuit shall be caused to switch an essentially resistive load adjusted for a value of load current equal to 1.5 times the ampere rating of the device and a power factor within the range of 0.90 – 1.0. A DC rated device shall be caused to switch a circuit adjusted for a value of noninductive load current equal to 1.5 times the ampere rating of the device.

27.3 The supply circuit for the test mentioned in 27.2 shall have the capacity to provide a closed-circuit voltage not less than 85 percent of the rated voltage of the device. Except when a higher value is agreed to by those concerned, the open-circuit voltage shall be in the range of 100 – 105 percent of the rated voltage of the device. A 1-A fuse shall be connected between the grounded conductor of a grounded supply circuit and accessible conductive parts of the device. This fuse shall not operate to open the circuit.

27.4 In performing the test mentioned in 27.2 the device shall be switched “on” and, after no less than one cycle, switched “off”, for a total of 50 cycles of operation, at the rate of six cycles per minute.

27.5 In the event that the device operation does not permit the cycle times indicated in 27.4, cycle times as close as possible to these shall be used.

27.6 A device intended to switch a particular specific load that does not operate on 60 Hz or DC shall be caused to switch the intended load, or an equivalent load, adjusted for 150 percent of rated current 50 times. The device shall be operated at a rate not to exceed ten times per minute.

28 Endurance Test

28.1 A device shall have the necessary capacity for normal operation.

28.2 Except as permitted in 28.5, in order to determine compliance with 28.1, an AC rated device shall be caused to switch an essentially resistive load adjusted for a value of load current equal to the ampere rating of the device and a power factor within the range of 0.90 – 1.0. A DC rated device shall be caused to switch a noninductive load adjusted for a value of load current equal to the ampere rating of the device.

28.3 In performing the test described in 28.2, the device shall be switched “on” and, after one second, switched “off” at a rate of approximately 6 cycles of operation per minute for 6000 cycles. For devices that include a manual supervisory circuit, 3000 of the 6000 cycles shall be performed with automatic tripping by way of the supervisory circuit.

28.4 In performing the test described in 28.2, the capacity of the supply circuit shall be such as to allow a closed-circuit voltage not less than 97.5 percent of the rated voltage of the device. Except when a higher value is agreed to by those concerned, the open-circuit voltage shall be in the range of 100 – 105 percent of the rated voltage of the device. A 1-A fuse shall be connected between the grounded conductor of a grounded supply circuit and accessible conductive parts of the device. This fuse shall not operate to open the circuit.

28.5 A device intended to switch a specific load shall be tested only with the specific load or the equivalent.

29 Low-Resistance Ground Fault Test

29.1 A charging circuit interrupting device shall operate to interrupt the circuit when a low-resistance ground fault is present.

29.2 In order to determine compliance with the provisions of 29.1 the circuit shall be as described in 27.3. The resistance R1 plus R2 shall be adjusted for a value of current equal to 1.5 times the rating of the device and connected as shown in Figure 14 so as to simulate a ground fault. The values of R1 and R2 shall be equal and connected in the line and load circuits, as shown in Figure 14 to simulate the condition where the interrupting device is located near the fault but a long distance from the source. The current shall be initiated 10 times, at intervals of 10 seconds, or longer when it is necessary to reset the device. The 1-A fuse (shown in Figure 14) connected to accessible conductive parts of the device shall not open. Automatic interruption of the fault current shall occur each time in not more than T seconds as determined in accordance with the equation:

$$T = 1.25\left(\frac{10}{V}\right)^{1.43}$$

the average value of time for the 10 operations is not to exceed:

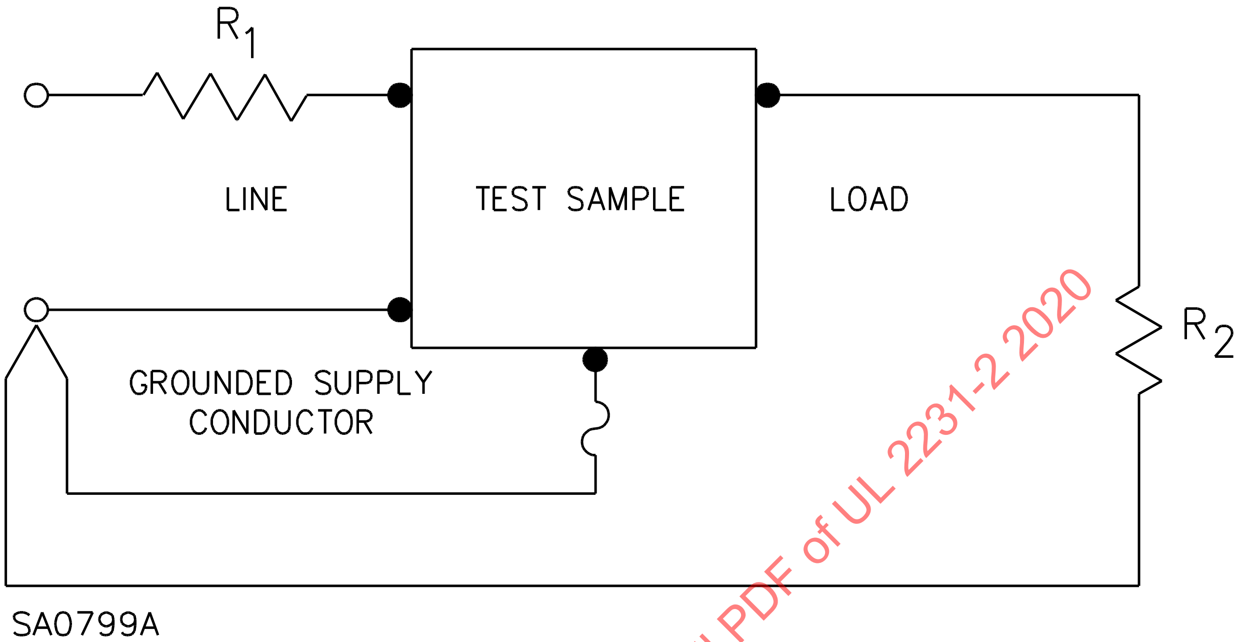
$$T = \left(\frac{10}{V}\right)^{1.43}$$

in which:

V is the value of closed circuit voltage at the line terminals of the device.

Figure 14

Low-resistance ground-fault test circuit



30 Supervisory Circuit Test

30.1 A device with a manual supervisory circuit shall withstand, without damage, being tripped by means of the supervisory circuit and reset, at rated voltage without load, 25 times in as rapid succession as practicable.

30.2 A device with an automatic testing circuit shall withstand, without damage, restarting (when that causes the test to be repeated) 25 times in as rapid succession as practicable.

31 Abnormal Operations Test

31.1 A device shall not become a risk of fire or shock when operating while in an abnormal condition, such as with a short-circuited or open-circuited component.

31.2 A single layer of cheesecloth shall be loosely draped over the device. In addition, a cord-connected device shall rest on white tissue paper supported by a softwood surface. A 1-A fuse shall be connected between the grounded supply conductor and accessible conductive parts of the device.

31.3 The cheesecloth mentioned in 31.2 shall be bleached cheesecloth running approximately 26 – 28 square meters per kilogram mass (14 – 15 square yards per pound mass), and having for any square centimeter, 13 threads in one direction and 11 in the other direction (what is known in the trade as a "count of 32 by 28", that is, for any square inch, 32 threads in one direction and 28 threads in the other direction).

31.4 A device operating under abnormal conditions is considered to have become a risk of injury when:

a) There is glowing or flaming of the cheesecloth or tissue paper mentioned in 31.2,

b) There is emission of molten metal,

c) The fuse mentioned in 31.2 operates to open the circuit,

d) Except when the device is likely to be removed from service, there is dielectric failure (see 31.5),

e) It is possible to touch a part with the articulated probe shown in Figure 1 while there is a risk of shock at that part, or

f) There is any other evidence of a risk of injury.

31.5 When applying the requirements of 31.4 (d),

a) Failure to comply with the provisions of 26.1 is determined to be dielectric failure.

b) A device that is no longer able to complete the electric circuit to the load is considered likely to be removed from service.

31.6 When normal operation of the supervisory circuit after abnormal operation provides an indication of proper functioning of the device, the device shall be capable of complying with the applicable provisions of 23.1.

32 Extra-Low-Resistance Ground Fault Test

32.1 A device intended for use on circuits where such faults can occur shall withstand extra-low-resistance ground faults.

32.2 In order to determine compliance with the provisions of 30.1, the supply circuit shall have an open-circuit voltage in the range of 100 – 105 percent of the rating of the device. The impedance of the supply shall be such as to provide a prospective current as shown in Table 12 as a minimum.

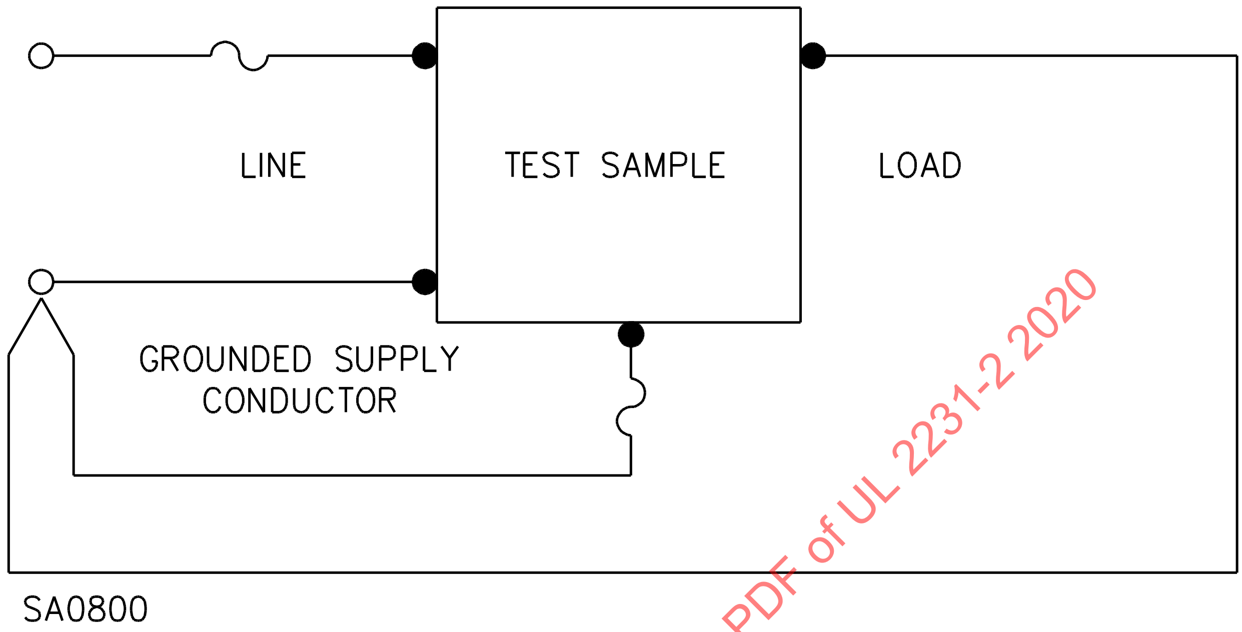
Table 12
Test circuit parameters

Protector type and/or rating	Current	Power factor/time constant		
	(A)	(%)		(S)
Permanently-connected rated up to 100 A	5000	45 – 50	/	0.003
Permanently-connected rated > 100 A	10,000	45 – 50	/	0.008
Portable rated up to 50 A	2000	90 – 100	/	0.003
Portable rated > 50 A	5000	90 – 100	/	0.003

32.3 Each line terminal of a device shall be connected to the supply mentioned in 32.2 using 1.2 m (4 ft) of insulated wire, sized for the rating of the device. A Type K5 fuse with an ampere and voltage rating appropriate for the rating of the device shall be connected in series with the ungrounded line conductor(s). An identical conductor shall be connected between a load terminal of the device and a terminal of the supply so as to represent a ground fault. The device shall be in any position determined to be normal in service. A 1-A fuse shall be connected between the supply terminal representing the grounded circuit conductor and accessible conductive parts of the device. Surgical cotton shall cover openings of the device where flame is capable of being be emitted. See Figure 15.

Figure 15

Extra-low-resistance ground-fault test circuit



32.4 For a portable device, conductors are capable of being attached to the attachment plug blades of the device so as not to be dislodged during the test.

32.5 The prospective current shall be initiated once by means of a switch in the supply circuit, and once by means of any control of the device, providing that a single representative device is not required to experience more than one current initiation. The 1-A fuse shall not operate to open the circuit, and there shall not be any flaming of the cotton, both mentioned in 32.3.

32.6 It shall be permissible to increase the value of prospective current shown in Table 12 to any of the values shown in Table 13 at the request of the manufacturer. An overcurrent protective device with an appropriate voltage, ampere, and interrupting rating shall be used in place of the fuse mentioned in 32.3.

Table 13
Current interrupting ratings

(RMS Symmetrical or DC Amperes)		
3500	20000	50000
5000	22000	65000
7500	25000	85000
10000	30000	100000
14000	35000	125000
18000	42000	150000
		200000

33 Short Circuit Test

33.1 A device shall withstand short circuits.

33.2 In order to determine compliance with the provisions of 33.1, conditions shall be as described in 32.2 – 32.4, except that:

a) The ground fault described in 32.3 shall not be connected, and

b) A 0.51 m (20 inch) length of wire of the same construction as the line conductors shall be connected between load terminals.

33.3 The test current shall be initiated by means of a switch in the supply circuit. The 1-A fuse shall not operate to open the circuit and there shall not be any flaming of the cotton, both mentioned in 32.3.

33.4 A device that was not subjected to the Extra-Low-Resistance Ground Fault Test, Section 32, because such faults do not occur in the system to which they are connected shall also be subjected to a test where the representative device is closed onto the short circuit. A separate representative device is capable of being used for this test.

34 Terminal Lead Strain-Relief Test

34.1 A device that is provided with terminal leads intended to be connected in the field shall be subjected to the test described in 34.2. Following the test there shall be no indication that either the device or the lead has sustained damage as a result of the test.

34.2 Each terminal lead shall be subjected to a tensile force increased gradually to 89 N (20 lbf), and maintained at that value for five minutes.

35 Power-Supply Cord Strain-Relief Test

35.1 A device that is provided with a power-supply cord shall be subjected to the test described in 35.2. Following the test there shall be no indication that the force was transmitted to the cord-conductor terminations.

35.2 The cord shall be subjected to a tensile force increased gradually to 156 N (35 lbf) and maintained at that value for one minute.

36 Mechanical Tests

36.1 A device that is provided with pressure wire connectors or wire binding screw terminals intended for field wiring shall be subjected to the tests described in 36.2 or 36.3.

36.2 There shall be no breakage or damage of any part of the device when 110 percent of the marked terminal tightening torque is applied to the wire-securing means of a pressure wire connector, securing the specified size of conductor.

36.3 A wire binding screw or nut shall be tightened on a conductor selected in accordance with the ampere rating of the device, but no less than 2.08 mm^2 (14 AWG), to a torque of 2.3 N·m (20 lbf-in) without causing displacement of the wire or damage to the terminal assembly or the wire. Except where the configuration of the terminal assembly does not permit, or markings allow, the use of unformed wire, the wire shall be formed into a 3/4 loop that will just be accommodated by the assembly, before tightening.