



IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding

IEEE Power and Energy Society

Developed by the
Substations Committee

IEEE Std 837™-2024
(Revision of IEEE Std 837-2014)

STANDARDS

IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding

Developed by the

Substations Committee
of the
IEEE Power and Energy Society

Approved 12 November 2024

IEEE SA Standards Board

Abstract: Direction and methods for qualifying permanent connections used for substation grounding are provided in this standard. This standard particularly addresses the connection used within the grid system, the connection used to join ground leads to the grid system, and the connection used to join the ground leads to equipment and structures.

Keywords: conductor, conductor combination, connection, connection thermal capacity, control conductor, current loop cycle, equalizer, grid system, grounding, grounding connection, IEEE 837™, permanent connection

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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Published 11 April 2025. Printed in the United States of America.

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PDF: ISBN 979-8-8557-1796-9 STD27679
Print: ISBN 979-8-8557-1797-6 STDPD27679

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Thomas Barnes	Lee Herron	Arthur Neubauer
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Introduction

This introduction is not part of IEEE Std 837-2024, IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.

This standard has been updated by Working Group G9 of the IEEE PES Substations Committee to fulfill a need for standardization of terminology and test requirements for permanent grounding connections. The most significant changes were made to the electromagnetic force (EMF) test criteria that address the connections to above-grade rigid structures and equipment ground pads. Many types of connections are available that may be used as permanent grounding connections even though they were designed for use as power connections. This standard provides a meaningful reproducible test program that will enable connection manufacturers to qualify their products as permanent grounding connections. The users can then be reasonably assured that the qualified permanent grounding connection will be capable of performing satisfactorily over the lifetime of the installation. This standard addresses the parameters for testing grounding connections on copper, steel, copper-bonded steel, copper-clad steel, galvanized steel, and stainless steel.

Revision notes are as follows:

- Clarified pass/fail criteria
- Clarified tolerance range sample and test setup
- Refined scope of document to focus on connections used within the grid system and connections used to join ground leads to the grid system
- Introduced a testing summary document to improve consistent documentation of connection test results

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IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding

1. Overview

1.1 Scope

This standard provides direction and methods for qualifying permanent connections used for substation grounding. It particularly addresses the connection used within the grid system, the connection used to join ground leads to the grid system, and the connection used to join the ground leads to equipment and structures. Connections that are not intended to withstand fault current, for example a connection to bond equipment cabinets and fences, are outside the scope of this standard. The scope also does not include requirements for distribution and transmission structures outside the substation ground grid.

1.2 Purpose

The purpose of this standard is to help give assurance to the user that a connection meeting the requirements of this standard will perform in a satisfactory manner over the lifetime of the installation, provided that the proper connection is selected for the application and that the connection is installed correctly. Grounding connections that meet the test criteria stated in this standard for a particular conductor size range and material should satisfy all of the criteria for connections as outlined in IEEE Std 80™ [B2].⁶

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{7,8}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

⁶ The numbers in brackets correspond to those of the bibliography in Annex A.

⁷ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁸ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTMA363, Specification for Zinc-Coated (Galvanized) Steel Overhead Ground Wire Strand.⁹

ASTM A510/A510M, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel, and Alloy Steel.

ASTM A752M, Specification for General Requirements for Wire Rods and Coarse Round Wire, Alloy Steel (Metric).

ASTM B1, Standard Specification for Hard-Drawn Copper Wire.

ASTM B8, Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft.

ASTM B49, Standard Specification for Copper Rod Drawing Stock for Electrical Purposes.

ASTM B117, Standard Practice for Operating Salt Spray (Fog) Apparatus.

ASTM B172, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors.

ASTM B173, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors.

ASTM B174, Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors.

ASTM B227, Standard Specification for Hard-Drawn Copper-Clad Steel Wire.

ASTM B228, Standard Specification for Concentric-Lay-Stranded Copper-Clad Steel Conductors.

ASTM B229, Standard Specification for Concentric-Lay-Stranded Copper and Copper-Clad Steel Composite Conductors.

ASTM B258, Standard Specification for Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes Solid Round Wires Used as Electrical Conductors.

ANSI/NEMA GR 1, Grounding Rod Electrodes and Grounding Rod Electrode Couplings.¹⁰

⁹ ASTM publications are available from the American Society for Testing and Materials (<https://www.astm.org/>).

¹⁰ NEMA publications are available from the National Electrical Manufacturers Association (<https://www.nema.org/>).

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹¹

conductor: A metallic substance that allows a current of electricity to pass continuously along it. It includes cable (wire), rods (electrodes), and metallic structures.

conductor combination: The various conductors that are joined by a connection. *See also:* **conductor**; **connection**.

connection: A metallic device of suitable electrical conductance and mechanical strength used to join conductors. *See also:* **conductor**.

connection family: A group of connections with different conductor combinations but with conductors arranged in the same orientation and with the same style. *See also:* **conductor**; **connection**.

connection style: Characterization of a connection by the means of installation, such as compression, exothermic, or mechanical methods. *See also:* **connection**.

connection thermal capacity: The ability of a connection to withstand the amount of current required to produce a specified temperature on the control conductor without increasing the resistance of the connection beyond that specified. *See also:* **control conductor**; **connection**.

control conductor: The conductor that is utilized to measure equivalent changes in temperature, size, and so forth that are occurring in at least one of the conductors joined by the connection under test. *See also:* **conductor**; **connection**.

current loop cycle: The combination of conductors and connections that carries the current of the circuit under test. *See also:* **conductor**; **connection**.

equalizer: A device to provide equipotential planes for resistance measurements.

grid system: A system consisting of interconnected bare conductors buried in the earth or in concrete to provide a common ground for electrical devices and metallic structures. *See also:* **conductor**.

permanent connection: A grounding connection that will retain its electrical and mechanical integrity for the design life of the conductor within limits established by this standard. *See also:* **conductor**; **connection**.

4. Qualification tests

4.1 General

A listing of the tests to be performed for all types of connections is given in [Table 1](#). The connections shall be tested individually and sequentially, as shown in [Table 1](#). If during the testing, one of the four test samples fails, the testing shall be discontinued. A group of four new samples from a different lot can then be retested. If one of the samples from the new group fails, the connection design does not meet the requirements of this standard and is considered as failed. This is applicable to all of the tests detailed in [Table 1](#). Connection testing and compliance shall be presented to the end user, using the cover page template in [Annex F](#).

¹¹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

Table 1—Qualification test sequences and quantities ^a

Test		Clause	Number of samples per test ^b
Mechanical tests	Electromagnetic force test	8.2	4
Sequential test groups	Current-temperature cycling	9.1–9.7	4 for salt spray sequence 4 for acid sequence
	Freeze-thaw	10.1–10.5	
	Corrosion—salt spray, acid	11.1–11.3	
	Fault current	12.1–12.8	

^aSee [Annex D](#) for additional information.

^bThese are the number of connection samples of each connection design and conductor combination tested.

Qualification tests shall be performed for each connection style (e.g., mechanical, crimped, and exothermic) and for each connection family (e.g., cable to cable straight connection, tap connection, cross connection, cable to ground rod connection, cable to lug, and cable to structural steel connection). Refer to [Annex D](#) for the qualification test sequence. See test setup examples in [8.2.3](#) for additional connection family examples. Within a connection family, more robust connections need not be tested. For example, bolted pressure plate lugs using four (4) bolts need not be tested if two (2) bolts lugs have been tested successfully for the same size. Similarly, for a family of connections tested for 4/0 AWG copper or 19/#8 copper clad steel [at 90% of fusing test current for the electromagnetic force (EMF) test], smaller sizes may be qualified by passing only the initial resistance tests from [5.3.2.2](#). For these smaller sizes, no other tests are required. However, connections for conductors sized 4/0 AWG and larger shall be tested for each size connection.

When a connection design allows for a range of conductors, each of the tests outlined in [Table 1](#) and [Annex D](#) shall be performed on the “largest to largest” combination as well as the “largest to smallest” combination. Connections shall be tested for all materials for which they are intended to be qualified per this standard. For example, copper-clad steel conductors and connections that are designed to be used on copper-bonded steel ground rods shall be qualified by all of the tests in this standard. Several test parameters for connections for use on 40% copper-clad steel conductors and copper-bonded steel ground rods are based upon electrical equivalency of copper conductors as listed in [Clause 9](#). The test parameters for conductor and ground rods not listed in [Clause 8](#) shall be calculated as per [Annex C](#).

4.2 Mechanical test sequence

[Table 1](#) identifies all testing and samples required for qualifying connections per this standard. [Figure 1](#) walks through the steps of the mechanical test sequence; see [Annex D](#) for further details on pass/fail criteria for this sequence.

4.3 Sequential test sequence

[Table 1](#) identifies all testing and samples required for qualifying connections per this standard. [Figure 2](#) walks through the steps of the sequential test sequence; see [Annex D](#) for further details on pass/fail criteria for these tests.

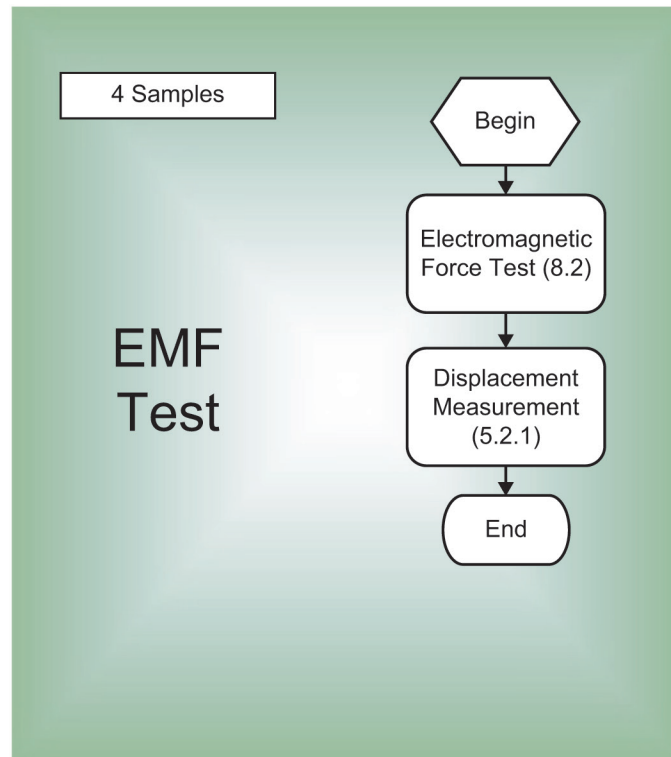


Figure 1—Mechanical (EMF) test flow diagram

5. Performance criteria

5.1 General

When installed and tested in accordance with this standard, all connections shall conform to the performance criteria given in 5.2 and 5.3.

5.2 Mechanical tests

5.2.1 Electromagnetic force (EMF) withstand criteria

When tested in accordance with 8.2, the connection shall remain intact. The maximum allowable movement of the test conductor at each location shown in Figure 3 after two EMF surges shall not exceed either 10.0 mm (0.39 in) or the outer diameter of the conductor, whichever is less (the note in Figure 3, “X” illustrates what is meant by movement).

5.3 Sequential tests

5.3.1 Temperature criteria

The temperature of the connections tested in accordance with Clause 9 shall not exceed the temperature of the control conductor.