



IEEE Guide for Selection and Application of Terminations for Shielded AC Power Cable Rated 5 kV to 46 kV

IEEE Power and Energy Society

Developed by the
Insulated Conductors Committee

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STANDARDS

IEEE Guide for Selection and Application of Terminations for Shielded AC Power Cable Rated 5 kV to 46 kV

Developed by the

**Insulated Conductors Committee
of the
IEEE Power and Energy Society**

Approved 24 September 2020

IEEE SA Standards Board

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Abstract: A step-by-step process for selecting an appropriate termination that is commensurate with a particular shielded power cable design is provided in this guide. Over the years, shielded power cables have been developed that employ many different insulating materials and many different shielding systems, such that, there are numerous issues to consider when selecting a termination for a particular cable design. Over the same period of time, many different termination methods and designs have been developed that serve the same purpose, but employ different application methodologies. No attempt is made in this guide to cover every cable and termination design, and it is generally restricted to single conductor underground residential distribution (URD) and shielded power cable that have a voltage rating from 5 kV to 46 kV, which includes some industrial cables. By nature, the terminations referred to in this guide are considered to be “live front,” in that the terminations comprise a transition from a shielded power cable system to an energized component or bus that is either bare or simply covered.

Keywords: IEEE 1637™, power cable, shielded, termination

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Introduction

This introduction is not part of IEEE Std 1637-2020, IEEE Guide for Selection and Application of Terminations for Shielded AC Power Cable Rated 5 kV to 46 kV.

This guide was developed within the IEEE Insulated Conductors Committee of the Power and Energy Society as an introduction to the process of selecting and applying the appropriate termination for application on a particular cable design and within a particular environment. This guide is intended as an introduction to the selection process.

In its current form, this guide is general in nature and provides only a broad overview. Many factors can influence the selection and application of a particular termination for any given application, including user personal preferences. This guide is not intended to be exhaustive in covering the considerations necessary in making a termination selection. Consequently, the user should consult the expertise of knowledgeable individuals before making final choices.

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1. Overview

1.1 Scope

This guide ~~discusses~~ ~~will discuss~~ the reasons why a termination is necessary on a shielded power cable. Included is a short tutorial on termination theory, a general discussion of design and materials, ~~and~~ a selection flow chart, ~~and an application spacing guide~~.

1.2 Purpose

The purpose of this project is to guide the reader in selecting ~~and applying~~ terminations for shielded-power ~~cables rated~~ ~~cable~~ 5 kV ~~to~~ 46 kV.

1.3 General

This guide provides the reader with guidance in selecting ~~and applying~~ terminations for shielded-power cables rated 5 kV ~~to~~ 46 kV.

1.4 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*).^{1, 2}

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*).

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.

ANSI C119.4, Electric Connectors—Connectors for Use Between Aluminum-to-Aluminum and Aluminum-to-Copper Conductors Designed for Normal Operation at or Below 93°C and Copper-to-Copper Conductors Designed for Normal Operation at or Below 100°C.³

¹The use of the word *must* is deprecated and shall not be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

²The use of *will* is deprecated and shall not be used when stating mandatory requirements; *will* is only used in statements of fact.

³ANSI publications are available from the American National Standards Institute (<https://www.ansi.org/>).

[ANSI/NEMA CC 1, Electric Power Connection for Substations.](#)⁴

IEEE Std 48™, IEEE Standard for Test Procedures and Requirements for Alternating-Current Cable Terminations used on Shielded Cables having Laminated Insulation Rated 2.5 kV through 765 kV or Extruded Insulation Rated 2.5 kV through 500 kV.^{5,6}

NOTE—All terminations discussed in this guide meet the requirements set forth in IEEE Std 48.⁷[†]

[IEEE Std 1651™, IEEE Guide for Reducing Bird-related Outages.](#)

[IEEE Std 1816™, IEEE Guide Cable Prep Techniques for Installing Accessories.](#)

3 Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary [Online](#): ~~Glossary of Terms & Definitions~~ should be [consulted](#) ~~referenced~~ for terms not defined in this clause.⁸²

apparatus termination: A termination designed for use in sealed enclosures where the external dielectric strength is dependent upon liquid or special gaseous dielectric and where the ambient temperature of the medium immediately surrounding the termination may reach 65 °C.

⁴NEMA publications are available from the National Electrical Manufacturers Association (<https://www.nema.org/>).

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⁸² ~~The~~ IEEE 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 ~~Glossary of Terms & Definitions is available at~~ <http://shop.ieee.org/>.

NOTE—The temperature change from 55 °C to 65 °C was recommended to match the switchgear specification of 65 °C.

ethylene propylene rubber cable (EPR): A cable insulated with extruded ethylene propylene rubber or similar synthetic rubber.

extruded polymeric cable: A cable insulated with a polymer such as ethylene propylene rubber, polyethylene, or a similar synthetic plastic or rubber that is applied through the extrusion process.

high-voltage cable termination: A device used for terminating power cables having laminated or extruded insulation rated 2.5 kV and above, which are classified according to the following:

- a) Class 1 termination: Provides electric stress control for the cable insulation shield terminus; provides external insulation between the cable conductor(s) and ground; and provides a seal to the end of the cable against the entrance of the external environment and maintains the operating design pressure, if any, of the cable system. This class is divided into the following two types:
 - 1) Class 1A: For use on extruded dielectric cable
 - 2) Class 1B: For use on laminated dielectric cable
- b) Class 2 termination: Provides electric stress control for the cable insulation shield terminus, and provides external insulation between the cable conductor(s) and ground.
- c) Class 3 termination: Provides electric stress control for the cable insulation shield terminus.

impregnated, paper insulated, lead covered cable (PILC): A cable whose primary insulation is paper tapes impregnated with dielectric fluid and sealed from moisture with a solid lead sheath.

polyethylene cable (PE): A cable insulated with extruded thermoplastic polyethylene, cross-linked polyethylene, tree retardant cross-linked polyethylene, or other similar polymer.

routine tests: Tests made on each cable termination or upon a representative number of devices, or parts thereof, during production for purposes of quality control.

4 Termination

4.1 Termination theory

4.1.1 Shielded power cable configuration

Shielded power cable is designed with two concentric conductors, one within the other separated by an insulating material. The coaxial configuration forces the electric field energy associated with the alternating current (ac) into a symmetrical pattern. This configuration causes the total insulation to symmetrically contain the electric ~~field forces~~ within the cable.

4.1.2 ~~Electric~~ ~~Dielectric~~ field

In all shielded power ~~cables~~ ~~cable~~, an electric field exists when the conductor is energized. This ~~electric~~ ~~dielectric~~ field can be depicted graphically with the use of electrostatic flux lines and equipotential lines (see Figure 1). Electrostatic flux lines represent the electric stress between electrodes having different electric potential. Equipotential lines represent points of equal potential between electrodes having different electric potential. They represent the radial voltage stresses in the insulation and their relative spacing indicates the magnitude of the voltage stress; the closer the lines, the higher the stress.

The coaxial configuration of a shielded power cable keeps the electric stresses symmetrical and under control as long as the cable components are left intact. To facilitate electric stress control at the end of a shielded power cable, the insulation shield is removed axially for a distance ~~sufficient~~ to ~~sufficiently reduce~~ ~~prevent~~ interaction between the conductor and the insulation shield. When the insulation shield is ended, this leads to a concentration of electric stress at the shield terminus (see Figure 2). Shielded power cable terminations are designed to relieve this concentration of electric stress at the insulation shield terminus. Figure 3 shows how this electric stress is overcome with a geometric type of electric stress control, and Figure 4 shows how this electric stress is overcome with nonlinear types of electric stress control.

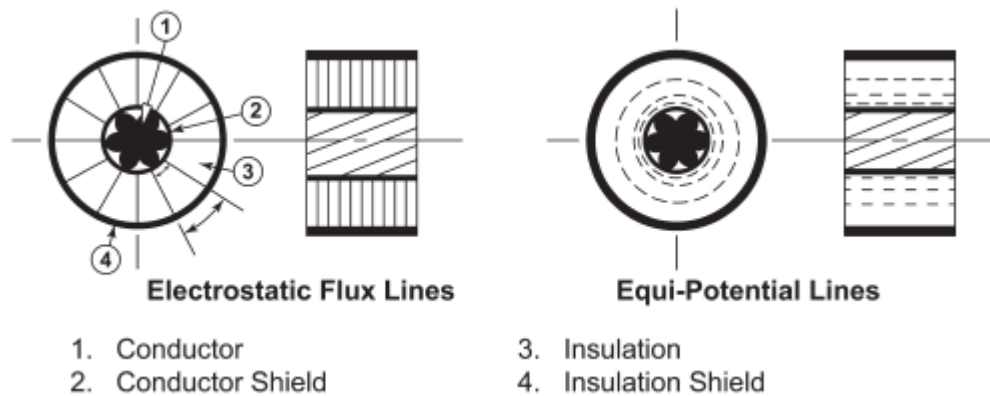


Figure 1—Electric ~~Dielectric~~ field in shielded cable ~~at shield terminus~~
without gradient material

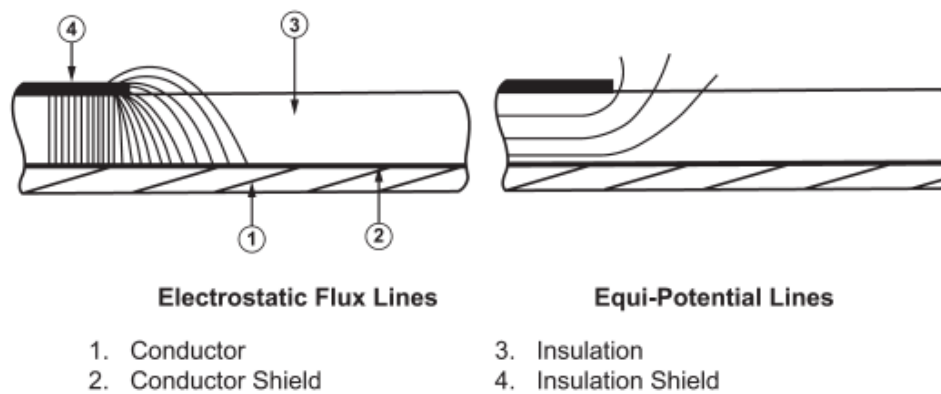


Figure 2—Electric ~~Dielectric~~ field at shield terminus without gradient
material

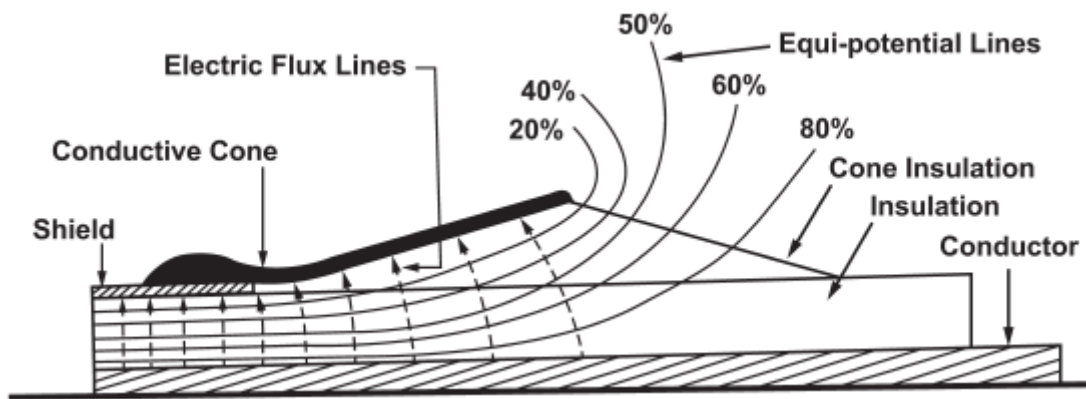


Figure 3—**Electric Dielectric** field at shield terminus with geometric electric stress control

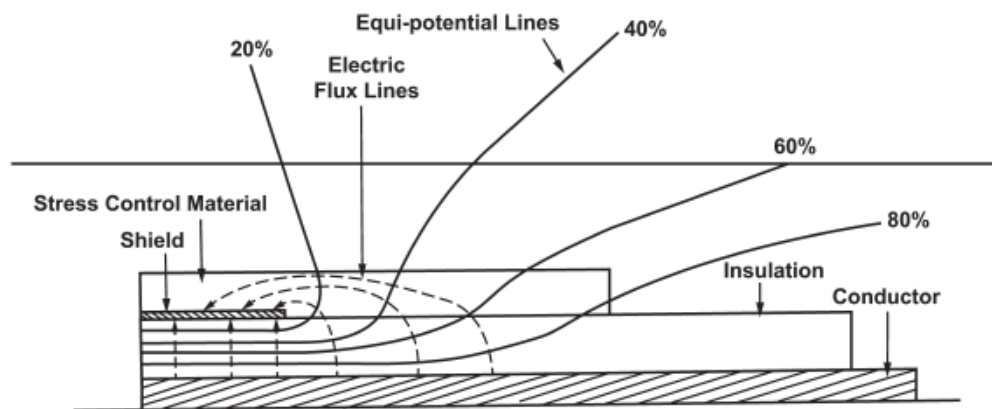


Figure 4—**Electric Dielectric** field at shield terminus with gradient material electric stress control

4.1.3 Electric stress relief

A shielded power cable is composed of a conductor, a conductor shield, insulation, a coaxial insulation shield, [and](#) a metallic shield or sheath, and [it](#) may or may not have an overall jacket. The conductor shield and insulation shield are generally formed of semiconductive material that is compatible with the cable insulation. The coaxial conductor and insulation shields cause the electric field within the cable insulation to be uniformly distributed, thus, allowing optimization of the insulation thickness. Metallic shields are available in a wide variety of designs, including tapes, wires, and straps that are applied in helical, longitudinal, or corrugated designs. Many factors influence the choice of a metallic shield design, including such issues as shield losses, short-circuit duty, magnetic forces during faults, and historic practices by the user.

When a cable ends, the insulation shield and metallic shield have to be separated from the conductor and conductor shield, a sufficient distance to reduce the electrical interaction between the two. ~~This separation may be accomplished with a gradient type material as shown in Figure 4 or with geometric stress grading in the form of a force fit slip on molded or taped termination, as shown in Figure 3.~~ When the insulation shield is ended abruptly, [the equipotential lines are very close together, indicating that](#) a destructively high electric field is present at the insulation shield terminus. This electric stress must be relieved to provide a long life for the installation. [The high electrical stress concentration is mitigated through the use of a gradient type material as shown in Figure 4 or with geometric stress grading as shown in Figure 3.](#)

[Geometric stress control, as shown in Figure 3, gradually increases the insulation from the end of the cable insulation shield in the shape of a cone. The cable insulation shield is extended to the peak of the cone insulation and then ended. The equipotential lines are still close together at the end of the extended shield, but the combination of the cable insulation and the stress cone insulation provide enough insulation to handle this high electrical stress.](#)

[Gradient-material stress control, as shown in Figure 4, uses the difference in electrical properties between the termination stress control material and the cable insulation. This causes the electric field lines to refract and spreads the equipotential lines farther apart instead of being concentrated at the end of the cable insulation shield.](#)

4.1.4 Track resistance

4.2.4 Electro-chemical track resistance

The surface of the termination insulation that lies between the conductor and the insulation shield terminus is under electric stress and is susceptible to electric discharge that can cause erosion and chemical decomposition of both the cable and termination. This vulnerable area can be protected by the choice of ~~materials and/or the geometry of the~~ termination materials. This track-resistant outer housing must be in contact with the metallic ground to bleed off leakage current. This allows the leakage current to travel from the track-resistant material ~~directly to metallic~~ ground without eroding other ~~components~~areas of the ~~termination~~system.

4.2 Parts of termination

A shielded power cable termination may comprise ~~be comprised~~ of several elements. All terminations ~~must~~ have an electric stress control component. In addition, terminations may include the cable end seal, the connector, and a electro-chemical track-resistant outer ~~resistance on the surface of the termination~~ between the insulation shield terminus and the cable conductor.

4.2.1 Cable end seal

Class 1 terminations provide a seal to keep the environment out of the cable and, when necessary, to keep any gas, liquid, or semisolid in the cable.

4.2.2 Connector

When terminating a shielded power cable, a connection is ~~has to be~~ made between ~~from~~ the cable conductor and ~~to~~ a piece of equipment. Most conventional terminal connectors (aerial lugs) consist of a connector barrel with bore to connect to the conductor and some configuration of terminal for connection to an equipment terminal, bare wire, or other.

The barrel of the connector is ~~Termination connections used for power cables are~~ most commonly compression ~~type connectors~~, but it may also ~~can~~ be soldered, welded, exothermically welded, bolted, ~~or fastened by means of a set screw~~, or shear bolt.

The terminal side of the connector is most commonly a NEMA-patterned tang, but it may also be available as pin/stem, bolted, threaded pin/stem, stem and hood nut, or barrel.

IEEE Std 48 qualifies terminations using connectors meeting ANSI C119.4 Class A (heavy duty) current cycle class and Class 2 (partial tension) tension class. Selected connectors should meet or exceed these ANSI C119.4 ratings.

Regardless of what type of ~~connector connection~~ is used, all terminations require a connector to be the following ~~that is listed as follows:~~

- a) ~~is~~ compatible with the cable conductor metal
- b) Compatible with the wire or equipment terminal, to which the termination is connected
- c) ~~seals the power cable conductor, in~~ combination with other termination components, the power cable conductor is sealed from ~~from the~~ entry of moisture (in liquid and/or vapor form) and/or environmental contaminants into the conductor, and prevents ~~or the~~ leakage of any fluids, ~~when present~~, from the conductor

4.2.2.1 Connector barrel

The connector is typically attached to the conductor using one of the following methods:

- Compression
- Soldered
- Welded
- Exothermic welded

- Bolted
- Set screw
- Shear bolt

It is imperative that the connector is properly sized and rated for the intended application. prior to the installation of the connector, the cable conductor strands and connector bore are to be clean and free of contaminants and corrosion, including surface oxidation. This helps to make a resilient ~~solid,~~ ~~permanent~~ connection, which will perform as designed. Best industry practices for preparation of power cable conductors are discussed in IEEE Std 1816.

4.2.2.1.1 Compression connectors

Compression connectors are rated for use with ~~are~~ either copper, aluminum, or a combination of both ~~(bimetallic). Copper cable conductors can use either a copper connector (CU-rated) or a~~ (dual rated) connector (AL/CU-rated).

Aluminum barrels are intended for use on aluminum conductors or, if Dual rated, on either aluminum or copper conductors. Dual-rated connectors often, but not necessarily, employ an intermediate metal between the copper and aluminum, usually in the form of a tin and/or nickel plating applied to the aluminum connector barrel. Aluminum barrels are typically preloaded with an oxide inhibitor, which Compression connectors for aluminum conductors require an inhibitor to fill the area between the conductor strands and the interior connector wall. Inhibitor generally comes preinstalled within the connector and is critical to its function. Inhibitors shall Inhibitor should not be removed from a connector prior to installation. Inhibitors are intended to limit the formation of oxidation on the metal surfaces within the connector and on the surfaces of the cleaned conductor strands. Inhibitors also serve to limit moisture intrusion into the connection interface and help prevent galvanic corrosion; however, it does not function as a water stop. They connector and may include particles to enhance electrical contact and/or assist in breakdown of oxide layer(s) between the metals. Since Because the inhibitor may can contain conductive particles and/or may be deleterious to polymeric materials, excess inhibitor squeezed out of the connector during installation should be completely cleaned away. in the area between the end of the connector and the cable insulation. This helps avoid contamination of the insulation surface during termination assembly and helps avoid contamination of insulating fluids, which that may fill some types of terminations.

Copper connectors and plated copper connectors shall only be used on copper conductors. The use of a copper lug on an aluminum conductor is not likely to provide satisfactory performance. Due to the different coefficients of thermal expansion, the aluminum conductor expands faster than the copper barrel. This could result in the aluminum conductor cold-flowing over an extended time period. As the parts cool down, the aluminum shrinks back faster than the copper. After numerous thermal cycles, the connection becomes loose and may result in overheating. Overheated connections may degrade the dielectric strength of the insulation and lead to failure.

~~Only aluminum connectors or dual rated connectors are applied to aluminum cable conductors. In some cases, a transition from aluminum to copper is needed. For example, aerial connections, where an aluminum cable conductor connects to a copper conductor, require a transition connector. In this instance, a bimetal connector provides the transition. A commonly used bimetal termination connector has an aluminum barrel with a copper stem. The transition area of the connector may have an intermediate metal at the interface or the interface may be spun welded to eliminate access of air and moisture to the metal junction. This type of connector is sometimes referred to as a pin connector.~~

~~Compression indents on a connector can create sharp metal protrusion off the edge of a connector, commonly referred to as flashing. In most cases, these protrusions should be removed to avoid damaging components within the termination during the assembly process.~~

Compression connectors are installed onto the conductor using compression tools and dies ~~Once the proper connector is selected, the manufacturer's recommendation for tooling and installation shall be carefully followed in order to provide a proper connection. It is very important to follow the tooling recommendations and installation procedures required for the connector.~~ Selection of the proper tool and die combination is important to maximize electrical contact between the connector and the various strand layers within the conductor without overly reducing the mechanical strength of the conductor at the transition to the connector. Improper ~~A poor~~ connector installation may lead ~~leads~~ to problems with the cable termination during the service life of the cable system.

IEEE Std 1816 provides a detailed overview of best industry practices for installation of compression connectors.