

IEEE Guide for the Design, Testing, and Application of Moisture- Impervious, Solid Dielectric, 5–35 kV Power Cable Using Metal-Plastic Laminates

Sponsor

**Insulated Conductors Committee
of the
IEEE Power Engineering Society**

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Abstract: The user of underground cables is provided with information on the design, testing, and application of moisture-impervious, medium-voltage, solid dielectric power cable using metal-plastic laminates as moisture barriers. Information is also provided on selection of jacketing materials and installation practices. Other types of moisture barriers, such as extruded metal sheaths and bare metallic tapes with sealed seams, are beyond the scope of this guide.

Keywords: cable jackets, metal-plastic laminates, moisture-impervious cable, on-core moisture barrier, pulling tension calculations, semiconducting jackets, sidewall bearing pressure (SWBP) test, under-jacket moisture barrier, water blocking, water-swellaable powders, water-swellaable tapes, water treeing test

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Introduction

(This introduction is not a part of IEEE Std 1142-1995, IEEE Guide for the Design, Testing, and Application of Moisture-Impervious, Solid Dielectric, 5–35 kV Power Cable Using Metal-Plastic Laminates.)

This guide was prepared by Working Group 6–23 of the Sheaths and Coverings Subcommittee (No. 6) of the Insulated Conductors Committee of the IEEE Power Engineering Society. Members of this working group represent a cross-section of the affected parties including cable users, consulting engineers, cable manufacturers, and suppliers of cable materials. The purpose is to provide users of underground medium-voltage cable with guidelines and considerations pertaining to moisture-impervious power cable design and application.

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IEEE Guide for the Design, Testing, and Application of Moisture-Impervious, Solid Dielectric, 5–35 kV Power Cable Using Metal-Plastic Laminates

1. Overview

1.1 Scope

This guide will provide the user of underground cables with information on the design, testing, and application of moisture-impervious, medium-voltage, solid dielectric power cable using metal-plastic laminates as moisture barriers. References will be found in clause 2. A complete bibliography of pertinent technical papers together with patent and specification references relating to the content of this guide will be found in clause 8. The annexes provide information on selection of jacketing materials and installation practices. It is recognized that there are other types of moisture barriers available, such as extruded metal sheaths and bare metallic tapes with sealed seams (referred to in 1.5), that are beyond the scope of this guide. This guide should not be interpreted as precluding their use.

1.2 Concepts

In recent years, there have been widespread failures of polyethylene-insulated, medium-voltage cables in underground applications due to the water treeing phenomenon. These failures, mostly in underground residential distribution systems, have kindled a strong interest in measures to prevent water intrusion into cable cores. While metallic sheaths, such as lead and aluminum, have been effective in past years as barriers to moisture, their relative cost along with installation difficulties has tended to diminish their usage. Recently, thin metal-plastic laminates have found application as moisture barriers in medium-voltage power cables. Aluminum, copper, and lead substrates are used with polymeric compounds adhesively laminated on one or both sides. The tapes are usually applied longitudinally, with an overlapped and sealed seam, either directly over the core of the cable or under the jacket. In addition, other measures have been taken to block the longitudinal movement of moisture through the conductor and the shield interfaces so that water-impervious cables are now available. This guide will provide information on the use of such laminates in cable constructions as well as the use of other materials for longitudinal water blocking. Cable users should find this information of value in the selection, specification, installation, and testing of moisture-impervious, medium-voltage cables.

1.3 Development history

Thin metal-plastic laminates were first developed as moisture barriers for telephone cable in the early 1960s. They have been successfully utilized for many years in this application. These laminates have also been used for moisture barriers and shielding in many other types of low-voltage cables, such as control, coaxial, instrumentation, fiber optic, undersea, etc. Only in recent years have such laminates found application as moisture barriers for medium- and high-voltage power cable, where design parameters have been more restrictive. These restrictions and their solutions will be covered in this guide.

1.4 Utilization and trends

A number of power cable designs making use of such moisture barriers have been commercialized and there is an upward trend in their acceptance on a worldwide basis. Clause 8 provides further references to the many designs and the various countries, industries, and utilities that have selected, specified, and installed cable with moisture barriers and moisture-blocking materials.

1.5 Other designs

There are other means for providing radial moisture barriers in power cable designs, beyond the use of metal-plastic laminates, that are outside the scope of this guide. Extruded lead and aluminum sheaths can be used for this purpose and have been available for many years. Metal sheaths with welded seams and lateral corrugations have also been utilized in the past for this purpose. More recently, thin copper tapes, without plastic coatings, have been used as a combination moisture barrier and shield. Such tapes are applied longitudinally under the jacket, with an overlapped seam. The seam is sealed with an adhesive to block the entrance of moisture. Information on these designs should be obtained from other guides and standards or from manufacturers of such cable.

2. References

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

AEIC CS 5-94, Specifications for Cross-Linked Polyethylene Insulated Shielded Power Cables Rated 5 Through 46 kV, 10th ed.¹

AEIC CS 6-87, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 through 69 kV, 5th ed.

ASTM B 736-92a, Specification for Aluminum, Aluminum Alloy, and Aluminum-Clad Steel Cable Shielding Stock.²

ASTM D 903-93, Test Method for Peel or Stripping Strength of Adhesive Bonds.

ASTM D 991-89, Test Method for Rubber Property—Volume Resistivity of Electrically Conductive and Antistatic Products.

ASTM D 1248-84 (Reaff 1989), Specification for Polyethylene Plastics Molding and Extrusion Materials.

¹AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P. O. Box 2641, Birmingham, AL 35291-0992, USA.

²ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

ASTM D 1876-93, Test Method for Peel Resistance of Adhesives (T-Peel Test).

ASTM D 2861-87 (Reaff 1993), Test Methods for Flexible Composites of Copper Foil with Dielectric Film or Treated Fabrics.

ASTM D 4565-90a, Test Methods for Physical and Environmental Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable.

ASTM E 796-94, Test Method for Ductility Testing of Metallic Foil.

ICEA T-31-610-1989, Water Penetration Resistance Test, Sealed Conductor.³

IEEE Std 48-1990, IEEE Standard Test Procedures and Requirements for High-Voltage Alternating-Current Cable Terminations (ANSI).⁴

IEEE Std 383-1974 (Reaff 1992), IEEE Standard for Type Test of Class 1E Electrical Cables, Field Splices, and Connections for Nuclear Power Generating Stations (ANSI).

IEEE Std 404-1993, IEEE Standard for Cable Joints for Use with Extruded Dielectric Cable Rated 5000–138 000 V and Cable Joints for Use with Laminated Dielectric Cable Rated 2500–500 000 V (ANSI).

IEEE Std 422-1986 (W1994), IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations (ANSI).⁵

IEEE Std 525-1992, IEEE Guide for the Design and Installation of Cable Systems in Substations (ANSI).

IEEE Std 576-1989, IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry (ANSI).

IEEE Std 690-1984 (W1994), IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations (ANSI).⁶

IEEE Std 930-1987 (W1994), IEEE Guide for the Statistical Analysis of Electrical Insulation Voltage Endurance Data (ANSI).⁷

IEEE Std 1202-1991, IEEE Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies (ANSI).

NEMA WC 7-1991 (ICEA S-66-524), Cross-Linked Polyethylene Insulated Wire and Cable for Transmission and Distribution of Electrical Energy.⁸

NEMA WC 8-1991 (ICEA S-68-516), Ethylene-Propylene Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

³ICEA publications are available from ICEA, P.O. Box 411, South Yarmouth, MA 02664, USA.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁵IEEE Std 422-1986 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

⁶IEEE Std 690-1984 has been withdrawn. It is available in the IEEE Nuclear Power Standards Collection (1990 Edition).

⁷IEEE Std 930-1987 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

⁸NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Suite 300, Washington, DC 20037, USA.

3. Definitions

3.1 blocked conductor: A stranded conductor whose interstices are filled with a compound that prevents the migration of moisture along the interstices. *Syn:* strand-filled conductor.

3.2 cable core: The portion of a cable that includes the conductor, the conductor shield, the insulation, and the extruded insulation shield.

3.3 metal-plastic laminate: A tape made of aluminum, copper, lead, or other metal substrate that is laminated on one or both sides with a tightly adhering plastic film. The film used may consist of either an adhesive polyolefin copolymer that self-bonds to the metal substrate during the laminating process or another polymeric compound that is adhered through the use of a supplemental adhesive.

3.4 moisture barrier: A metal barrier that prevents moisture from permeating radially into the cable core.

3.5 moisture block: A means for preventing moisture from migrating longitudinally along the cable core, either through the conductor or within the space allowable between the extruded insulation shield and the jacket.

3.6 on-core type: A moisture barrier applied directly over the cable core.

3.7 swellable powder: A powder that swells upon contact with moisture. A jelly like material is formed to block the longitudinal transmission of moisture.

3.8 under-jacket type: A moisture barrier applied under the jacket and over the metallic shield or concentric neutral of a cable. Also, a combination moisture barrier and shield.

3.9 water-blocking tape: A nonwoven synthetic tape impregnated with a swellable powder. Also called a water-swellable tape. Such tapes may also provide cushioning to absorb expansion of the cable core and may also be semiconducting.

4. Cable designs utilizing moisture barriers

4.1 Cables with under-jacket moisture barriers

The under-jacket design incorporates a metallic moisture barrier directly under the jacket of a power cable intended for underground applications. The metallic moisture barrier is a laminate structure consisting of a metallic substrate coated on one or both sides with adhesive coatings. The laminate is overlapped longitudinally over the cable core. The coating on the laminate is bonded to the cable jacket by the heat transferred during the extrusion of the jacket. The extrusion process also provides heat to form a seal of the overlapped seam. The seam can be sealed by the adhesive coatings and/or a hot melt adhesive applied in the overlap. Specific types of adhesive coatings are required for adhesive compatibility with the various types of polyethylene (PE) jackets, and other types are required for compatibility with polyvinyl chloride (PVC) jackets. An illustration of this design is shown in figure 1.

Normally a mechanical stress relief layer is required under the metallic moisture barrier to allow for expansion and contraction of the core during thermal loading. In some cable designs, a layer of synthetic material is used that serves to cushion the expansion of the core. In other designs a special fluted construction for the insulation screen is utilized to absorb expansion. The screen flattens during thermal loading. In other designs, longitudinal corrugations are placed in the metal-plastic laminate to absorb thermal expansion and contraction.

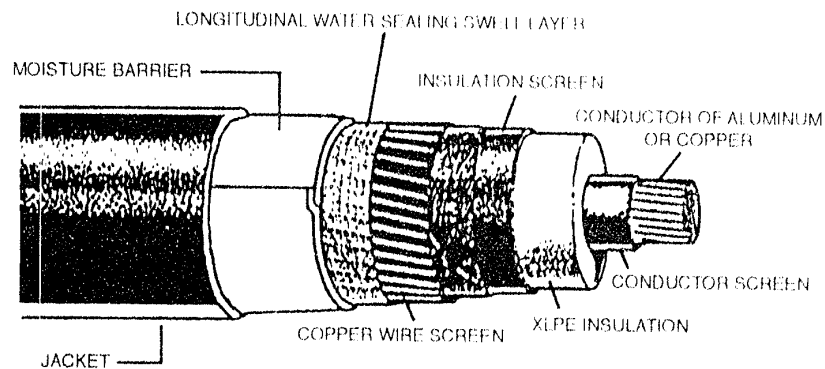


Figure 1—Under-jacket type with concentric neutrals

Another design consideration is that longitudinal water flow must be blocked in the interface between the moisture barrier and the core. Since the moisture barrier is separated from the core by the neutral wires and/or cushion layers, a moisture path is left in this interface. A fabric tape containing water-swellable powder is normally used for this purpose. Water-swellable yarns, as well as water-swellable powder alone, have also been utilized in certain designs. In any case, water flow is blocked by the gelling action of the powder in the event that water is present at a point of sheath rupture, or at an unsealed cable end. Water-blocking tapes can also function as cushion layers to absorb insulation expansion as described in 4.5.

The principal advantage of the under-jacket design is the use of metallic moisture barriers that are thick enough to ensure there are no pinholes and mechanically strong enough to withstand installation and use without rupture. With optimal combinations of jacket thickness and metal thickness, the under-jacket design can combine the flexibility of the plastic jacket with the strength of the metallic tape. The overall mechanical properties of the cable are improved over those that can be accomplished with the same materials unbonded. The bonded sheath has been shown to have increased hoop strength, which facilitates the installation process. The sheath has reduced shrinkback after installation. The longitudinally formed metallic tape with a sealed overlap is proven technology as a moisture barrier for cable as demonstrated by the many references to this construction listed in the bibliography (see clause 8).

The metallic moisture barrier can serve strictly as a moisture barrier over the wire neutral, or act as a shield either alone or to supplement the wire neutral. The choice depends on short-circuit requirements, cable design considerations, and economics. The choices of grounding techniques for these three constructions are detailed in 7.3. Even when the laminate is intended mainly as a moisture barrier, it is necessary to consider that it is going to form part of the shielding system of the cable, and that adequate contact with other metallic components of the insulation shield must be provided.

A more recent development of the under-jacket design combines the moisture barrier and the electrical shield or neutral into one common metallic layer. This design is illustrated in figure 2. A copper tape of sufficient thickness to safely carry fault or neutral currents is applied longitudinally with an overlapped and sealed seam. The tape is corrugated laterally for larger diameter cables to provide flexibility. The outer side of the tape is laminated to an adhesive film that bonds the laminate to the outer jacket of the cable. This provides improved mechanical properties and corrosion resistance. Semiconducting water-blocking tapes are used under the shield/moisture barrier to block longitudinal moisture transmission, to provide electrical continuity between the metallic shield and the semiconducting insulation shield, and to provide a cushioning layer for expansion control.

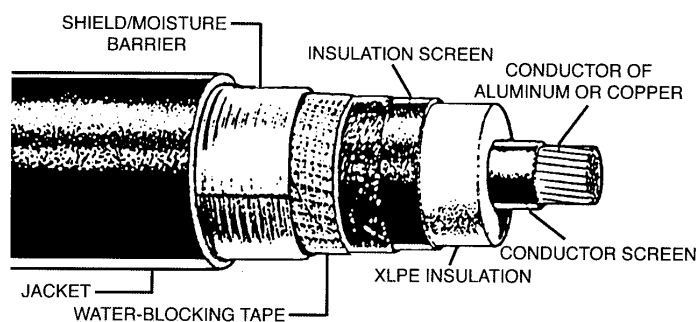


Figure 2—Under-jacket type with combined shield and moisture barrier

4.2 Cables with on-core moisture barriers

In the on-core construction, a laminate composed of a lead tape coated on both sides with a semiconducting adhesive copolymer is utilized. The lead is quite thin, about 2 mils (0.05 mm) thick and the laminate is designed to expand and contract with the cable core. The moisture barrier laminate is placed directly over the semiconducting screen. A semiconducting bedding tape is normally placed over the moisture barrier. The neutrals and a jacket are applied over the bedding tape. Most jacketing materials may be utilized. An illustration of the design is shown in figure 3. The sealed moisture barrier should not be applied in the manufacturing process until the extruded insulation has been degassed.

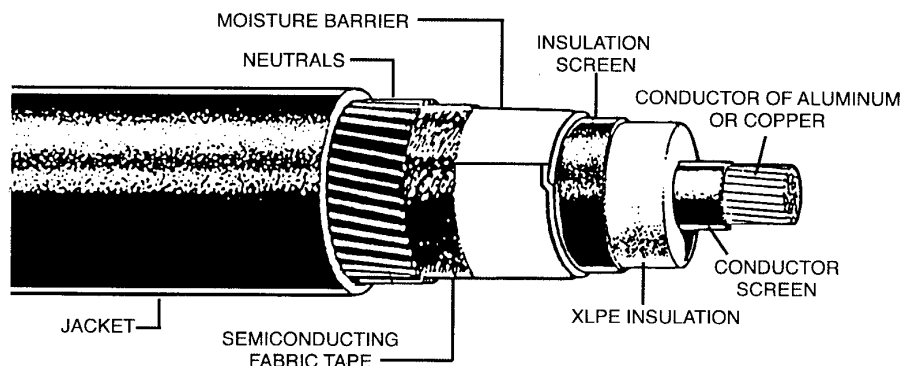


Figure 3—On core type

The primary function of the on-core moisture barrier is to prevent radial permeation of moisture. A primary advantage is that the moisture barrier is adhered directly to the core and thus guards against longitudinal water migration between the moisture barrier and the core. Another advantage of this design is that standard methods for splicing and terminating may be utilized. See 7.2 for further details. Since the on-core moisture barrier is directly adhered to the core, it must be able to expand and contract with the core under conditions of thermal loading. The bedding tape over the moisture barrier is required to prevent damage to the moisture barrier by the neutral wires when the core expands during thermal loading. The neutral wires and outer-jacket in turn mechanically protect the moisture barrier.