

IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables

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

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Foreword

(This Foreword is not a part of IEEE Std 635-1989, IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables.)

Guidance on protective coverings is not included in this guide. This topic is covered in a separate guide, IEEE Std 532-1982, IEEE Guide for Selecting and Testing Jackets for Cables. It is not the intent of this guide to make direct comparison with other metallic sheathing materials.

This guide will be revised from time to time to incorporate the latest information available. Indebtedness is hereby acknowledged to other engineers, whose names are not listed herein, for offering valuable comments and suggestions.

This guide was originally prepared by a Working Group of the Insulated Conductors Committee of the IEEE Power Engineering Society. The members of this group were as follows:

Z. S. Paniri, Chair

H. Amino
J. Bentham
G. Buettner

J. Cronin
K. Crook
E. E. McIlveen
S. Krishnasamy

G. Ludasi
N. Spencer
D. Stein

The guide was revised under the leadership of the members of the following Working Group:

L. J. Hiivala, Chair

K. E. Bow

Z. S. Paniri

The Insulated Conductors Balloting Committee, which approved this guide for submission to the IEEE Standards Board, had the following members:

T. Aabo
K. N. Akay
P. Alex
R. W. Allen, Jr.
W. O. Andersen, Jr.
T. P. Arnold
T. A. Balaska
E. W. Bennett
C. W. Blades
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V. J. Boliver
R. R. Borowski
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R. H. W. Watkins
A. C. Westrom
C. A. White
R. O. Wilkinson
C. Woodell
J. T. Zimnoch

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IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables

1. Purpose and Scope

1.1 Purpose

The purpose of this guide is as follows:

- 1) Outline requirements and establish design guidelines for the selection of aluminum sheaths for extra-high, high-, medium-, and low-voltage cables.
- 2) Establish basic installation parameters for aluminum-sheathed cables.
- 3) Provide references to industry standards and codes incorporating design and installation requirements of aluminum-sheathed cables.
- 4) Provide a comprehensive bibliography of literature related to the subject.

1.2 Scope

This guide covers power cables incorporating aluminum sheaths, except those of the SF₆ rigid-bus type.

2. Definitions

aluminum sheath: An impervious aluminum or aluminum alloy tube, either smooth or corrugated, which is applied over a cable core to provide mechanical protection.

low-voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage of 1000 V or less, the cable having an aluminum sheath as a major component in its construction.

medium-voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 1000 V to 72 500 V, the cable having an aluminum sheath as a major component in its construction.

high-voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 72 500 V to 242 000 V, the cable having an aluminum sheath as a major component in its construction.

extra-high voltage aluminum-sheathed power cable: Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 242 000 V, the cable having an aluminum sheath as a major component in its construction.

3. References

The cable may be in accordance with one or more of the references listed below. The installation must be in accordance with the applicable electrical code or wiring regulations.

- [1] ANSI/NFPA 70-1990, National Electrical Code.¹
- [2] CSA Std C22.1-1990, Canadian Electrical Code, pt. I, Safety Standards for Electrical Installations.²
- [3] CSA Std C22.2, no. 123-M1985, Aluminum Sheathed Cables.³
- [4] CSA Std C68.1-1965, Paper-Insulated Power Cable “Solid” Type.
- [5] *Aluminum Standards and Data*, Jan. 1976 (5th ed.), The Aluminum Association, Inc.
- [6] ICEA P-45-482-1979 (2nd ed.), Short-Circuit Performance of Metallic Shielding and Sheaths of Insulated Cable.⁴
- [7] NEMA WC4-1988 (ICEA S-65-375, 2nd ed.), Varnished-cloth-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy. (See references [21] through [24] in this section.)⁵
- [8] AEIC 1-68-1968, Impregnated-paper-insulated lead-covered cable (10th ed.), Supplement 2.⁶
- [9] EEI 55-16, *Underground Systems Reference Book*. New York: The Edison Electric Institute Transmission and Distribution Committee, 1957.⁷
- [10] SCHIFFREEN, C. S. Cyclic Movement of Cable—Its Causes and Effects on Cable Sheath Life. *AIEE Transactions*, vol. 63, 1944, pp. 1121–1129.
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- [12] HALFMANN, E. S. Critical Inside Dimensions for Power Cable Manholes. *AIEE Transactions*, vol. 69, pt. II, 1950, pp. 1576–1581.
- [13] IEC (International Electromechanical Commission) 141-1 (1976), pt. I, Oil-Filled, Paper-Insulated, Metal-Sheathed Cables and Accessories for Alternating Voltages up to and including 400 kV.⁸
- [14] YANAGIUCHI, H. Analysis of Strain in Corrugated Aluminum Sheath of Cables. *Journal of the Institute of Electrical Engineering of Japan*, vol. 85-12, no. 927, Dec. 1965, pp. 103–107.

¹The National Electrical Code is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. Copies are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

²In the US, CSA Standards are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018. In Canada they are available at the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Rexdale, Ontario, Canada M9W 1R3.

³In the US, this document is available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

⁴ICEA publications are available from Insulated Cable Engineers Association, Inc., P.O. Box P, South Yarmouth, MA 02664.

⁵NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037.

⁶AEIC documents are available from the Publication Department, the Association of Edison Illuminating Companies, 600 N. 18th Street, Birmingham, AL 35291-0992.

⁷EEI publications are available from the Edison Electric Institute, 1111 19th Street, NW, Washington, DC 20036.

⁸IEC publications are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

- [15] BIANCHI, G., DURSO, M. A., and OCCHINI, E. Design and Test of a Flexible EHV Cable Connection for a Floating Plant. *IEEE Transactions on Power Apparatus and Systems*, PAS-96, no. 2, Mar./Apr. 1977.
- [16] LANFRANCONI, G. M., GUALTIERE, G., and CAVALLI, M. 330 kV Oil-Filled Cables Laid in 1600 ft. Vertical Shaft at Kafue Gorge Hydraulic Plant. *IEEE Paper T73-126-0*.
- [17] Weld-joints for 115 kV Cable Sheath. *Electrical World*, Dec. 15, 1972.
- [18] AEIC CS4-1979, Impregnated-Paper-Insulated Low-Pressure Oil-Filled Cable.
- [19] BS 6480-1988, British Standard Impregnated Paper-Insulated Cables for Electricity Supply: pt. I, Lead or Lead Alloy Sheathed Cables for Working Voltages up to and including 33 kV.⁹
- [20] JIS C3613-1987, O. F. Type Paper-Insulated Aluminum-Sheathed Power Cables.¹⁰
- [21] NEMA WC3-1980 (R 1986) (ICEA S-19-81, 5th ed.), Rubber-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.
- [22] NEMA WC5-1973 (R 1979, 1985) (ICEA S-61-402, 3rd ed.). Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.
- [23] NEMA WC8-1976 (R 1982, 1988) (ICEA S-68-516), Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.
- [24] NEMA WC7-1982 (R 1988) (ICEA S-66-524), Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electric Energy.
- [25] AEIC CS5-1987, Specifications for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 through 35 kV, 9th ed.
- [26] AEIC CS7-1987, Specifications for Crosslinked Polyethylene Insulated Shielded Power Cables Rated 46 through 138 kV, 2nd ed.
- [27] AEIC CS6-1989, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 through 69 kV, 5th ed.
- [28] Test Program for Corrugated Type ALS Aluminum-Sheathed Cables, Underwriters' Laboratories, Inc.
- [29] VDE 0255/11.72, Specifications for Mass-Impregnated Paper-Insulated Metal-Sheathed Cables for Electricity Supply (except external gas-pressure and oil-filled cables).¹¹
- [30] IEC 55, Paper-Insulated Metal-Sheathed Cables for Rated Voltages up to 18/30 kV, 55-1 (1978) pt. I: Tests, 55-2 (1965), Tests on Impregnated-Paper-Insulated Metal-Sheathed Cables.
- [31] McILVEEN, E. E. Aluminum-Sheathed Control Cable. *AIEE Transactions on Power Apparatus and Systems*, no. 22, 1956, pp. 1376–1384.

⁹BS Standards are published by the British Standards Institution, 2 Park Street, London W1A 2BS UK. Copies are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

¹⁰JIS Standards are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

¹¹VDE Standards are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

4. Advantages and Limitations of Aluminum Sheaths

A cable designer or user should be aware of the merits and limitations of aluminum-sheathed cable and assign an order of importance to each property to satisfy the requirements of the specific application where power cables are involved.

4.1 Advantages

4.1.1

The use of an aluminum sheath reduces the weight of the cable compared with those having other metallic sheaths, thereby simplifying installation and lowering shipping costs. Furthermore, longer pulling lengths are possible with reduced cable weight.

4.1.2

As a sheath, aluminum is characterized by high electrical conductance and consequently by high short-circuit capability. In addition, high conductance offers excellent protection against lightning.

4.1.3

Aluminum has very good mechanical properties, for example, hardness and fatigue resistance. Therefore, the possibility of sheath fatigue failure due to vibrations and movement induced by thermal cycling is minimal.

4.1.4

Aluminum has a higher yield point, higher tensile strength, and less creep by comparison with other more ductile sheathing materials. These attributes permit fewer clamps for installations in tunnels or above ground. The high hoop strength of aluminum sheath is particularly important in pressurized cables, since it may permit a reduction in the number of stop joints and pressure tanks.

4.2 Limitations

4.2.1

Aluminum is a relatively active metal chemically, and care must be taken to provide adequate protection against corrosion.

4.2.2

Because of its rigidity, smooth aluminum-sheathed cable is more difficult to bend than corrugated aluminum-sheathed cable.

4.2.3

For jointing and terminating, aluminum sheath requires techniques different from those applicable to other commonly used metals, and retraining of splicing and terminating crews may be necessary.

4.2.4

Because of its high electrical conductance, losses resulting from induced sheath currents and eddy currents are substantial. These losses can be reduced by selecting thinner sheaths and by using special sheath bonding methods for single-conductor cables.

5. Applications

5.1 Background

In the mid-1940's, attention was focused on aluminum as a sheathing material because of the scarcity of lead. As the technical and economic advantages of aluminum were recognized, its use escalated rapidly.

Initially, aluminum was used in applications previously dominated by lead, namely, solid-type paper-insulated medium-voltage cables. The aluminum sheath was of the smooth type; corrugated sheath was not used initially because of compound drainage. Subsequently, however, the corrugated sheath found widespread acceptance, mainly in low-voltage extruded-dielectric cables, and large-size oil-filled high-voltage cables, where impregnating compound drainage into the corrugations is not a factor for consideration.

5.2 Products and Installation Conditions

5.2.1

Considerable experience has been gained in the use of aluminum-sheathed cables in the following products and installation conditions:

- 1) Low-voltage cables, type MC in accordance with SCHIFFREEN [11]¹² and types RA60, RA75 and RA90 in accordance with CSA Std C22.1-1986 [2] and CSA Std C22.2 no. 123-M1985 [3].
- 2) General purpose, pressurized, self-contained paper-insulated oil-filled medium and high-voltage cables
- 3) Shaft cables, mainly self-contained oil-filled and extruded-dielectric types
- 4) Tunnel cables
- 5) Nonpressurized impregnated-paper-insulated medium-voltage cables with a smooth sheath used in vertical risers

5.2.2

Medium-voltage solid-type impregnated-paper-insulated cables, incorporating annular-corrugated aluminum sheaths, may be used provided that the impregnate is of the nondraining type, and that the corrugations are filled with a suitable compound.

5.2.3

Severe expansion and contraction of the cable in aerial installations may take place during load or ambient cycles. Extreme care must be exercised to provide for this behavior.

6. Aluminum Metals and Alloys

6.1 General

Aluminum sheathing metals and alloys are characterized by good general corrosion resistance, high thermal and electrical conductivity, good mechanical properties, and excellent workability. Such metals are typified by those in *Aluminum Standards and Data* [5]. Furthermore, no instance of failure due to stress corrosion cracking in service or in a laboratory is known. A moderate increase in strength may be obtained by work hardening. Iron and silicon are the major impurities.

¹²Numbers in brackets correspond to those of the references listed in Section 3.

Alloys in the categories considered are not normally expected to stress-corrode in any environment. Aluminum corrodes in strong alkalis, mercurial compounds, most strong acids, and aqueous solutions containing copper and other heavy metals. These environments should be avoided. Chloride pitting can be a problem in some environments. These pits can initiate fatigue damage or even penetrate the specimen.

6.2 Selection and Application

In general, the selection of the proper sheathing alloy is determined by the manufacturing method, and for the purpose of this guide the two principal alloys used for sheathing with their respective methods of application are described below:

6.2.1 Universal Aluminum Metals

The metals in this group contain 99.45-99.6% aluminum; the balance includes mainly silicon and iron. The composition of a typical metal is shown in Table 1.

Universal aluminum metals are used for general purpose sheaths of cables installed in vertical shafts, for seam-welded strip, and for aluminum tube used for the “sinking” (draw-down) manufacturing process. For example, Aluminum 1350, 1145, 1050 and 1060 belong to this group.

Table 1—Composition of a Typical Universal Aluminum Metal

Aluminum minimum (%)	Iron maximum (%)	Silicon maximum (%)	Other Elements maximum (%)
99.45	0.3	0.3	0.17

6.2.2 Pure Aluminum Metals

The metals in this group contain at least 99.7% aluminum. They are normally supplied in the form of billets and used for the direct sheath extrusion process. Typical composition and properties are shown in Table 2.

Table 2—Composition of Some Typical Pure Aluminum Metals

Aluminum minimum (%)	Iron maximum (%)	Silicon maximum (%)	Other Elements maximum (%)	
			each	total
99.80	0.10	0.06	0.03	0.10
99.75	0.12	0.08	0.03	0.10
99.70	0.20	0.10	0.03	0.10

Other aluminum metals and alloys may be used for applications requiring special properties; none of them are heat-treatable. Alloy 3003 has been used; the conductivity of this alloy is significantly lower than that of Aluminum 1350.

For further information on aluminum and aluminum alloys, refer to the appropriate national and international standards or handbooks listed in Section 3., for example, *Aluminum Standards and Data* [5].