



**STANDARD FOR
EXTRUDED INSULATION POWER CABLES
RATED ABOVE 46 THROUGH 345 KV**

Approved by

AMERICAN NATIONAL STANDARDS INSTITUTE

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INSULATED CABLE ENGINEERS ASSOCIATION, Inc

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ICEA S-108-720-2012

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Typographical error corrected in Table 9-3 on 3/6/13

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FOREWORD

This Standards Publication for Extruded Insulation Power Cables Rated above 46 to 345 kV (ICEA S-108-720) was developed by the Insulated Cable Engineers Association Inc. (ICEA).

ICEA standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for his particular need. Existence of an ICEA standard does not in any respect preclude the manufacture or use of products not conforming to the standard. The user of this Standards Publication is cautioned to observe any health or safety regulations and rules relative to the manufacture and use of cable made in conformity with this Standard.

Requests for interpretation of this Standard must be submitted in writing to the Insulated Cable Engineers Association, Inc., P. O. Box 1568, Carrollton, Georgia 30112. An official written interpretation will be provided. Suggestions for improvements gained in the use of this Standard will be welcomed by the Association.

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Part 1 GENERAL

1.1 SCOPE

This standard applies to materials, constructions, and testing of crosslinked polyethylene (XLPE) and ethylene propylene rubber (EPR) insulated single conductor shielded power cables rated above 46 to 345 kV used for the transmission of electrical energy.

1.2 GENERAL INFORMATION

This publication is arranged to allow for selection of individual components (such as conductors, insulation, extruded shields, metallic shields, jackets, etc.) as required for specific installation and service conditions.

Parts 2 to 7 cover the major components of cables:

- Part 2 - Conductor
- Part 3 - Conductor Shield
- Part 4 - Insulation
- Part 5 - Extruded Insulation Shield
- Part 6 - Metallic Shielding
- Part 7 - Jacket

Each of these parts designates the materials, material characteristics, dimensions, and tests applicable to the particular component.

Part 8 covers identification of cables.

Part 9 covers production test procedures applicable to cable component materials and to completed cables.

Part 10 covers qualification test procedures.

Part 11 contains appendices of pertinent information.

U.S. customary units, except for temperature, are specified throughout this standard. Approximate International System of Units (SI) equivalents are included for information only.

1.3 INFORMATION TO BE SUPPLIED BY PURCHASER

When requesting proposals from cable manufacturers, the prospective purchaser should describe the cable desired by reference to pertinent provisions of these standards. To help avoid misunderstandings and possible misapplication of the cable, the purchaser should also furnish the following information:

1.3.1 Characteristics of Systems on which Cable is to be Used

- a. Desired ampacity for normal and emergency operation.
- b. Frequency.
- c. Nominal phase-to-phase operating voltage.
- d. Maximum phase-to-phase operating voltage.
- d. Basic Impulse Insulation Level (BIL).
- e. Symmetrical and asymmetrical fault current and duration for conductor and metallic shield/sheath.
- f. Daily load factor.

1.3.2 Description of Installation

- a. Installation method and geometry, for example:
 1. In underground ducts.
 2. Direct buried in ground.
 3. In air and whether the effects of wind and/or solar radiation should be considered.
 4. In tunnel and whether there are special fire retardant features.
 5. Descriptions other than the foregoing.
- b. Installation conditions.
 1. Ambient air temperature and/or ambient ground temperature at burial depth.
 2. Minimum temperature at which cable will be installed.
 3. Number of loaded cables in direct buried cable chase, duct bank or conduit system. If in cable chase, describe cable spacing and burial depth. If in conduit, describe size (ID and OD) type of conduit (metallic or nonmetallic), number of occupied and unoccupied conduits, whether enclosed or exposed, spacing between conduits and burial depth of conduits.
 4. Method of bonding and grounding of metallic shield/sheath. Presence, number and size of any ground continuity conductors (GCC).
 5. Wet or dry location.
 6. Thermal resistivity (ρ) of soil, concrete and/or thermal backfill.

1.3.3 Quantities and Description of Cable

- a. Total cable length, including any special test lengths, and specific shipping lengths if required.
- b. Nominal phase-to-phase rated voltage.
- c. Type of conductor - copper or aluminum, filled or unfilled strand.
- d. Size of conductors in circular mils. If conditions require other than standard stranding, a complete description should be given.
- e. Type of insulation system.
- f. Type of metallic shield/sheath.
- g. Type of jacket.
- h. Maximum allowable overall diameter, if limited by conduit inside diameter or other considerations.
- i. Method of cable identification.

1.4 INFORMATION TO BE SUPPLIED BY MANUFACTURER

When submitting proposals to the prospective purchaser, cable manufacturers shall describe the cable proposed to this standard. To help avoid misunderstandings, the manufacturer shall furnish at least the following information:

- a. Nominal insulation thickness.
- b. A complete description of the cable including dimensions and material description of each layer. This information may be in the form of a drawing.
- c. Nominal phase-to-phase voltage.
- d. Normal conductor maximum operation temperature the cable was designed to meet.
- e. Emergency conductor maximum operation temperature the cable was designed to meet.
- f. Fault capacity as defined by customer parameters.
- g. The voltage stress at the conductor shield/insulation interface (maximum stress) and at the insulation/insulation shield interface (minimum stress).
- h. Maximum allowable pulling tension and sidewall bearing pressure.
- i. Dielectric constant.
- j. Minimum bending radius.
- k. Weight per unit of length.

1.5 DEFINITIONS AND SYMBOLS

Active Length:	Length of cable covered by insulation shield and metallic shield.
Agglomerate:	A discernible area of compound constituents in ethylene propylene based insulation which is generally opaque and can be broken apart.
Amber:	A localized area in crosslinked polyethylene insulation which is dissimilar in color (ranging from bright yellow to dark red) from the surrounding insulation, which passes light and is not always readily removable from the insulation matrix. This does not include clouds, swirls or flow patterns which are normally associated with the extrusion process.
AWG:	American Wire Gauge
BIL:	Basic Impulse Insulation Level.
Cable Core:	The portion of a cable which includes the conductor, the conductor shield, the insulation, and the extruded insulation shield.
Cable Core Extruder Run:	A continuous run of cable core with one conductor size, one conductor shield compound, one insulation compound and thickness, and one insulation shield compound.
Certified Test Report:	A report containing the results of production tests or qualification tests which declares that the cable shipped to a customer meets the applicable requirements of this standard.
Completed Cable:	A length of cable which has finished all manufacturing processes, but may not have been fully tested.
Contaminant:	Any solid or liquid material which is not an intended ingredient.
Dielectric Constant:	The ratio of the capacitance of a given configuration of electrodes with the material as a dielectric to the capacitance of the same electrode configuration with a vacuum (or air for most practical purposes) as the dielectric.
Discharge-Free Cable Design:	A cable meeting the maximum partial discharge magnitude requirements of this standard, when measured in the manner described herein, at the specified partial discharge test voltage.
Discharge-Resistant Cable Design:	A cable design capable of withstanding electrical discharge.
Dissipation Factor:	The cotangent of the dielectric phase angle of a dielectric material or the tangent of the dielectric loss angle. It is often called $\tan \delta$.
Dry Location:	A location not normally subject to dampness or wetness.
EPR Insulating Compound:	A mixture of ethylene propylene base resin and selected ingredients.

Gel:	A discernible region of compound constituents in ethylene propylene based insulation which is gelatinous, not readily removable from the insulation, and generally translucent.
High Dielectric Constant Compound:	An extruded compound used for the conductor shield which has a dielectric constant typically between 8 and 200.
Jacket Extruder Run:	A cable with a jacket which was applied in one continuous run with one jacket compound and one jacket thickness.
kcmil:	Thousands of circular mils.
Lot (Cable):	The quantity of cable requiring one test.
Lot (Material):	A quantity of material used in cable construction which is produced at the same location under the same manufacturing conditions during the same time period.
Master Length:	A continuous length of cable collected on a reel at the end of an extrusion line.
Maximum Conductor Temperatures:	
Normal Operating:	The highest conductor temperature permissible for any part of the cable under normal operating current load.
Emergency Overload:	The highest conductor temperature permissible for any part of the cable during emergency overload of specified time, magnitude, and frequency of application.
Short Circuit:	The highest conductor temperature permissible for any part of the cable during a circuit fault of specified time and magnitude.
Nominal Value:	The value by which a quantity is designated and often used in tables (taking into account specified tolerances).
Partial Discharge Level:	The largest repeatedly occurring partial discharge magnitude, measured in picocoulombs, at the specified partial discharge test voltage.
pC:	picocoulombs
Production Tests:	Tests defined in Part 9 of this standard with specific test frequency.
Qualification Tests:	Tests defined in Part 10 of this standard with specific test frequency.
Rated Voltage:	Nominal phase-to-phase voltage rating of the cable.
Room Temperature (RT):	25 ±5°C air temperature.
Shipping Length:	A completed length of cable which has passed all test requirements. It may or may not be cut into shorter lengths before it is supplied to the end use customer.

Shipping Reel:	A completed reel of cable shipped to the end use customer.
Thermoplastic:	A polymeric material which repeatedly can be softened by heating and hardened by cooling through a temperature range characteristic of the material and that, in softened state, can be shaped through the application of force.
Thermoset:	A polymeric material which when crosslinked, will not flow on subsequent heating. Crosslinking is accomplished either chemically or by irradiation.
Translucent:	A localized area in crosslinked polyethylene insulation dissimilar to the surrounding insulation which passes light and is not readily removable from the insulation matrix. There are no requirements for transluents in this standard.
V_g :	Nominal phase-to-ground operating voltage
V_t :	Phase-to-ground test voltage
Void:	Any cavity in a compound, either within or at the interface with another extruded layer.
Water Blocking Component:	A non-metallic material incorporated in a cable construction intended as an impediment to water penetration. A water blocking component can be a pumpable or extrudable conductor filler compound, a water swellable tape, yarn, or powder, or a combination thereof.
Wet Location:	Installations underground or in concrete slabs or masonry in direct contact with the earth; in locations subject to saturation with water or other liquids and in unprotected locations exposed to weather.
XLPE Insulation:	Crosslinked polyethylene insulation.

Part 2 CONDUCTOR

2.0 GENERAL

Conductors shall meet the requirements of the appropriate ASTM standards referenced in this standard except that resistance shall determine cross-sectional area as noted in 2.4 and diameters shall be in accordance with 2.5. Requirements of a referenced ASTM standard shall be determined in accordance with the procedure or method designated in the referenced ASTM standard unless otherwise specified in this standard.

The following technical information on typical conductors may be found in Appendix G:

- a. Approximate diameters of individual wires in stranded conductors.
- b. Approximate conductor weights.

2.1 PHYSICAL AND ELECTRICAL PROPERTIES

The conductors used in the cable shall be copper in accordance with 2.1.1 or aluminum in accordance with 2.1.2, as applicable, except as noted in 2.0. Conductors shall be stranded. The outer layer of a stranded copper conductor may be tin coated to assist with free stripping of the adjacent polymeric layer. There shall be no water in stranded conductors in accordance with 9.14.

2.1.1 Copper Conductors

1. ASTM B 3 for soft or annealed uncoated copper.
2. ASTM B 5 for electrical grade copper.
3. ASTM B 8 for Class A, B, C, or D stranded copper conductors.
4. ASTM B 33 for soft or annealed tin-coated copper wire.
5. ASTM B 496 for compact round stranded copper conductors.
6. ASTM B 784 for modified concentric-lay-stranded copper conductor.
7. ASTM B 787 for 19 wire combination unilay-stranded copper conductors.
8. ASTM B 835 for compact round stranded copper conductors using single input wire constructions.

2.1.2 Aluminum Conductors

1. ASTM B 230 for electrical grade aluminum 1350-H19.
2. ASTM B 231 for Class A, B, C, or D stranded aluminum 1350 conductors.
3. ASTM B 233 for electrical grade aluminum 1350 drawing stock.
4. ASTM B 400 for compact round stranded aluminum 1350 conductors.
5. ASTM B 609 for electrical grade aluminum 1350 annealed and intermediate tempers.
6. ASTM B 786 for 19 wire combination unilay-stranded aluminum 1350 conductors.
7. ASTM B 800 for 8000 series aluminum alloy annealed and intermediate tempers.
8. ASTM B 801 for 8000 series aluminum alloy wires, compact round, compressed and concentric-lay Class A, B, C and D stranded conductors.
9. ASTM B 836 for compact round stranded aluminum conductors using single input wire constructions.

2.1.3 Special Conductors

Special conductors (segmental, etc.) shall be made up according to characteristics and details of construction as agreed to by the manufacturer and purchaser.

2.1.3.1 Segmental Conductors

Each segment shall conform, as to the number of individual strand splices, to the requirements of ASTM B 8 or B 231 whichever is applicable.

Binder tapes when used, shall be nonmagnetic and shall have sufficient mechanical strength so that they can be applied with tension adequate to minimize the displacement of the segments. Binder tapes shall be applied substantially free of indents, creases, tears or wrinkles. Defects shall be such that they do not protrude through the conductor shield.

The eccentricity of cabled segmental conductors shall be determined from measurement of both maximum callipered and circumference tape diameters taken at five locations spaced approximately one foot (0.3 m) apart along the conductor. The average of the five maximum callipered diameters shall not exceed the average of the five circumference tape diameters by more than 2 percent. At any one location, the maximum callipered diameter shall not exceed the circumference tape diameter by more than 3 percent.

2.2 OPTIONAL WATER BLOCKING COMPONENTS FOR STRANDED CONDUCTORS

If required by the purchaser, water blocking components designed as an impediment to longitudinal water penetration shall be incorporated in the interstices of the stranded conductor. Compatibility with the conductor shield shall be determined in accordance with ICEA Publication T-32-645. Longitudinal water penetration resistance shall be determined in accordance with ICEA Publication T-31-610 and shall meet a minimum requirement of 1.4 psig (1 meter head).

2.3 CONDUCTOR SIZE UNITS

Conductor size shall be expressed by cross-sectional area in thousand circular mils (kcmil). The metric equivalents for all sizes are described in Table 2-3 (Metric).

2.4 CONDUCTOR DC RESISTANCE

The dc resistance per unit length of each conductor in a shipping length of completed cable shall be not more than 2% greater than the appropriate nominal value specified in Table 2-2. The dc resistance shall be determined in accordance with 2.4.1. Nominal dc resistance is calculated in accordance with 2.4.2. Table 2-2 shows nominal resistance for standard conductor sizes.

For conductor strandings or sizes not listed in Tables 2-2, the nominal direct current resistance per unit length of a completed single conductor cable shall be calculated from the factors given in Table 2-5 using the following formula:

$$R = \frac{f}{A} \times 10^{-3}$$

Where:

R = Conductor resistance in Ω /1000 ft.

f = Factor from Table 2-5

A = Cross-sectional area of conductor in kcmil, determined in accordance with 9.3.2

Where the outer layer of a stranded copper conductor is coated, the direct current resistance of the resulting conductor shall not exceed the value specified for an uncoated conductor of the same size.

2.4.1 Direct Measurement of dc Resistance Per Unit Length

The dc resistance per unit length shall be determined by measurements made in accordance with 9.3.1 to an accuracy of 2 percent or better. If measurements are made at a temperature other than 25°C, the measured value shall be converted to resistance at 25°C by using either of the following:

1. The appropriate multiplying factor obtained from ICEA T-27-581/NEMA WC-53.
2. A multiplying factor calculated using the applicable formula in ICEA T-27-581/NEMA WC-53.

If verification is required for the direct-current resistance measurement made on an entire length of completed cable, a sample at least 1 foot (0.3 m) long shall be cut from that reel length, and the direct-current resistance of each conductor shall be measured using a Kelvin-type Bridge or a potentiometer. This verification test does not constitute a retest and cannot be the basis to pass the entire length of cable.

2.4.2 Calculation of dc Resistance Per Unit Length

The dc resistance per unit length at 25°C shall be calculated using the following formula:

$$R = K \cdot \frac{\rho}{A}$$

Where:

R = Conductor resistance in $\Omega/1000$ ft

K = Weight increment factor, as given in Table 2-1.

ρ = volume resistivity in $\Omega \cdot \text{cmil/ft}$, determined in accordance with ASTM B 193 using round wires (see Table 2-5)

A = Cross-sectional area of conductor in kcmil , determined in accordance with 9.3.2.

When the volume resistivity is expressed in nanoohm meters ($\text{n}\Omega \cdot \text{m}$) and area is expressed in square millimeters (mm^2) the resistance is expressed in milliohms per meter ($\text{m}\Omega/\text{m}$).

2.5 CONDUCTOR DIAMETER

The conductor diameter shall be measured in accordance with 9.3.3. The diameter shall not differ from the nominal values shown in Table 2-3 by more than ± 2 percent.

Table 2-1
Weight Increment Factors *

Conductor Type/Size	Weight Factor (K)
Concentric-lay Strand, Class A, B, C and D	
250 - 2000 kcmil (127 - 1013 mm^2)	1.02
>2000 - 3000 kcmil (>1013 - 1520 mm^2)	1.03
>3000 - 5000 kcmil (>1520 - 2530 mm^2)	1.04
Combination Unilay Strand All Sizes	1.02
Concentric-lay Strand 8000 Series Aluminum All Sizes	1.02

* Based on the method specified in either ASTM B 8, ASTM B 231, ASTM B 400, ASTM B 496, ASTM B 786, ASTM B 787, or ASTM B 801 as applicable.

Table 2-2
Nominal Direct Current Resistance in Ohms Per 1000 Feet at 25°C
of Concentric Lay Stranded and Segmental Conductor

Conductor Size kcmil	Concentric Lay Stranded*					Segmental	
	Aluminum	Copper				Aluminum	Copper
		Uncoated	Coated				Uncoated
			Class B,C,D	Class B	Class C		
250	0.0707	0.0431	0.0448	0.0448	0.0448	...	...
300	0.0590	0.0360	0.0374	0.0374	0.0374	...	...
350	0.0505	0.0308	0.0320	0.0320	0.0320	...	...
400	0.0442	0.0269	0.0277	0.0280	0.0280	...	...
450	0.0393	0.0240	0.0246	0.0249	0.0249	...	...
500	0.0354	0.0216	0.0222	0.0224	0.0224	...	...
550	0.0321	0.0196	0.0204	0.0204	0.0204	...	...
600	0.0295	0.0180	0.0187	0.0187	0.0187	...	...
650	0.0272	0.0166	0.0171	0.0172	0.0173	...	...
700	0.0253	0.0154	0.0159	0.0160	0.0160	...	...
750	0.0236	0.0144	0.0148	0.0149	0.0150	...	...
800	0.0221	0.0135	0.0139	0.0140	0.0140	...	...
900	0.0196	0.0120	0.0123	0.0126	0.0126	...	...
1000	0.0177	0.0108	0.0111	0.0111	0.0112	0.0177	0.0108
1100	0.0161	0.00981	0.0101	0.0102	0.0102	0.0161	0.00981
1200	0.0147	0.00899	0.00925	0.00934	0.00934	0.0147	0.00899
1250	0.0141	0.00863	0.00888	0.00897	0.00897	0.0141	0.00863
1300	0.0136	0.00830	0.00854	0.00861	0.00862	0.0136	0.00830
1400	0.0126	0.00771	0.00793	0.00793	0.00801	0.0126	0.00771
1500	0.0118	0.00719	0.00740	0.00740	0.00747	0.0118	0.00719
1600	0.0111	0.00674	0.00694	0.00700	0.00700	0.0111	0.00674
1700	0.0104	0.00634	0.00653	0.00659	0.00659	0.0104	0.00634
1750	0.0101	0.00616	0.00634	0.00640	0.00640	0.0101	0.00616
1800	0.00982	0.00599	0.00616	0.00616	0.00622	0.00982	0.00599
1900	0.00931	0.00568	0.00584	0.00584	0.00589	0.00931	0.00568
2000	0.00885	0.00539	0.00555	0.00555	0.00560	0.00885	0.00539
2250	0.00794	0.00484	0.00498	...	...	0.00794	0.00484
2500	0.00715	0.00436	0.00448	...	...	0.00715	0.00436
2750	0.00650	0.00396	0.00408	...	...	0.00650	0.00396
3000	0.00596	0.00363	0.00374	...	...	0.00596	0.00363
3250	0.00555	0.00338	0.00348	...	...	0.00555	0.00338
3500	0.00515	0.00314	0.00323	...	...	0.00515	0.00314
3750	0.00481	0.00293	0.00302	...	...	0.00481	0.00293
4000	0.00451	0.00275	0.00283	...	...	0.00451	0.00275
4250	...	...	...	...	...	0.00431	0.00259
4500	...	...	...	...	...	0.00407	0.00244
4750	...	...	...	...	...	0.00385	0.00232
5000	...	...	...	...	...	0.00366	0.00220

* Concentric lay stranded includes compressed and compact conductors.

Table 2-2 (Metric)
Nominal Direct Current Resistance in Milliohms Per Meter at 25°C
of Concentric Lay Stranded and Segmental Conductor

Conductor Size		Concentric Lay Stranded*					Segmental	
		Aluminum	Copper				Aluminum	Copper
kcmil	mm ²	Class B,C,D	Uncoated	Coated				
			Class B,C,D	Class B	Class C	Class D	Uncoated	
250	127	0.232	0.141	0.147	0.147	0.147	...	...
300	152	0.194	0.118	0.123	0.123	0.123	...	...
350	177	0.166	0.101	0.105	0.105	0.105	...	...
400	203	0.145	0.0882	0.0909	0.0918	0.0918	...	...
450	228	0.129	0.0787	0.0807	0.0817	0.0817	...	...
500	253	0.116	0.0708	0.0728	0.0735	0.0735	...	...
550	279	0.105	0.0643	0.0669	0.0669	0.0669	...	...
600	304	0.0968	0.0590	0.0613	0.0613	0.0613	...	...
650	329	0.0892	0.0544	0.0561	0.0564	0.0567	...	...
700	355	0.0830	0.0505	0.0522	0.0525	0.0525	...	...
750	380	0.0774	0.0472	0.0485	0.0489	0.0492	...	...
800	405	0.0725	0.0443	0.0456	0.0459	0.0459	...	...
900	456	0.0643	0.0394	0.0403	0.0413	0.0413	...	...
1000	507	0.0581	0.0354	0.0364	0.0364	0.0367	0.0581	0.0354
1100	557	0.0528	0.0322	0.0331	0.0335	0.0335	0.0528	0.0322
1200	608	0.0482	0.0295	0.0303	0.0306	0.0306	0.0482	0.0295
1250	633	0.0462	0.0283	0.0291	0.0294	0.0294	0.0462	0.0283
1300	659	0.0446	0.0272	0.0280	0.0282	0.0283	0.0446	0.0272
1400	709	0.0413	0.0253	0.0260	0.0260	0.0263	0.0413	0.0253
1500	760	0.0387	0.0236	0.0243	0.0243	0.0245	0.0387	0.0236
1600	811	0.0364	0.0221	0.0228	0.0230	0.0230	0.0364	0.0221
1700	861	0.0341	0.0208	0.0214	0.0216	0.0216	0.0341	0.0208
1750	887	0.0331	0.0202	0.0208	0.0210	0.0210	0.0331	0.0202
1800	912	0.0322	0.0196	0.0202	0.0202	0.0204	0.0322	0.0196
1900	963	0.0305	0.0186	0.0192	0.0192	0.0193	0.0305	0.0186
2000	1013	0.0290	0.0177	0.0182	0.0182	0.0184	0.0290	0.0177
2250	1140	0.0260	0.0159	0.0163	...	...	0.0260	0.0159
2500	1266	0.0235	0.0143	0.0147	...	...	0.0235	0.0143
2750	1393	0.0213	0.0130	0.0134	...	...	0.0213	0.0130
3000	1520	0.0196	0.0119	0.0123	...	...	0.0196	0.0119
3250	1647	0.0182	0.0111	0.0114	...	...	0.0182	0.0111
3500	1773	0.0169	0.0103	0.0106	...	...	0.0169	0.0103
3750	1900	0.0158	0.0096	0.0099	...	...	0.0158	0.0096
4000	2027	0.0148	0.0090	0.0093	...	...	0.0148	0.0090
4250	2154	...	...	...	...	...	0.0141	0.0085
4500	2280	...	...	...	...	...	0.0134	0.0080
4750	2407	...	...	...	...	...	0.0126	0.0076
5000	2530	...	...	...	...	...	0.0120	0.0072

* Concentric lay stranded includes compressed and compact conductors.

Table 2-3
Nominal Diameters for Round Copper and Aluminum Conductors

Conductor Size	Nominal Diameters (Inches)						
kcmil	Concentric Lay Stranded					Combination Unilay	Unilay Compressed
	Compact*	Compressed	Class B**	Class C	Class D		
250	0.520	0.558	0.575	0.576	0.576	0.554	0.542
300	0.570	0.611	0.630	0.631	0.631	0.607	0.594
350	0.616	0.661	0.681	0.681	0.682	0.656	0.641
400	0.659	0.706	0.728	0.729	0.729	0.701	0.685
450	0.700	0.749	0.772	0.773	0.773	0.744	0.727
500	0.736	0.789	0.813	0.814	0.815	0.784	0.766
550	0.775	0.829	0.855	0.855	0.855	...	0.804
600	0.813	0.866	0.893	0.893	0.893	...	0.840
650	0.845	0.901	0.929	0.930	0.930	...	0.874
700	0.877	0.935	0.964	0.965	0.965	...	0.907
750	0.908	0.968	0.998	0.999	0.998	...	0.939
800	0.938	1.000	1.031	1.032	1.032	...	0.969
900	0.999	1.061	1.094	1.093	1.095	...	1.028
1000	1.060	1.117	1.152	1.153	1.153	...	1.084
1100	...	1.173	1.209	1.210	1.211	...	1.137
1200	...	1.225	1.263	1.264	1.264	...	1.187
1250	...	1.251	1.289	1.290	1.290	...	1.212
1300	...	1.276	1.315	1.316	1.316	...	1.236
1400	...	1.323	1.364	1.365	1.365	...	1.282
1500	...	1.370	1.412	1.413	1.413	...	1.327
1600	...	1.415	1.459	1.460	1.460	...	1.371
1700	...	1.459	1.504	1.504	1.504	...	1.413
1750	...	1.480	1.526	1.527	1.527	...	1.434
1800	...	1.502	1.548	1.548	1.549	...	1.454
1900	...	1.542	1.590	1.590	1.591	...	1.494
2000	...	1.583	1.632	1.632	1.632	...	1.533
2250	...	1.678	1.730	1.731	1.731	...	...
2500	...	1.769	1.824	1.824	1.824	...	...
2750	...	1.856	1.914	1.914	1.914	...	...
3000	...	1.938	1.998	1.999	1.999	...	...
3250	...	2.018	2.081	2.081	2.081	...	...
3500	...	2.094	2.159	2.159	2.158	...	...
3750	...	2.168	2.235	2.236	2.234	...	...
4000	...	2.240	2.309	2.309	2.309	...	...

* Diameters shown are for compact round, compact modified concentric and compact single input wire.

** Diameters shown are for concentric round and modified concentric.

Table 2-3 (Metric)
Nominal Diameters for Round Copper and Aluminum Conductors

Conductor Size		Nominal Diameters (mm)						
kcmil	mm ²	Concentric Lay Stranded					Combination Unilay	Unilay Compressed
		Compact*	Compressed	Class B**	Class C	Class D		
250	127	13.2	14.2	14.6	14.6	14.6	14.1	13.8
300	152	14.5	15.5	16.0	16.0	16.0	15.4	15.1
350	177	15.6	16.8	17.3	17.3	17.3	16.7	16.3
400	203	16.7	17.9	18.5	18.5	18.5	17.8	17.4
450	228	17.8	19.0	19.6	19.6	19.6	18.9	18.5
500	253	18.7	20.0	20.7	20.7	20.7	19.9	19.5
550	279	19.7	21.1	21.7	21.7	21.7	...	20.4
600	304	20.7	22.0	22.7	22.7	22.7	...	21.3
650	329	21.5	22.9	23.6	23.6	23.6	...	22.2
700	355	22.3	23.7	24.5	24.5	24.5	...	23.0
750	380	23.1	24.6	25.3	25.4	25.3	...	23.9
800	405	23.8	25.4	26.2	26.2	26.2	...	24.6
900	456	25.4	26.9	27.8	27.8	27.8	...	26.1
1000	507	26.9	28.4	29.3	29.3	29.3	...	27.5
1100	557	...	29.8	30.7	30.7	30.8	...	28.9
1200	608	...	31.1	32.1	32.1	32.1	...	30.1
1250	633	...	31.8	32.7	32.8	32.8	...	30.8
1300	659	...	32.4	33.4	33.4	33.4	...	31.4
1400	709	...	33.6	34.6	34.7	34.7	...	32.6
1500	760	...	34.8	35.9	35.9	35.9	...	33.7
1600	811	...	35.9	37.1	37.1	37.1	...	34.8
1700	861	...	37.1	38.2	38.2	38.2	...	35.9
1750	887	...	37.6	38.8	38.8	38.8	...	36.4
1800	912	...	38.2	39.3	39.3	39.3	...	36.9
1900	963	...	39.2	40.4	40.4	40.4	...	37.9
2000	1013	...	40.2	41.5	41.5	41.5	...	38.9
2250	1140	...	42.6	43.9	44.0	44.0	...	...
2500	1266	...	44.9	46.3	46.3	46.3	...	...
2750	1393	...	47.1	48.6	48.6	48.6	...	...
3000	1520	...	49.2	50.7	50.8	50.8	...	...
3250	1647	...	51.3	52.9	52.9	52.9	...	...
3500	1773	...	53.2	54.8	54.8	54.8	...	...
3750	1900	...	55.1	56.8	56.8	56.7	...	...
4000	2027	...	56.9	58.6	58.6	58.6	...	...

* Diameters shown are for compact round, compact modified concentric and compact single input wire.

** Diameters shown are for concentric round and modified concentric.

Table 2-4
Nominal Diameters for Segmental
Copper and Aluminum Conductors

Conductor Size		Segmental Conductor Diameter* (Four segments)	
kcmil	mm ²	Inches	mm
1000	507	1.140 to 1.152	29.0 to 29.3
1100	557	1.195 to 1.209	30.4 to 30.7
1200	608	1.235 to 1.263	31.4 to 32.1
1250	633	1.260 to 1.289	32.0 to 32.7
1300	659	1.285 to 1.315	32.6 to 33.4
1400	709	1.325 to 1.364	33.7 to 34.6
1500	760	1.375 to 1.412	34.9 to 35.9
1600	811	1.420 to 1.459	36.1 to 37.1
1700	861	1.460 to 1.504	37.1 to 38.2
1750	887	1.480 to 1.526	37.6 to 38.8
1800	912	1.500 to 1.548	38.1 to 39.3
1900	963	1.530 to 1.590	38.9 to 40.4
2000	1013	1.570 to 1.632	39.9 to 41.5
2250	1140	1.665 to 1.730	42.3 to 43.9
2500	1266	1.740 to 1.824	44.2 to 46.3
2750	1393	1.830 to 1.913	46.5 to 48.6
3000	1520	1.910 to 1.998	48.5 to 50.7
3250	1647	1.985 to 2.080	50.4 to 52.8
3500	1773	2.085 to 2.159	53.0 to 54.8
3750	1900	2.150 to 2.234	54.6 to 56.7
4000	2027	2.225 to 2.309	56.5 to 58.6
4250	2154	2.245 to 2.378	57.0 to 60.4
4500	2280	2.315 to 2.448	58.8 to 62.2
4750	2407	2.375 to 2.516	60.3 to 63.9
5000	2534	2.435 to 2.581	61.8 to 65.6

* Diameter over binder tape.

Table 2-5*
Factors† for Determining Nominal Resistance of Stranded Conductors Per 1000 Feet at 25°C

Conductor Size	All Sizes		Diameter of Individual Coated Copper Wires in Inches for Stranded Conductors				
	Aluminum	Uncoated Copper	0.460 to 0.290, Inclusive	Under 0.290 to 0.103, Inclusive	Under 0.103 to 0.0201, Inclusive	Under 0.0201 to 0.0111, Inclusive	Under 0.0111 to 0.0010, Inclusive
Concentric Stranded							
250 - 2000 kcmil (127 – 1013 mm ²)	17692	10786	11045	11102	11217	11456	11580
> 2000 - 3000 kcmil (>1013 - 1520 mm ²)	17865	10892	11153	11211	11327	11568	11694
> 3000 - 5000 kcmil (>1520 - 2530 mm ²)	18309	10998	11261	11319	11437	11680	11807
Conductivity utilized for above factors, (%)	61	100	97.66	97.16	96.16	94.16	93.15

* The factors given in Table 2-5 shall be based on the following:

A. Resistivity

1. A volume resistivity of 10.575 Ω -cmil/ft (0.017580 Ω -mm²/m) at 25°C for uncoated (bare) copper (100% conductivity).
2. A 25°C volume resistivity converted from the 20°C values specified in ASTM B 33 for tin coated copper.
3. A volume resistivity of 17.345 Ω -cmil/ft (0.028835 Ω -mm²/m) at 25°C for aluminum (61.0% conductivity).

B. Increase in Resistance Due to Stranding

1. The value of K (weight increment factor) given in Table 2-1.

† See 2.4 for Use of Factors.

Part 3 CONDUCTOR SHIELD

3.1 MATERIAL

The conductor shall be covered with an extruded thermosetting conductor shield material. A semiconducting tape may be used between the conductor and the extruded shield in which case it shall not be considered as part of the extruded shield thickness.

The extruded material shall be either semiconducting or nonconducting for ethylene propylene rubber (EPR) type insulation and semiconducting only for crosslinked polyethylene (XLPE) type insulation. The extruded shield shall be compatible with all cable component materials with which it is in contact. The allowable operating temperatures of the conductor shield shall be equal to or greater than those of the insulation. The conductor shield shall be easily removable from the conductor and the outer surface of the extruded shield shall be bonded to the overlying insulation.

3.2 EXTRUDED CONDUCTOR SHIELD THICKNESS

(See 9.4.2). The extruded conductor shield minimum thickness shall be as follows:

**Table 3-1
Extruded Conductor Shield Thickness**

Conductor Size, kcmil (mm ²)	Extruded Shield Thickness	
	Minimum Point	
	mils	mm
250 - 550 (127 - 279)	16	0.41
551 - 1000 (279 - 507)	20	0.51
1001 - 1500 (507 - 760)	24	0.61
1501 and larger (761 and larger)	30*	0.76

* For cables rated 138 kV and below the thickness can be reduced to 24 mils for conductor sizes up to and including 2000 kcmil.

3.3 PROTRUSIONS AND IRREGULARITIES

(See 9.4.13). The interface between the extruded conductor shield and the insulation shall be cylindrical and free from protrusions and irregularities that extend more than 3 mils (0.076 mm) into the insulation and 3 mils (0.076 mm) into the extruded conductor shield.

3.4 VOIDS

(See 9.4.13). The interface between the extruded conductor shield and the insulation shall be free of any voids larger than 2 mils (0.051 mm) in its greatest dimension.

3.5 PHYSICAL REQUIREMENTS

The crosslinked material(s) intended for extrusion as a conductor shield shall have an elongation of no less than 100 percent after air oven aging for 168 hours at $121 \pm 1^\circ\text{C}$ for insulations rated 90°C (see 9.4.14). It shall also meet brittleness requirements (see 10.3.4) at temperatures not warmer than -25°C .

3.6 ELECTRICAL REQUIREMENTS

3.6.1 Extruded Semiconducting Material

(See 9.8.1). The volume resistivity of the extruded semiconducting conductor shield shall not exceed 1000 ohm-meter at the maximum normal operating temperature and emergency operating temperature.

3.6.2 Extruded Nonconducting Material (For EPR Insulation Only)

The extruded nonconducting conductor shield shall withstand a 2.0 kV dc spark test. For test frequency see Table 9-4.

(See 10.3.6). The extruded nonconducting conductor shield shall meet the following requirements at room temperature, at the maximum normal operating temperature, and emergency operating temperature:

Dielectric Constant, range	8 - 200
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Minimum ac voltage (49-61 Hz) withstand stress $kV / mm = \frac{60}{\text{dielectric constant}}$

3.6.3 Semiconducting Tape

If a semiconducting tape is used over the conductor, the dc resistance of the tape at room temperature shall not exceed 10,000 ohms per unit square when determined in accordance with ASTM D 4496.

3.7 CROSSLINKED (THERMOSET) REQUIREMENTS

(See 9.4.12). The extruded thermoset conductor shield shall be crosslinked as determined by the wafer boil test.

Part 4 INSULATION

4.1 MATERIAL

The insulation shall be one of the following materials meeting the dimensional, electrical, and physical requirements specified in this section:

- Crosslinked polyethylene (XLPE) with no mineral fillers
- Ethylene propylene rubber (EPR)

Crosslinked polyethylene is suitable for dry locations and wet locations with radial water barrier at voltages above 46 up to and including 345 kV phase-to-phase.

Ethylene propylene rubber insulation has two classifications. Class I is for Discharge-Free and Discharge-Resistant designs. Class II is for Discharge-Free designs only. Ethylene propylene rubber insulation is suitable for wet or dry locations at voltages above 46 up to and including 138 kV phase-to-phase.

The conductor temperature shall not exceed the following:

Table 4-1
Conductor Maximum Operation Temperatures

Insulation Material†	Rated Voltage	Normal Operation	Emergency Overload*	Short Circuit**
XLPE and EPR Classes I, II	Greater than 46 through 138 kV	90°C	105 to 130°C	250°C
XLPE	Greater than 138 through 345 kV	90°C	105°C	250°C

*See Appendix B

**Conductor fault current may be determined in accordance with ICEA P-32-382.

†Other insulation materials composed of Ethylene and Alkene units, which are designated as EAM, may be available and can meet the same physical and electrical requirements as the insulation materials described in this standard. See Appendix H and/or contact the manufacturer for further information.

4.2 INSULATION THICKNESS

The nominal insulation thickness shall be designed based on electrical stress. The electrical stress at the conductor shield shall not exceed the values given in Table 4-2 or the stress qualified by the manufacturer, whichever is lower. The stress limits are based on rated voltage, given in Table 4-2. The manufacturer shall specify the nominal wall thickness to be supplied. The minimum point thickness shall be not less than 90 % of the specified nominal wall thickness.

$$t = R_s \cdot \left[e^{\left(\frac{V_g}{G_{\max} \cdot R_s} \right)} - R_s \right]$$

Where:

- t = Calculated nominal insulation thickness in mm
- R_s = Nominal radius of the conductor shield/insulation interface in mm
- V_g = Rated Voltage to ground in kV
- G_{max} = Maximum stress at the conductor shield/insulation interface in kV/mm

The above formula calculates insulation thickness based on electrical stress at the conductor shield/insulation interface for cables with a semiconducting conductor shield. For EPR cables with nonconducting conductor shield, see Appendix K for the method to calculate electrical stress. Traditional insulation thicknesses are listed in Appendix F.

4.2.1 Selection of Insulation Thickness

The nominal insulation thickness is calculated by using the lower value of the maximum voltage stress from Table 4-2 for the appropriate voltage class or the maximum voltage stress qualified by the manufacturer. Maximum stress levels in Table 4-2 assume the actual operating voltage shall not exceed the rated voltage by more than 5 percent during continuous operation or 10 percent during emergencies lasting not more than 15 minutes.

Either the 15 minute, 30 minute or 60 minute ac test is required. The ac test levels for the appropriate rated voltage are to be used as the basis for ac testing should insulation stresses other than those in Table 4-2 be utilized.

All ac tests shall be conducted at room temperature and at power frequency (49-61 Hz). The waveform shall be substantially sinusoidal. All ac voltages are rms values.

For other voltage ratings and conductor sizes, specific agreement between purchaser and manufacturer in the selection of insulation maximum stress for each application is required. There may also be unusual installations and/or operating conditions where mechanical considerations dictate the use of a larger insulation thickness. When such conditions are anticipated, the purchaser should consult with the cable manufacturer to determine the appropriate insulation thickness.

The minimum size conductor is recommended to be in accordance with Table 4-2.

A threshold ac test limit of 27 kV/mm to 30 kV/mm should not be exceeded for some insulations (as specified by the manufacturer), in order to avoid any possible weakening of the insulation prior to delivery which might later cause a failure in service. The voltage may be lowered, but with a correspondingly longer testing time in order to avoid too high stresses. However, the voltage level shall not be below 1.5 V_g and the duration not longer than 10 hours.

Lower maximum stress may be required because of the type of cable joints and terminations or because of cable environmental conditions. Consult cable manufacturer for further information. (See Appendix D4)

The cable insulation stress specified is for applications where the system is provided with circuit protection such that ground faults will be cleared as rapidly as possible, but in any case within one minute. While these cables are applicable to installations which are on grounded systems, they may also be used on other cable systems, provided the above clearing requirements are met in completely de-energizing the faulted section. In common with other electrical equipment, the use of cables is not recommended on systems where the ratio of the zero to positive sequence phase reactance of the system at the point of cable application lies between -1 and -40 since excessively high voltages may be encountered in the case of ground faults.

Table 4-2
Conductor Sizes, Maximum Insulation Eccentricity, Insulation Maximum Stress and Test Voltages

Rated Voltage, kV	Conductor Size, kcmil	Conductor Size, mm ²	Maximum Insulation Eccentricity %	Insulation Maximum Stress Level kV/mm (V/mil)	ac Test Voltage		
					60 Min. Test 2.0 Vg kV	30 Min. Test 2.5 Vg kV	15 Min. Test 3.0 Vg kV
69	250-5000	127-2534	12	6 (152)	80	100	120
115	750-5000	380-2534	12	8 (203)	135	160	200
120	750-5000	380-2534	12	8 (203)	140	175	205
138	750-5000	380-2534	12	8 (203)	160	200	240
161	750-5000	380-2534	10	9 (229)	185	230	280
230	1000-5000	507-2534	10	11 (279)	265	330	N/A
345	1000-5000	507-2534	10	16 (406)	400	N/A	N/A

4.2.2 Insulation Eccentricity

The eccentricity of the insulation layer shall not exceed the value given in Table 4-2 when calculated as shown below:

$$\frac{T_{\max} - T_{\min}}{T_{\max}} \times 100$$

Where $T_{\max}$ and $T_{\min}$ are maximum and minimum values measured around the same cable cross-section.

4.3 INSULATION REQUIREMENTS

4.3.1 Physical and Aging Requirements

When tested in accordance with Part 9, the insulation shall meet the following requirements: