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**5-46KV Shielded Power Cable for Use in the
Transmission and Distribution of Electric Energy**





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*5-46kV Shielded Power Cable for Use in the Transmission and Distribution
of Electric Energy*

Prepared and Sponsored by:

Insulated Cable Engineers Association, Inc.
P.O. Box 1568
Carrollton, Georgia 30112

www.icea.net

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Foreword

This Standards Publication for 5-46 kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy was developed by the Insulated Cable Engineers Association (ICEA) and approved by the National Electrical Manufacturers Association (NEMA).

ICEA/NEMA Standards are adopted in the public interest and are designed to eliminate misunderstanding between the manufacturer and the user and to assist the user in selecting and obtaining the proper product for his particular need. Existence of an ICEA/NEMA Standard does not in any respect preclude the manufacture or use of products not conforming to the standard. The user of this Standard 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:

Insulated Cable Engineers Association
P.O. Box 1568
Carrollton, GA 30112, USA

An official written interpretation will be provided once approved by ICEA and NEMA. Suggestions for improvements gained in the use of this Standard will be welcomed by the Association.

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Section 1 GENERAL

1.1 SCOPE

This standard applies to materials, constructions, and testing of 5000 volt to 46,000 volt shielded crosslinked polyethylene, and ethylene propylene rubber insulated wires and cables which are used for the transmission and distribution of electrical energy for normal conditions of installation and service, either indoors, outdoors, aerial, underground, or submarine.

1.2 GENERAL INFORMATION

This standard covers the requirements for conductors, the insulations and protective coverings and general constructional and dimensional details common to most standard shielded types of wires and cables. Constructions of specific types are covered in Section 11 or in other ICEA documents. Where a conflict exists between the requirements of Section 11, or other ICEA documents, and those of Sections 1 to 9 inclusive, the requirements of specific types shall apply. See Appendix A for complete titles and dates of ICEA publications and ASTM Standards to which reference is made in this publication. See Section 9 for test procedures not elsewhere referenced. Recommended minimum bending radii are given in Appendix I.

In classifying crosslinked insulations and jackets in this standard, the term "rubber" when used alone without further description shall mean synthetic rubber.

Insulation thicknesses are designated in terms of cable insulation levels (see 4.2).

In classifying jackets and sheaths in this standard, the term "jacket" refers to a continuous nonmetallic covering and "sheath" to a continuous metallic covering.

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

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.

1.3 INFORMATION TO BE SUPPLIED BY PURCHASER

When requesting design proposals from cable manufacturers, the prospective purchaser should furnish the following information:

1.3.1 Characteristics of System on Which Cable is to be Used

1. Current - alternating or direct.
2. Frequency - hertz.
3. Normal operating voltage between phases or, in direct current, between conductors.
4. Number of phases and conductors.
5. Cable insulation level (see 4.2).
6. Minimum temperature at which cable will be installed.
7. Description of installation.
 - a. In buildings.
 - b. In underground ducts.

- c. Aerial.
 - (1) On messenger in metal rings.
 - (2) Preassembled.
 - (3) Field spun.
- d. Direct burial in ground.
- e. Submarine.
- f. Descriptions other than the foregoing.
- 8. Conditions of installation.
 - a. Ambient temperature.
 - b. Number of loaded cables in duct bank or conduit. Duct/conduit type, conduit (metallic or nonmetallic, magnetic/non-magnetic), size, number of loaded conduits/ducts, enclosed or exposed, and spacing between conduits/ducts.
 - c. Load factor.
 - d. Method of bonding and grounding of shields or sheaths.
 - e. Wet or dry location.
- 9. Other special conditions.

1.3.2 Quantities and Description of Cable

- 1. Total number of feet, including test lengths, and shipping reel lengths if specific lengths are required.
- 2. Type of cable. Describe as single conductor, two-conductor, three-conductor, etc.
- 3. Rated circuit voltage, phase-to-phase and desired BIL level, if non-standard.
- 4. Type of conductor - copper or aluminum.
- 5. Size of conductor. If conditions require other than standard stranding, a complete description should be given.
- 6. Type of insulation.
- 7. Thickness of insulation.
- 8. Type of shield.
- 9. Type of outer covering.
- 10. Maximum allowable overall diameter. When duct space is not limited, it is desirable not to restrict the overall diameter.
- 11. Method of conductor identification.
- 12. Special markings.

1.4 DEFINITIONS AND SYMBOLS

AWG:	American Wire Gauge
BIL:	Basic Impulse Insulation Level.
Bowtie Water Tree:	A water tree which originates within the insulation (usually at a contaminant or other imperfection) and develops radially toward the insulation shield and the conductor shield.
Completed Cable:	A length of cable which has finished all manufacturing processes but may not have been fully tested.
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	A cable meeting the maximum partial discharge magnitude requirements of

Cable Design:	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 $\tan \delta$.
EPR Insulating Compound:	A mixture of ethylene propylene base resin and selected ingredients.
Filled Crosslinked Polyethylene Insulation:	XLPE and TRXLPE insulation containing 10 percent or more of mineral fillers by weight.
kcmil:	thousands of circular mils (formerly MCM)
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.
Maximum Conductor Temperatures:	
Normal Operating:	The highest conductor temperature permissible for any part of the cable line under normal operating current load.
Emergency Overload:	The highest conductor temperature permissible for any part of the cable line during emergency overload of specified time, magnitude, and frequency of application.
Short Circuit:	The highest conductor temperature permissible for any part of the cable line 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) but does not require testing or measurement for verification.
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.
Room Temperature (RT):	25 °C $\pm$ 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 can be repeatedly softened by heating and hardening 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.
Tree Retardant XLPE Insulation:	A tree retardant crosslinked polyethylene (TRXLPE) insulation compound containing an additive, a polymer modification or filler that retards the development and growth of water trees in the insulation compound.
Unfilled Crosslinked Polyethylene:	XLPE and TRXLPE insulation containing less than 10 percent mineral filler by weight.
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, yam, or powder, or a combination thereof.
Water Tree:	Microchannels in the insulation which develop in the presence of moisture, voltage stress and some type of catalyst such as a contaminant, a protrusion, space charge or ion(s).
XLPE Insulation:	A crosslinked polyethylene insulation.

Section 2 CONDUCTOR

Conductors shall meet the requirements of the appropriate ASTM standards referenced in 2.1 except that resistance will determine cross-sectional area as noted in 2.4 and diameters will be in accordance with 2.5. Compliance with cross-sectional area is not required.

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 H:

- 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 solid or stranded. The outer layer of an uncoated stranded copper conductor may be coated to obtain free stripping of the adjacent polymeric layer. There shall be no moisture in stranded conductors in accordance with 9.13.

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.
9. ASTM B 902 for Compressed Round Stranded Copper Conductors, Hard, Medium-Hard, or Soft Using Single Input Wire Construction.

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.
10. ASTM B 901 for Compressed Round Stranded Aluminum Conductors Using Single Input Wire Construction.

2.2 OPTIONAL WATER BLOCKING COMPONENTS FOR STRANDED CONDUCTORS

With the approval of the purchaser, water blocking components designed as an impediment to longitudinal water penetration may 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 5 psig.

2.3 CONDUCTOR SIZE UNITS

Conductor size shall be expressed by cross-sectional area in thousand circular mils (kcmil). The AWG equivalents for small sizes shall be found in Table 2-4. The metric equivalents for all sizes are found in Table 2-4 (Metric). The nominal cross sectional area shown in these tables is not a requirement.

2.4 CONDUCTOR DC RESISTANCE PER UNIT LENGTH

The dc resistance per unit length of each conductor in a production or shipping length of completed cable shall not exceed the value determined from the schedule of maximum dc resistances specified in Table 2-2 when using the appropriate nominal value specified in Table 2-3 or 2-3 (Metric). The dc resistance shall be determined in accordance with 2.4.1. Nominal dc resistance is calculated in accordance with 2.4.2. Table 2-3 shows nominal resistance for standard conductor sizes.

Where the outer layer of an uncoated 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.

When a sample is taken from a multiple conductor cable, the resistance shall comply with the appropriate maximum resistance value specified for a single conductor cable.

2.4.1 Direct Measurement of dc Resistance

The dc resistance per unit length shall be determined by dc resistance measurements made in accordance with ICEA Publication T-27-581/WC 53 to an accuracy of 2% 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 the methods specified in ICEA T-27-581/NEMA WC53.

If verification is required for the direct-current resistance measurement made on an entire length of completed cable, a sample at least 1 foot (0.305 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:

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

- R = Conductor resistance in $\Omega/1000$ ft.
 K = Weight increment factor, as given in Table 2-1.
 ρ = Volume resistivity in $\Omega \cdot \text{cmil}/\text{ft.}$, determined in accordance with ASTM B 193 using round wires.
 A = Cross-sectional area of conductor in kcmil, determined in accordance with T-27-581/NEMA WC-53.

When the volume resistivity is expressed in nanoohm•meter (nΩ•m) and area is expressed in square millimeters (mm²) the resistance is expressed in milliohm per meter (mΩ/m).

2.5 CONDUCTOR DIAMETER

The conductor diameter shall be measured in accordance with ICEA T-27-581/NEMA WC-53. The diameter shall not differ from the nominal values shown in Table 2-4 and Table 2-4 (Metric) by more than plus or minus 2 percent.

Table 2-1
WEIGHT INCREMENT FACTORS*

Conductor Type/Size	Weight Factor (K)
Solid All Sizes	1
Concentric-lay Strand, Class A, B, C and D 8 AWG - 2000 kcmil (8.37 - 1013 mm ²) >2000 - 3000 kcmil (>1013 - 1520 mm ²)	1.02 1.03
Combination Unilay Strand All Sizes	1.02
Concentric-lay Strand 8000 Series Aluminum 8 AWG - 2000 kcmil (8.37 - 1013 mm ²)	1.02

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

Table 2-2
**SCHEDULE FOR ESTABLISHING MAXIMUM DIRECT CURRENT RESISTANCE
PER UNIT LENGTH OF COMPLETED CABLE CONDUCTORS LISTED IN TABLE 2-4**

Cable Type	Maximum dc Resistance
Single Conductor Cables and Flat Parallel Cables	Table 2-3* Value Plus 2% (R max = R x 1.02)
Twisted Assemblies of Single Conductor Cables	Table 2-3* Value Plus 2% Plus An Additional 2% - For One Layer of Conductors (R max = R x 1.02 x 1.02)

* For conductor strandings or sizes not listed in Tables 2-3, 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:

Where:

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

R = Conductor resistance in Ω/1000 ft.

f = Factor from Table 2-5.

A = Nominal Cross-sectional area of conductor in kcmil.

Table 2-3
NOMINAL DIRECT CURRENT RESISTANCE IN OHMS PER 1000 FEET AT 25°C
OF SOLID AND CONCENTRIC LAY STRANDED CONDUCTOR

Conductor Size AWG or kcmil	Solid			Concentric Lay Stranded*				
	Aluminum	Copper		Aluminum	Copper			
		Uncoated	Coated		Uncoated	Coated		
				Class A,B,C,D	Class B,C,D	Class B	Class C	Class D
8	1.05	0.640	0.659	1.07	0.652	0.678	0.678	0.680
7	0.833	0.508	0.522	0.851	0.519	0.538	0.538	0.538
6	0.661	0.403	0.414	0.675	0.411	0.427	0.427	0.427
5	0.524	0.319	0.329	0.534	0.325	0.338	0.339	0.339
4	0.415	0.253	0.261	0.424	0.258	0.269	0.269	0.269
3	0.329	0.201	0.207	0.336	0.205	0.213	0.213	0.213
2	0.261	0.159	0.164	0.266	0.162	0.169	0.169	0.169
1	0.207	0.126	0.130	0.211	0.129	0.134	0.134	0.134
1/0	0.164	0.100	0.102	0.168	0.102	0.106	0.106	0.106
2/0	0.130	0.0794	0.0813	0.133	0.0810	0.0842	0.0842	0.0842
3/0	0.103	0.0630	0.0645	0.105	0.0642	0.0667	0.0669	0.0669
4/0	0.0819	0.0500	0.0511	0.0836	0.0510	0.0524	0.0530	0.0530
250	0.0694	...	...	0.0707	0.0431	0.0448	0.0448	0.0448
300	0.0578	...	...	0.0590	0.0360	0.0374	0.0374	0.0374
350	0.0495	...	...	0.0505	0.0308	0.0320	0.0320	0.0320
400	0.0433	...	...	0.0442	0.0269	0.0277	0.0280	0.0280
450	0.0385	...	...	0.0393	0.0240	0.0246	0.0249	0.0249
500	0.0347	...	...	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
1100	...	...	...	0.0161	0.00981	0.0101	0.0102	0.0102
1200	...	...	...	0.0147	0.00899	0.00925	0.00934	0.00934
1250	...	...	...	0.0141	0.00863	0.00888	0.00897	0.00897
1300	...	...	...	0.0136	0.00830	0.00854	0.00861	0.00862
1400	...	...	...	0.0126	0.00771	0.00793	0.00793	0.00801
1500	...	...	...	0.0118	0.00719	0.00740	0.00740	0.00747
1600	...	...	...	0.0111	0.00674	0.00694	0.00700	0.00700
1700	...	...	...	0.0104	0.00634	0.00653	0.00659	0.00659
1750	...	...	...	0.0101	0.00616	0.00634	0.00640	0.00640
1800	...	...	...	0.00982	0.00599	0.00616	0.00616	0.00622
1900	...	...	...	0.00931	0.00568	0.00584	0.00584	0.00589
2000	...	...	...	0.00885	0.00539	0.00555	0.00555	0.00560
2500	...	...	...	0.00715	0.00436	0.00448	...	...
3000	...	...	...	0.00596	0.00363	0.00374	...	...

* Concentric lay stranded includes compressed and compact conductors.

Table 2-3 (Metric)
NOMINAL DIRECT CURRENT RESISTANCE IN MILLIOHMS PER METER AT 25°C
OF SOLID AND CONCENTRIC LAY STRANDED CONDUCTOR

Conductor Size AWG or kcmil	Solid			Concentric Lay Stranded*				
	Aluminum	Copper		Aluminum	Copper			
		Uncoated	Coated		Uncoated	Coated		
				Class A,B,C,D	Class B,C,D	Class B	Class C	Class D
8	3.44	2.10	2.16	3.51	2.14	2.22	2.22	2.23
7	2.73	1.67	1.71	2.79	1.70	1.76	1.76	1.76
6	2.17	1.32	1.36	2.21	1.35	1.40	1.40	1.40
5	1.72	1.05	1.08	1.75	1.07	1.11	1.11	1.11
4	1.36	0.830	0.856	1.39	0.846	0.882	0.882	0.882
3	1.08	0.659	0.679	1.10	0.672	0.699	0.699	0.699
2	0.856	0.522	0.538	0.872	0.531	0.554	0.554	0.554
1	0.679	0.413	0.426	0.692	0.423	0.440	0.440	0.440
1/0	0.538	0.328	0.335	0.551	0.335	0.348	0.348	0.348
2/0	0.426	0.260	0.267	0.436	0.266	0.276	0.276	0.276
3/0	0.338	0.207	0.212	0.344	0.211	0.219	0.219	0.219
4/0	0.269	0.164	0.168	0.274	0.167	0.172	0.174	0.174
250	0.228	...	...	0.232	0.141	0.147	0.147	0.147
300	0.190	...	...	0.194	0.118	0.123	0.123	0.123
350	0.162	...	...	0.166	0.101	0.105	0.105	0.105
400	0.142	...	...	0.145	0.0882	0.0909	0.0918	0.0918
450	0.126	...	...	0.129	0.0787	0.0807	0.0817	0.0817
500	0.114	...	...	0.116	0.0708	0.0728	0.0735	0.0735
550	...	...	...	0.105	0.0643	0.0669	0.0669	0.0669
600	...	...	...	0.0968	0.0590	0.0613	0.0613	0.0613
650	...	...	...	0.0892	0.0544	0.0561	0.0564	0.0567
700	...	...	...	0.0830	0.0505	0.0522	0.0525	0.0525
750	...	...	...	0.0774	0.0472	0.0485	0.0489	0.0492
800	...	...	...	0.0725	0.0443	0.0456	0.0459	0.0459
900	...	...	...	0.0643	0.0394	0.0403	0.0413	0.0413
1000	...	...	...	0.0581	0.0354	0.0364	0.0364	0.0367
1100	...	...	...	0.0528	0.0322	0.0331	0.0335	0.0335
1200	...	...	...	0.0482	0.0295	0.0303	0.0306	0.0306
1250	...	...	...	0.0462	0.0283	0.0291	0.0294	0.0294
1300	...	...	...	0.0446	0.0272	0.0280	0.0282	0.0283
1400	...	...	...	0.0413	0.0253	0.0260	0.0260	0.0263
1500	...	...	...	0.0387	0.0236	0.0243	0.0243	0.0245
1600	...	...	...	0.0364	0.0221	0.0228	0.0230	0.0230
1700	...	...	...	0.0341	0.0208	0.0214	0.0216	0.0216
1750	...	...	...	0.0331	0.0202	0.0208	0.0210	0.0210
1800	...	...	...	0.0322	0.0196	0.0202	0.0202	0.0204
1900	...	...	...	0.0305	0.0186	0.0192	0.0192	0.0193
2000	...	...	...	0.0290	0.0177	0.0182	0.0182	0.0184
2500	...	...	...	0.0235	0.0143	0.0147	...	...
3000	...	...	...	0.0195	0.0119	0.0123	...	...

* Concentric lay stranded includes compressed and compact conductors.

Table 2-4
NOMINAL DIAMETERS FOR COPPER AND ALUMINUM CONDUCTORS

Conductor Size		Nominal Diameters (Inches)								
AWG	kcmil	Solid	Compact*	Reverse Lay Compressed	Concentric Lay Stranded					Unilay Compressed
					Class A	Class B**	Class C	Class D	Combination Unilay	
8	16.51	0.1285	0.134	0.142	...	0.146	0.148	0.148	0.143	...
7	20.82	0.1443	...	0.159	...	0.164	0.166	0.166	0.160	...
6	26.24	0.1620	0.169	0.178	...	0.184	0.186	0.186	0.179	...
5	33.09	0.1819	...	0.200	...	0.206	0.208	0.208	0.202	...
4	41.74	0.2043	0.213	0.225	0.232	0.232	0.234	0.235	0.226	...
3	52.62	0.2294	0.238	0.252	0.260	0.260	0.263	0.264	0.254	...
2	66.36	0.2576	0.268	0.283	0.292	0.292	0.296	0.297	0.286	...
1	83.69	0.2893	0.299	0.322	0.328	0.332	0.333	0.333	0.321	0.313
1/0	105.6	0.3249	0.336	0.362	0.368	0.373	0.374	0.374	0.360	0.352
2/0	133.1	0.3648	0.376	0.405	0.414	0.419	0.420	0.420	0.404	0.395
3/0	167.8	0.4096	0.423	0.456	0.464	0.470	0.471	0.472	0.454	0.443
4/0	211.6	0.4600	0.475	0.512	0.522	0.528	0.529	0.530	0.510	0.498
	250	0.5000	0.520	0.558	0.574	0.575	0.576	0.576	0.554	0.542
	300	0.5477	0.570	0.611	0.629	0.630	0.631	0.631	0.607	0.594
	350	0.5916	0.616	0.661	0.679	0.681	0.681	0.682	0.656	0.641
	400	0.6325	0.659	0.706	0.726	0.728	0.729	0.729	0.701	0.685
	450	0.6708	0.700	0.749	0.772	0.772	0.773	0.773	0.744	0.727
	500	0.7071	0.736	0.789	0.813	0.813	0.814	0.815	0.784	0.766
	550	...	0.775	0.829	0.853	0.855	0.855	0.855	...	0.804
	600	...	0.813	0.866	0.891	0.893	0.893	0.893	...	0.840
	650	...	0.845	0.901	0.929	0.929	0.930	0.930	...	0.874
	700	...	0.877	0.935	0.964	0.964	0.965	0.965	...	0.907
	750	...	0.908	0.968	0.998	0.998	0.999	0.998	...	0.939
	800	...	0.938	1.000	1.031	1.031	1.032	1.032	...	0.969
	900	...	0.999	1.060	1.094	1.094	1.093	1.095	...	1.028
	1000	...	1.060	1.117	1.152	1.152	1.153	1.153	...	1.084
	1100	...	...	1.173	1.209	1.209	1.210	1.211	...	1.137
	1200	...	...	1.225	1.263	1.263	1.264	1.264	...	1.187
	1250	...	...	1.250	1.288	1.289	1.290	1.290	...	1.212
	1300	...	...	1.275	1.314	1.315	1.316	1.316	...	1.236
	1400	...	...	1.323	1.364	1.364	1.365	1.365	...	1.282
	1500	...	...	1.370	1.411	1.412	1.413	1.413	...	1.327
	1600	...	...	1.415	1.459	1.459	1.460	1.460	...	1.371
	1700	...	...	1.459	1.504	1.504	1.504	1.504	...	1.413
	1750	...	...	1.480	1.526	1.526	1.527	1.527	...	1.434
	1800	...	...	1.502	1.547	1.548	1.548	1.549	...	1.454
	1900	...	...	1.542	1.590	1.590	1.590	1.591	...	1.494
	2000	...	...	1.583	1.630	1.632	1.632	1.632	...	1.533
	2500	...	...	1.769	1.823	1.824	1.824	1.824	...	...
	3000	...	...	1.938	1.998	1.998	1.999	1.999	...	...

* 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 (Metric)
NOMINAL DIAMETERS FOR COPPER AND ALUMINUM CONDUCTORS

Conductor Size		Nominal Diameters (mm)								
AWG or kcmil	mm ²	Concentric Lay Stranded								
		Solid	Compact*	Compressed	Class A	Class B**	Class C	Class D	Combination Unilay	Unilay Compressed
8	8.37	3.26	3.40	3.58	...	3.71	3.76	3.76	3.63	...
7	10.6	3.67	...	4.01	...	4.17	4.22	4.22	4.06	...
6	13.3	4.11	4.29	4.52	...	4.67	4.72	4.72	4.55	...
5	16.8	4.62	...	5.08	...	5.23	5.28	5.31	5.13	...
4	21.1	5.19	5.41	5.72	5.89	5.89	5.94	5.97	5.74	...
3	26.7	5.83	6.05	6.40	6.60	6.60	6.68	6.71	6.45	...
2	33.6	6.54	6.81	7.19	7.42	7.42	7.52	7.54	7.26	...
1	42.4	7.35	7.59	8.18	8.33	8.43	8.46	8.46	8.15	7.95
1/0	53.5	8.25	8.53	9.19	9.35	9.47	9.50	9.50	9.14	8.94
2/0	67.4	9.27	9.55	10.3	10.5	10.6	10.7	10.7	10.3	10.0
3/0	85.0	10.4	10.7	11.6	11.8	11.9	12.0	12.0	11.5	11.3
4/0	107	11.7	12.1	13.0	13.3	13.4	13.4	13.5	13.0	12.6
250	127	12.7	13.2	14.2	14.6	14.6	14.6	14.6	14.1	13.8
300	152	13.9	14.5	15.5	16.0	16.0	16.0	16.0	15.4	15.1
350	177	15.0	15.6	16.8	17.2	17.3	17.3	17.3	16.7	16.3
400	203	16.1	16.7	17.9	18.4	18.5	18.5	18.5	17.8	17.4
450	228	17.0	17.8	19.0	19.6	19.6	19.6	19.6	18.9	18.5
500	253	18.0	18.7	20.0	20.7	20.7	20.7	20.7	19.9	19.5
550	279	...	19.7	21.1	21.7	21.7	21.7	21.7	...	20.4
600	304	...	20.7	22.0	22.6	22.7	22.7	22.7	...	21.3
650	329	...	21.5	22.9	23.6	23.6	23.6	23.6	...	22.2
700	355	...	22.3	23.7	24.5	24.5	24.5	24.5	...	23.0
750	380	...	23.1	24.6	25.3	25.3	25.4	25.3	...	23.9
800	405	...	23.8	25.4	26.2	26.2	26.2	26.2	...	24.6
900	456	...	25.4	26.9	27.8	27.8	27.8	27.8	...	26.1
1000	507	...	26.9	28.4	29.3	29.3	29.3	29.3	...	27.5
1100	557	...	...	29.8	30.7	30.7	30.7	30.8	...	28.9
1200	608	...	...	31.1	32.1	32.1	32.1	32.1	...	30.1
1250	633	...	...	31.8	32.7	32.7	32.8	32.8	...	30.8
1300	659	...	...	32.4	33.4	33.4	33.4	33.4	...	31.4
1400	709	...	...	33.6	34.6	34.6	34.7	34.7	...	32.6
1500	760	...	...	34.8	35.8	35.9	35.8	35.9	...	33.7
1600	811	...	...	35.9	37.1	37.1	37.1	37.1	...	34.8
1700	861	...	...	37.1	38.2	38.2	38.2	38.2	...	35.9
1750	887	...	...	37.6	38.8	38.8	38.8	38.8	...	36.4
1800	912	...	...	38.2	39.3	39.3	39.3	39.3	...	36.9
1900	963	...	...	39.2	40.4	40.4	40.4	40.4	...	37.9
2000	1013	...	...	40.2	41.4	41.5	41.5	41.5	...	38.9
2500	1266	...	...	44.9	46.3	46.3	46.3	46.3	...	...
3000	1520	...	...	49.2	50.7	50.7	50.8	50.8	...	...

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

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

Table 2-5*
**† FACTORS FOR DETERMINING NOMINAL RESISTANCE OF STRANDED
CONDUCTORS PER 1000 FEET AT 25°C**

Conductor Size	All Sizes		Diameter of Individual Tin 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 8 AWG - 2000 kcmil	17692	10786	11045	11102	11217	11456	11580
> 2000 - 3000 kcmil	17865	10892	11153	11211	11327	11568	11694
Conductivity utilized for above factors, Percent	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 $\Omega \cdot \text{cmil/ft}$ (100% conductivity) at 25°C for uncoated (bare) copper.
 - 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 $\Omega \cdot \text{cmil/ft}$ (61.0% conductivity) at 25°C for aluminum.
- B. Increase in Resistance Due to Stranding
 - 1. The value of K (weight increment factor) given in Table 2-1.

† See Table 2-2 for Use of Factors.

Section 3 CONDUCTOR SHIELD (STRESS CONTROL LAYER)

3.1 MATERIAL

The conductor shall be covered with an extruded thermosetting conductor shield material. The stress control layer shall be a polymeric covering consisting of an extruded material or extruded material over a semiconducting tape. The extruded layer shall have a minimum thickness of 0.006" (0.15mm). If a semiconducting tape is utilized beneath the extruded layer the tape shall have a minimum 0.0025" (0.06mm) thickness.

The extruded material shall be either semiconducting or nonconducting for ethylene propylene rubber (EPR) type insulation and semiconducting only for crosslinked polyethylene (XLPE or TRXLPE) type insulation. 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 firmly bonded to the overlying insulation.

For 5 kV rated cables, the conductor shield may consist of only a semiconducting tape. Minimum tape thickness shall be 0.0025" (0.06mm).

3.2 PHYSICAL REQUIREMENTS

The crosslinked material intended for extrusion as a conductor shield shall meet the requirements shown in Table 3-1:

**Table 3-1
EXTRUDED CONDUCTOR SHIELD PHYSICAL REQUIREMENTS**

Physical Requirements*	Extruded Conductor Shield
Elongation after air oven test for 168 hours at 121°C ± 1°C (for insulations rated 90°C) or at 136°C ± 1°C (for insulations rated 105°C), minimum percent	100
Brittleness temperature not warmer than, °C	-25

* Material supplier's CTR may be substituted for performing these tests.

3.3 ELECTRICAL REQUIREMENTS

3.3.1 Extruded Semiconducting Material

(See 9.14.) 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.

3.3.2 Extruded Nonconducting Material (For EPR Insulation Only)

3.3.2.1 Withstand Test

The extruded nonconducting conductor shield shall withstand a 2.0 kV dc spark test applied to the layer prior to covering with insulation, per Table 9-1 of Section 9.

3.3.2.2 Electrical Requirements

(See 10.14) The extruded nonconducting conductor shield shall meet the following requirements at room temperature and at the maximum normal and emergency operating temperature

Dielectric Constant (SIC), range 8 – 200

60 Hz ac voltage withstand stress, kV per mm, min: $\frac{60}{\text{Dielectric Constant}}$

3.3.3 Semiconducting Tape

If a semiconducting tape is used over the conductor, the maximum dc resistance of the tape at room temperature shall be 10,000 ohms per unit square when determined in accordance with ASTM D 4496.

3.4 CROSSLINKED (THERMOSET) REQUIREMENTS

(See 9.12.) The extruded conductor shield shall be effectively crosslinked as determined by the wafer boil test..

Section 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:

- Filled or unfilled crosslinked polyethylene (XLPE)
- Filled or unfilled tree retardant crosslinked polyethylene (TRXLPE)
- Ethylene propylene rubber (EPR)

A filled crosslinked polyethylene or filled tree retardant crosslinked polyethylene insulation (XLPE, TRXLPE, XLPE Class III or TRXLPE Class III), meeting the requirements of this specification, is one that contains 10 percent or more of mineral fillers by weight. A tree retardant crosslinked polyethylene insulation is a compound containing the following: an additive, a polymer modification, or filler that retards the development and growth of water trees in the compound. These XLPE and TRXLPE insulations are intended for use only in cables of the "DISCHARGE-FREE" design concept.

Ethylene propylene rubber insulation has four classifications:

- I & II are for use only in cables of the "DISCHARGE-FREE" design;
- III can be used in either the "DISCHARGE-FREE" design or the "DISCHARGE-RESISTANT" design;
- IV is for use only in cables of the "DISCHARGE-RESISTANT" design.

All of the insulations are suitable for use on cables in wet or dry locations at voltages 5 through 46 kV between phases at the 100, 133 and 173 percent insulation level. The conductor temperature shall not exceed the following:

**Table 4-1
CONDUCTOR MAXIMUM RATED TEMPERATURES**

Insulation Material †	Normal Operation	Emergency Overload*	Short Circuit***
XLPE, TRXLPE, and EPR Classes I, II & IV	90 °C	130 °C	250 °C
XLPE Class III, TRXLPE Class III & EPR Class III	105 °C**	140 °C	250 °C

* See Appendix B

** Lower temperatures for normal operation may be required because of the type of material used in the cable joints and terminations or because of cable environmental conditions. Cable users should be aware that all of the jackets described in Section 7 are not necessarily suitable for cables having this maximum temperature rating. Consult cable manufacturer for further information.

*** Conductor fault current shall 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 J and/or contact the manufacturer for further information.

4.2 INSULATION THICKNESS

The insulation thicknesses given in Table 4-4 are based on the rated circuit voltage, phase-to-phase, conductor size and on the cable insulation level.

The minimum thickness and maximum thickness of the insulation shall be as specified in Table 4-4. (See 9.2.2 for method of measurement.)

For identification, nominal thicknesses are shown in Section 8 Table 8-3.

4.2.1 Selection of Proper Thickness

The thickness of insulation for various systems shall be determined as follows:

4.2.1.1 For Three-Phase Systems with 100, 133 or 173 Percent Insulation Level

Use the thickness values given in the respective columns of Table 4-4.

4.2.1.2 For Delta Systems Where One Phase May Be Grounded For Periods Over One Hour

Use the 173 percent thickness values given in Table 4-4. Also, see the 173 percent level note following Table 4-4.

4.2.1.3 For Single- and Two-Phase Systems with 100 Percent Insulation Level

Multiply the voltage to ground by 1.73 and use the resulting voltage value or next higher rating to select the corresponding insulation thickness in the 100 percent insulation level column of Table 4-4

4.2.1.4 For Single- and Two-Phase Systems with 133 Percent Insulation Level

Multiply the voltage to ground by 1.73 and use the resulting voltage value or next higher rating to select the corresponding insulation thickness in the 133 percent insulation level column of Table 4-4.

4.3 INSULATION REQUIREMENTS

Insulations used in both DISCHARGE-FREE and DISCHARGE-RESISTANT cable designs are described in 4.3.1.

4.3.1 Physical and Aging Requirements

When tested in accordance with Section 9, the insulation shall meet the requirements given in Table 4-2:

Table 4-2
INSULATION PHYSICAL REQUIREMENTS

Physical Requirements	Insulation Type					
	XLPE and TRXLPE	XLPE Class III and TRXLPE Class III	EPR Class			
			I	II	III	IV
Unaged Requirements						
Tensile Strength, Minimum Psi (MPa)	1800 (12.5)		700 (4.8)	1200 (8.2)	700 (4.8)	550 (3.8)
Elongation at Rupture, Minimum Percent	250		250			
Aging Requirements After Air Oven Aging for 168 hours						
Aging Temperature, °C ± 1 °C	121	136	121		136	121
Tensile Strength, Minimum Percentage of Unaged Value	75		75	80	75	
Elongation, Minimum Percentage of Unaged Value Minimum Percent at Rupture	75 -		75 -	80 -	75 -	- 175
Hot Creep Test at 150 °C ± 2 °C	Unfilled	Filled				
*Elongation, Maximum Percent			50			
*Set, Maximum Percent			5			

*For XLPE and TRXLPE insulations if this value is exceeded, the Solvent Extraction Test (see 9.11) may be performed and will serve as a referee method to determine compliance (a maximum of 30 percent weight loss after 20 hours drying time).

4.3.2 Electrical Requirements

4.3.2.1 Partial-Discharge Extinction Level for Discharge-Free Designs Only.

(See 9.8.2) Each length of completed cable shall be subjected to a partial discharge test. For cables shielded with a nonmetallic semiconducting layer extruded directly over the insulation, the partial discharge shall not exceed 5 picocoulombs at the ac test voltage given in Table 4-4 or 4-4 (Metric). For cables shielded with a semiconducting coating and a semiconducting tape, the partial discharge shall not exceed 5 picocoulombs at the ac test voltage given in Table 4-3:

Table 4-3
PARTIAL DISCHARGE REQUIREMENTS
FOR SEMICONDUCTING COATING AND TAPE DESIGNS ONLY

Rated Circuit Voltage, Phase to Phase, Volts	Minimum Partial Discharge Extinction Level, kV		
	100% Insulation Level	133% Insulation Level	173% Insulation Level
2001-5000	4	5*	6
5001-8000	6	8	10
8001-15000	11	15	18

* Unless otherwise indicated, the cable will be rated at the 100% insulation level.

4.3.2.2 Discharge (Corona) Resistance for Discharge-Resistant Designs Only.

(See 10.4) The insulation shall be verified as corona discharge resistant using a 21 kV 60 Hz voltage applied for 250 hours. No failure or surface erosion visible with 15 times magnification shall occur. Partial discharge measurements are not required for DISCHARGE-RESISTANT cables.

4.3.2.2.3 Voltage Tests

(See 9.8.1) Each length of completed cable shall withstand, without failure, the ac test voltages given in Table 4-4. The test voltage shall be based on the rated voltage of the cable and the size of the conductor.

Factory dc testing is not required by this specification. However, a dc test may be performed with prior agreement between the manufacturer and the purchaser. Suggested dc test voltages are listed in Appendix D.

4.3.2.4 Accelerated Water Absorption Test, Electrical Method at 60 Hz

(See 10.1.) When tested in accordance with T-27-581, the insulation shall meet the applicable requirements given in Table 10-1.

4.3.2.5 Insulation Resistance

(See 10.2.) Each insulated conductor in the completed cable shall have an insulation resistance not less than that corresponding to a constant of 20,000 megohms-1000 feet at 15.6°C.

Table 4-4
CONDUCTOR SIZES, INSULATION THICKNESSES AND TEST VOLTAGES

Rated Circuit Voltage, Phase-to-Phase Voltage ^a	Conductor Size, (AWG or kcmil) ^b	Insulation Thickness (mils)						a-c Test Voltage, kV ^d		
		100 Percent Level ^c		133 Percent Level ^c		173 Percent Level ^c		100 % Insulation Level	133 % Insulation Level	173 % Insulation Level
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum			
2001-5000	8-1000 ^e	85	120	85	120	135	170	18	18	28
	1001-3000	135	170	135	170	135	170	28	28	28
5001-8000	6-1000	110	145	135	170	165	205	23	28	35
	1001-3000	165	205	165	205	210	250	35	35	44
8001-15000	2-1000	165	205	210	250	245	290	35	44	52
	1001-3000	210	250	210	250	245	290	44	44	52
15001-25000	1-3000	245	290	305	350	400	450	52	64	84
25001-28000	1-3000	265	310	330	375	425	495	56	69	89
28001-35000	1/0-3000	330	375	400	460	550	630	69	84	116
35001-46000	4/0-3000	425	495	550	630	*	*	89	116	150

Table 4-4 (Metric)
CONDUCTOR SIZES, INSULATION THICKNESSES AND TEST VOLTAGES

Rated Circuit Voltage, Phase-to-Phase Voltage ^a	Conductor Size, (mm ²) ^b	Insulation Thickness,(mm)						a-c Test Voltage, kV ^d		
		100 Percent Level ^c		133 Percent Level ^c		173 Percent Level ^c		100 % Insulation Level	133 % Insulation Level	173 % Insulation Level
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum			
2001-5000	8.37-506.7 ^e	2.16	3.05	2.16	3.05	3.43	4.32	18	18	28
	506.8-1520	3.43	4.32	3.43	4.32	3.43	4.32	28	28	28
5001-8000	13.3-506.7	2.79	3.68	3.43	4.32	4.19	5.21	23	28	35
	506.8-1520	4.19	5.21	4.19	5.21	5.33	6.35	35	35	44
8001-15000	33.6-506.7	4.19	5.21	5.33	6.35	6.22	7.37	35	44	52
	506.8-1520	5.33	6.35	5.33	6.35	6.22	7.37	44	44	52
15001-25000	42.4-1520	6.22	7.37	7.75	8.89	10.12	11.4	52	64	84
25001-28000	42.4-1520	6.73	7.87	8.38	9.53	10.80	12.6	56	69	89
28001-35000	53.5-1520	8.38	9.53	10.2	11.7	13.97	16.0	69	84	116
35001-46000	107.2-1520	10.8	12.6	14.0	16.0	*	*	89	116	150

Notes on Table 4-4 & 4-4 (Metric):

^a The actual operating voltage shall not exceed the rated circuit voltage by more than (a) 5 percent during continuous operation or (b) 10 percent during emergencies lasting not more than 15 minutes.

^b To limit the maximum voltage stress on the insulation at the conductor to a safe value, the conductor size shall not be less than the minimum size shown for each rated circuit voltage category.

^c Selection of the cable insulation level to be used in a particular installation shall be made on the basis of the applicable phase-to-phase voltage and the general system category as outlined below:

100 Percent Level - Cables in this category may be applied where the system is provided with relay protection such that ground faults will be cleared as rapidly as possible, but in any case within 1 minute. While these cables are applicable to the great majority of cable installations that are on grounded systems, they may be used also on other systems for which the application of cable is acceptable provided the above clearing requirements are met in completely de-energizing the faulting section.

Where additional insulation thickness is desired, it shall be the same as for the 133 percent insulation level.