IEEE Guide for Specifying and Selecting Power, Control, and Special-Purpose Cable for Petroleum and Chemical Plants

Sponsor

Petroleum and Chemical Industry Committee
of the
IEEE Industrial Applications Society

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Abstract: Information on the specification and selection of power, control, and special-purpose cable, as typically used in petroleum, chemical, and similar plants, is provided in this guide. Materials, design, testing, and applications are addressed. More recent developments, such as strand filling, low-smoke, zero-halogen materials, and chemical-moisture barriers have been included.
Keywords: cable insulation, low-voltage cable, medium-voltage cable

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Introduction

(This introduction is not a part of IEEE Std 1242-1999, IEEE Guide for Specifying and Selecting Power, Control, and Special-Purpose Cable for Petroleum and Chemical Plants.)

This guide was prepared by Working Group P1242 of the Petroleum and Chemical Industry Committee (PCIC) of the IEEE Industrial Applications Society with joint membership coordination from Project 9-39 of the Special Purpose Cable Subcommittee (No. 9) of the Insulated Conductor Committee (ICC) of the IEEE Power Engineering Society. This working group fulfilled a unique role by linking the user community represented by the PCIC membership with the cable manufacturing, utility, and consulting community represented by the ICC. Joint membership provided for ease of input to the guide and cable design solutions that could only have been accomplished in this manner. The purpose of this guide is to provide the user with current cable technology in order to specify and select power, control, and special-purpose cable for use in the petroleum and chemical industry. Emphasis is placed on those areas of concern peculiar to the these industries, including such environmental effects as chemical atmospheres, hazardous areas, contamination, corrosion, and fire.

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IEEE Guide for Specifying and Selecting Power, Control, and Special-Purpose Cable for Petroleum and Chemical Plants

1. Overview

1.1 Scope

This guide provides information on the specification and selection of power, control, and special-purpose cable, as typically used in petroleum, chemical, and similar plants. It addresses materials, design, testing, and applications. More recent developments such as strand filling, low-smoke, zero-halogen materials and chemical-moisture barriers have been included. This guide is not intended to be a design document, although many of the problems associated with the specification and selection of power, control, and special-purpose cable for petroleum and chemical plant applications can be avoided by considering the information presented in this guide. It is recognized that there may be other types of cable used in the petroleum and chemical industries, especially considering the global marketplace. This guide should not be interpreted as precluding the use of such cables.

1.2 Purpose

The purpose of this guide is to provide the user with cable designs, applications, and test procedures that are common to the petroleum, chemical, or similar type of industry. It is intended as an informational tool for the new as well as the more seasoned engineer. In this capacity, it contains an extensive single-point reference and cross-reference list of standards as they apply to the wire and cable industry, including U.S. and Canadian standards. It provides application guidelines for the type of installations found in petroleum and chemical plants as they relate to electrical, mechanical, physical, thermal, and environmental properties of the cable. The use of this guide should help to eliminate premature cable failure due to improper specification, selection, and application of cable in petroleum and chemical plants.

2. References

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

CSA C22.1-98, Canadian Electrical Code, Part I, Safety Standard for Electrical Installations.[1]

IEEE Std 141-1993 (Reaff 1999), IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*).[2]

NFPA 70-1999, National Electrical Code® (NEC®).[3]

3. Typical constructions

3.1 General comments

This clause provides basic information on power and control cables that are typically utilized in petroleum and chemical plant applications. It is not intended to duplicate information contained in the references listed in Clause 2. Accordingly, listing of other sources of information is emphasized. Considerable reliance is placed on illustrations and photographs of typical cables that are not included in other references. Construction details, applicable standards, and application information are included with each figure. Also note that the illustrative information does not include all cables used in petroleum and chemical plants. Not included in this clause are instrument cables, communication cables, portable cords, preassembled aerial cables, submarine cables, mineral insulated cables, jumper cables, etc. Information on such special-purpose cables can be obtained from Clause 12 of this guide and from the documents listed in Clause 2 and Annex A. Also, refer to Clause 4 for general information on cable application and specifically to 4.4.2 for further information on flame rating.

3.2 Acronyms

Acronyms used in the figures are as follows:

CPE	chlorinated polyethylene (thermoplastic or thermoset)
CSPE	chlorosulfonated polyethylene (thermoset)
CWC	continuously welded, corrugated
EPDM	ethylene propylene diene monomer (thermoset)

[1]CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3 (http://www.csa.ca/).

[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://www.standards.ieee.org/).

[3]The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://www.standards.ieee.org/).

EPR ethylene propylene rubber (thermoset)

HMWPE high-molecular-weight polyethylene (thermoplastic)

LSZH low-smoke, zero-halogen polyoletin (thermoplastic or thermoset)

PE polyethylene (thermoplastic)

PVC polyvinyl chloride (thermoplastic)

SR silicone rubber (thermoset)

TRXLPE tree-retardant cross-linked polyethylene (thermoset)

XLPE cross-linked polyethylene (thermoset)

XLPO cross-linked polyolefin (thermoset)

3.3 Low-voltage cables

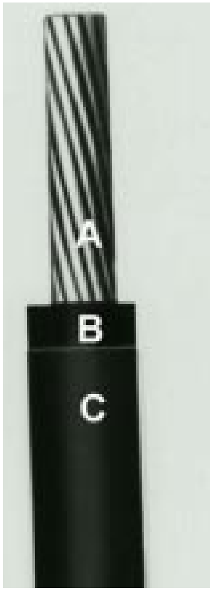
3.3.1 Listing of typical constructions

Illustrations of typical low-voltage (0–2000 V) cable constructions used in petroleum and chemical plants are shown in the figures contained in this clause. Note that the figures are in tabular form and contain descriptive information on construction, standards, fire ratings, and applications. Although a particular figure may be applicable to both U.S. and Canadian cable types, the actual construction and testing may be different due to standard requirements (i.e., different Canadian types are required to pass lower-temperature tests, provide different fire ratings, and may require different insulation thicknesses).

Constructions included in the subsequent figures are as follows:

Figure	U.S. types	Canadian types
1	THHN/THWN/THWN-2	T90 Nylon/TWN 75
2	XHHW/XHHW-2	RW75/RW90
3	RHH/RHW-2 (one pass)	RW75, RW90
4	RHH/RHW-2: USE/USE-2 (jacketed)	RW75, RW90
5	TC (PVC/nylon singles)	TC
6	TC (XLPE singles)	TC
7	TC (EPR singles)	TC
8	MC (armored)	TECK90

3.3.2 Illustrations and descriptive information on typical low-voltage cables



Construction:

A—Conductor: copper, bare or coated, solid or concentric stranded (aluminum available in large sizes)
B—Insulation: PVC
C—Jacket: nylon

Applicable standards: UL 83-1998 [B87].

Conductor temperature: THHN 90 °C dry or damp, THWN 75 °C dry or wet, THWN-2 90 °C wet or dry.

Flame rating: Optional UL-ratedVW-1, optional UL 1581-1997 [B92] vertical flame test for sizes #1/0 AWG and larger for cable tray use when specified.

Applications: THHN, conduit only. THWN, conduit or underground ducts. For sizes #1/0 or larger, both THHN and THWN can be installed in trays when marked for cable tray (CT) use, subject to the National Electric Code® (NEC®) (NFPA 70-1999) restrictions. Not recommended when exposed to sunlight.

Figure 1—600 V Type THHN, THWN, or THWN-2

Construction:

A—Conductor: copper, bare or coated, solid or concentric stranded (aluminum available in large sizes)
B—Insulation/jacket: normally black XLPE

Applicable standards: UL 44-1999 [B85], ICEA S-66-524-1991 [B50], CSA C22.2 No. 38-95 [B34].

Conductor temperature: XHHW 90 °C dry and damp, 75 °C wet, XHHW-2 90 °C wet or dry.

Flame rating: Optional UL 1581-1997 [B92] vertical flame test for sizes #1/0 AWG and larger for cable tray use when specified.

Applications: Conduit, underground ducts, or on messenger. Sizes #1/0 AWG or larger can be installed in trays when marked for CT use, subject to NEC restrictions.

Figure 2—600 V Type XHHW or XHHW-2

Construction:

A—Conductor: copper, bare or coated, solid or concentric stranded (aluminum available in large sizes)
B—Insulation/jacket: normally black XLPE or EPR

Applicable standards: UL 44-1999 [B85], UL 854-1996 [B88], ICEA S-68-516-1988 [B51] (EPR), ICEA S-66-524-1991 [B50] (XLPE), CSA C22.2 No. 38-95 [B34].

Conductor temperature: RHH 90 °C dry and damp, RHW/USE 75 °C dry or wet, RHW-2/USE-2 90 °C wet or dry.

Flame rating: Optional UL-rated VW-1, optional UL 1581-1997 [B92] vertical flame test for sizes #1/0 AWG and larger for cable tray use when specified.

Applications: Conduit, underground ducts, direct buried, or on messenger. Sizes #1/0 AWG or larger can be installed in trays when marked for CT use, subject to NEC restrictions.

Figure 3—600 V or 2000 V Type RHH, RHW or RHW-2, USE or USE-2 (one pass)

Construction:

A—Conductor: copper, bare or coated, solid or concentric stranded (aluminum available in large sizes)
B—Insulation: EPR or EPDM (can be XLPE)
C—Jacket: CSPE or CPE (thermoset)

Applicable standards: UL 44-1999 [B85], UL 854-1996 [B88], ICEA S-68-516-1988 [B51] (EPR), ICEA S-66-524-1991 [B50] (XLPE), CSA C22.2 No. 38-95 [B34].

Conductor temperature: RHH 90 °C dry and damp, RHW/USE 75 °C dry or wet, RHW-2/USE-2 90 °C dry or wet.

Flame rating: Optional UL-rated VW-1, optional UL 1581-1997 [B92] vertical flame test for sizes #1/0 AWG and larger for cable tray use when specified.

Applications: Conduit, underground ducts, direct buried, or on messenger. Sizes #1/0 AWG or larger can be installed in trays when marked for CT use, subject to NEC restrictions.

Figure 4—600 V or 2000 V Type RHH, RHW or RHW-2, USE or USE-2 (jacketed)

Construction:

A—Multiple conductors: copper, bare, soft, Class B, concentric stranded per ASTM B 8-1995 [B26]
B—Insulation: PVC/nylon
C—Fillers: nonhygroscopic
D—Binder tape
E—Jacket: PVC

Applicable standards: UL 1277-1996 [B90], ICEA S-61-402-1992 [B49] (power), ICEA S-73-532-1990 [B52] (control) CSA C22.2 No. 230-M1988 [B39] and CSA C22.2 No. 239-96 [B40].

Conductor temperature: THHN 90 °C dry or damp, THWN 75 °C dry or wet, TWHN-2 90 °C wet or dry.

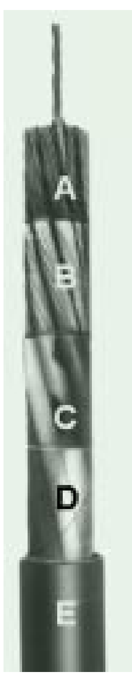
Flame rating: Optional UL-rated VW-1 conductors. Vertical flame test per UL 1277-1996 [B90] for complete cable.

Color code: Power conductors: black with white numbers per ICEA S-73-532-1990 [B52], Method 4, Control conductors: Table E-2. Composite cables: combination of above.

Applications: Raceways, tray, messenger, underground ducts or direct buried subject to UL approval. Open wiring is permitted for limited applications in industrial establishments where the cable meets the crush and impact requirements of type MC cable. See Article 340 of the NEC.

Remarks: Sunlight-resistant jacket, approved for direct burial. Grounding conductor optional. Singles normally dual-rated THHN/THWN. Special construction, with enhanced mechanical properties and ground wire, available for open wiring per NEC option.

Figure 5—600 V Type TC (PVC/nylon)



Construction:

A—Multiple conductors: copper, bare, soft (tinned conductors available), Class B, concentric stranded per ASTM B 8-1995 [B26]
B—Insulation: XLPE
C—Fillers: nonhygroscopic, flame-retardant available
D—Binder tape
E—Jacket: PVC or CPE (thermoplastic), CSPE or CPE (thermoset), LSZH, XLPO or neoprene

Applicable standards: UL 1277-1996 [B90], ICEA S-66-524-1991 [B50] (power), ICEA S-73-532-1990 [B52] (control), CSA C22.2 No. 230, and CSA C22.2 No. 239.

Conductor temperature: 90 °C wet or dry.

Flame rating: Vertical flame test per UL 1277-1996 [B90] for complete cable.

Color code: Power conductors: black with white numbers per ICEA S-73-532-1990 [B52], Method 4, Control conductors: Table E-2. Composite cables: combination of above.

Applications: Conduit, underground ducts, direct buried, or on messenger. Sizes #1/0 AWG or larger can be installed in trays when marked for CT use, subject to NEC restrictions.

Remarks: Sunlight-resistant jacket, approved for direct burial. Grounding conductor optional. Singles typically dual-rated XHH/XHHW or XHHW-2. Special construction, with enhanced mechanical properties and ground wire, available for open wiring per NEC option.

Figure 6—600 V or 2000 V Type TC (XLPE)

Construction:

A—Multiple conductors: copper, bare (tinned conductors available), soft, Class B, concentric stranded per ASTM B 8-1995 [B26]
B—Insulation: EPR
C—Fillers: nonhygroscopic, flame-retardant available depending upon flame test requirement
D—Binder tape
E—Jacket: PVC, CPE (thermoplastic), CSPE or CPE (thermoset), LSZH, XLPO, or neoprene

Applicable standards: UL 1277-1996 [B90], ICEA S-68-516-1988 [B51](power), ICEA S-73-532-1990 [B52] (control), CSA C22.2 No. 230-M1988 [B39] and CSA C22.2 No. 239-96 [B40].

Conductor temperature: 90 °C wet or dry.

Flame rating: Optional UL-rated VW-1 conductors. Vertical flame test per UL 1277-1996 [B90] for complete cable.

Color code: Power conductors: black with white numbers per ICEA S-73-532-1990 [B52]. Control conductors: Table E-2. Composite cables: combination of above.

Applications: Raceways, tray, messenger, or direct buried subject to UL approval.

Remarks: Sunlight-resistant jacket, approved for direct burial. Grounding conductor optional. Special construction, with enhanced mechanical properties and ground wire, available for open wiring per NEC option.

Figure 7—600 V or 2000 V Type TC (EPR)

Construction:

A—Multiple conductors: copper, bare, soft, Class B, concentric stranded per ASTM B 8-1995 [B26]
B—Insulation: XLPE or EPR
C—Fillers: nonhygroscopic
D—Binder tape or optional inner jacket (teck cable requires an inner jacket)
E—Grounding conductor: copper, bare, soft, Class B, concentric stranded per ASTM B 8-1995 [B26]
F—Armor: interlocked—aluminum or galvanized steel; continuous welded and corrugated (CWC) sheath—aluminum or copper
G—Jacket: normally PVC. Also available: CSPE (thermoset), CPE (thermoset or thermoplastic), LSZH (polyolefin), or neoprene

Applicable standards: UL 1569-1995 [B91], UL 2225-1996 [B95], ICEA S-66-524-1991 [B50] (power), ICEA S-73-532-1990 [B52] (control), CSA C22.2 No. 131-M89 [B37].

Conductor temperature: Conductor temperature is dependent on insulation of the singles. For example: XHHW-2 90 °C dry and wet; XHHW 90 °C dry and 75 °C wet.

Flame rating: Normally vertical flame test per UL 1581-1997 [B92]. Optional testing per IEEE Std 1202-1991 [B75] available.

Color code: Power conductors: black with white numbers per ICEA S-66-524-1991 [B50]. Control conductors: per ICEA S-73-532-1990 [B52], Table E-2. Composite cables: combination of above.

Applications: Raceways, tray, supported open runs, messenger, or direct buried.

Remarks: Approved for direct burial when identified for such use. Sunlight-resistant jacket. Cable with CWC armor is considered moisture impervious. Grounding conductor is required for interlocked armor cable but is optional for CWC. Type MC cable can be used in Division 2 hazardous locations subject to NEC restrictions. CWC Type MC cable, with grounding conductor, can be used in Class I, Division 1, or Zone 1 hazardous locations when identified as Type MC-HL.

Figure 8—600 V Type MC (armored)

3.4 Medium-voltage cables

3.4.1 Listing of typical constructions

Illustrations of typical medium-voltage cable constructions used in petroleum and chemical plants are shown in the figures contained in this clause. Note that the figures are in tabular form and contain descriptive information on construction, standards, fire rating, etc. Constructions included in the figures are as follows:

Figure	U.S. types	Canadian types
9	MV-90, MV-105, 5 kV, 1/C, nonshielded	Medium-voltage shielded cable in Canada is manufactured in accordance with CSA C68.3-97 [B42]. There are no type designations.
10	MV-90, MV-105, 5–35 kV, 1/C, helical tape or wire shield	
11	MV-90, MV-105, 5–35 kV, 1/C, LC tape shield	
12	MV-90, MV-105, 5–35 kV, 1/C, imbedded wire shield	
13	MV-90, MV-105, 5–35 kV, 1/C, moisture resistant	
14	MV-90, MV-105, 5 kV, 3/C, nonshielded	
15	MV-90, MV-105, 5 kV, 3/C, nonshielded, armored	
16	MV-90, MV-105, 5–35 kV, 3/C, shielded	
17	MV-90, MV-105, 5–35 kV, 3/C, shielded, armored	
18	Paper insulated, lead covered, 5–35 kV, 1/C	
19	Paper insulated, lead covered, 5–35 kV, 3/C	

3.4.2 Illustrations and descriptive information on typical medium-voltage cables

Construction:

A—Conductor: copper, bare (tinned may be used with EPR), soft, Class B, concentric stranded (compressed or compact option available) per ASTM B 8-1995 [B26] (aluminum also available)
B—Strand screen: extruded semiconducting EPR or polyolefin, semiconducting tape, or high SIC material
C—Insulation: EPR or XLPE
D—Jacket: PVC, CPE (thermoplastic), CSPE or CPE (thermoset), or LSZH. Jacket should be ozone-resistant, nontracking

Applicable standards: ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89].

Conductor temperature: 90 °C wet or dry, 105 °C available with EPR.

Flame rating: Normally capable of passing vertical flame test per UL 1581-1997 [B92] or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option.

Applications: Conduit, trays (size #1/0 AWG and larger), messenger, or underground ducts subject to NEC restrictions.

Remarks: Not suitable for direct burial. Stress cone terminations not required. Track resistant jacket material is desirable.

Figure 9—5 kV Type MV-90, 1/C, nonshielded

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26] (aluminum also available)
B—Strand screen: extruded thermoset semiconducting EPR or polyolefin
C—Insulation: EPR, XLPE, or TRXLPE
D—Insulation screen: extruded semiconducting EPR or polyolefin
E—Shield: helically applied overlapped copper tape or helically applied wire shield
F—Jacket: PVC, CPE (thermoplastic), CSPE or CPE (thermoset), or LSZH

Applicable standards: AEIC CS-5-1994 [B20] or AEIC CS-6-1996 [B22], ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89], CSA C68.3-97 [B42].

Conductor temperature: 90 °C wet or dry, 105 °C available with EPR.

Flame rating: Normally capable of passing vertical flame test per UL 1581-1997 [B92] or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option.

Applications: Conduit, tray (sizes #1/0 AWG and larger), messenger, direct burial, or underground ducts subject to NEC restrictions.

Remarks: Requires stress cone terminations. Give tree-retardancy consideration when selecting insulation for underground applications. Wire shield can be increased in numbers and size to provide additional fault current capability or for use as a concentric neutral.

Figure 10—5–35 kV Type MV-90, 1/C, helical tape or wire shield

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26] (aluminum also available)
B—Strand screen: extruded thermoset semiconducting EPR or polyolefin
C—Insulation:EPR, XLPE, or TRXLPE
D—Insulation screen: extruded, thermoset, semiconducting EPR or polyolefin
E—Shield: longitudinally corrugated copper tape.
F—Jacket: PE, PVC, or CPE (thermoplastic); CSPE or CPE (thermoset); LSZH

Applicable standards: AEIC CS-5-1994 [B21] or AEIC CS-6-1996 [B22], ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89], CSA C68.3-97 [B42].

Conductor temperature: 90 °C wet or dry, 105 °C available with EPR.

Flame rating: Normally capable of passing flame test per UL 1581-1997 [B92]or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option.

Applications: Raceways, ducts, direct burial, messenger, and tray subject to NEC and UL restrictions.

Remarks: Requires stress cone terminations. Longitudinal corrugated tape shield provides lower shield resistance. Use tree retardant insulation (TRXLPE or EPR) plus shield with sealed seam for underground installations to enhance protection from insulation failure due to treeing.

Figure 11—5–35 kV Type MV-90, 1/C, longitudinally applied corrugated shield

Construction:

A—Conductor: copper, bare, soft, Class B, concentric compact stranded per ASTM B 8-1995 [B26]
B—Strand screen: extruded thermoset semiconducting polyolefin
C—Insulation: EPR
D—Shield: longitudinal corrugated copper wires imbedded in jacket
E —Jacket: CPE (thermoplastic), semiconducting

Applicable standards: ICEA S-68-516-1988 [B51], UL 1072-1995 [B89].

Conductor temperature: 90 °C wet or dry.

Flame rating: Normally capable of passing vertical flame test per UL 1581-1997 [B92] or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option.

Applications: Raceways, ducts, direct burial, messenger and tray (sizes #1/0 and larger) subject to NEC and UL restrictions.

Remarks: Requires stress cone terminations. Embedded shield in semiconducting jacket and compact conductor minimizes overall diameter. Terminations simplified.

Figure 12—5–35 kV Type MV-90, 1/C imbedded and corrugated wire shield

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26] (aluminum also available)
B—Strand screen: extruded thermoset semiconducting EPR or polyolefin
C—Insulation: EPR, XLPE or TRXLPE
D—Insulation screen: extruded thermoset semiconducting EPR or polyolefin
E—Shield/moisture barrier: longitudinally corrugated copper tape, copolymer coated on outside, sealed overlap, bonded to outer jacket
F—Jacket: HMWPE or PVC (thermoplastic); CSPE or CPE (thermoset); LSZH

Applicable standards: AEIC CS-5-1994 [B21] or AEIC CS-6-1996 [B22], ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89], CSA C68.3-97 [B42].

Conductor temperature: 90 °C wet or dry, 105 °C available with EPR.

Flame rating: Normally capable of passing flame test per UL 1581-1997 [B92] or IEEE Std 1202-1991. CT use approval is required if installed in tray per UL 1072-1995 [B89] option.

Applications: Raceways, ducts, direct burial, messenger and tray subject to NEC and UL restrictions.

Remarks: Requires stress cone terminations. Especially suited for wet underground applications or other harsh environments. Strand filling should reduce need for tree retardancy consideration when selecting insulation for underground applications.

Figure 13—5–35 kV Type MV-90, 1/C, LC shielded, moisture/chemical impervious

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26]
B—Strand screen: extruded thermoset semiconducting EPR or polyolefin, track resistant
C—Insulation: EPR or XLPE
D—Grounding conductor: copper, bare, soft, class-B concentric stranded per ASTM B 8-1995 [B26]
E—Phase identification: typically ICEA method 4, may use colored tape (normally black, red, and blue)
F—Fillers and binder tape: Nonhygroscopic, moisture-resistant fillers and binder tape
G—Jacket: PE, PVC, or CPE (thermoplastic), CSPE or CPE (thermoset); LSZH

Applicable standards: ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89].

Conductor temperature: 90 °C wet or dry.

Flame rating: Normally capable of passing vertical flame test per UL 1581-1997 [B92], or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option. CT rating not normally available with PE jackets.

Applications: Raceways, ducts, direct burial, messenger, and tray subject to NEC and UL restrictions.

Remarks: Stress cone terminations not required.

Figure 14—5 kV Type MV-90, 3/C, nonshielded

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26]
B—Strand screen: extruded, thermoset, semiconducting EPR or polyolefin
C—Insulation: EPR, or XLPE
D—Grounding conductor: copper, bare, soft, Class B concentric stranded per ASTM B 8-1995 [B26]
E—Phase identification: typically ICEA method 4, may use colored tape (normally black, red and blue)
F—Fillers and binder tape: nonhygroscopic, moisture-resistant fillers and binder tape
G—Armor: continuous corrugated aluminum welded seam or interlocked aluminum or galvanized steel
H—Jacket: Normally PVC. CPE, CSPE, and LSZH are available.

Applicable standards: ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89].

Conductor temperature: 90 °C wet or dry.

Flame rating: Normally capable of passing flame test per UL 1581-1997 [B92], or IEEE 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option. CT rating not normally available with PE jackets.

Applications: Direct burial, messenger, metal racks, troughs, tray, or secured to supports not greater than 1.8 m (6 ft) apart subject to NEC and UL restrictions.

Remarks: Stress cone terminations not required. Can be used in hazardous areas subject to NEC restrictions. See Figure 8 remarks for further information.

Figure 15—5 kV Type MV-90 or Type MC, 3/C, nonshielded, armored

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26]
B—Strand screen: extruded thermoset semiconducting EPR or polyolefin
C—Insulation: EPR. XLPE or TRXLPE
D—Insulation screen: extruded, thermoset, semiconducting EPR or polyolefin
E—Phase identification: ICEA S-73-532-1990 [B52], method E2 colors or ICEA method 4 (printing on insulation shield) may be used
F—Grounding conductor: copper, bare, soft, class B stranded per ASTM B 8-1995 [B26], sized per UL 1072-1995 [B89]. Normally noninsulated.
G—Shield: Helically applied overlapped copper tape or optional wire shield. Corrugated wire shield embedded in semiconducting jacket on singles also available.
H—Fillers and binder tape: nonhygroscopic, moisture-resistant
J—Jacket: PVC, CPE (thermoplastic); CPE or CSPE (thermoset); LSZH.

Applicable standards: AEIC CS-5-1994 [B21] or AEIC CS-6-1996 [B22], ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89], CSA C68.3-97 [B42].

Conductor temperature: 90 °C wet or dry. 105 °C (normally EPR) available with limited jacket options.

Flame rating: Normally capable of passing 70 000 Btu/h flame test per UL 1581-1997 [B92] or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option.

Applications/remarks: Conduit, underground ducts, direct burial, messenger, or tray. Stress cone terminations are required.

Figure 16—5–35 kV Type MV-90, 3/C, shielded

Construction:

A—Conductor: copper, bare, soft, Class B, concentric stranded (compressed or compact options available) per ASTM B 8-1995 [B26]
B—Strand screen: extruded thermoset semiconducting EPR or polyolefin
C—Insulation: EPR. XLPE, or TRXLPE
D—Insulation screen: extruded, thermoset, semiconducting EPR or polyolefin
E—Phase identification: K2 colors or ICEA method 4 may be used (printing on insulation shield)
F—Grounding conductor copper, bare, soft, class B stranded per ASTM B 8-1995 [B26], sized per UL 1072-1995 [B89] (normally noninsulated)
G—Shield: helically applied overlapped copper tape or optional wire shield (corrugated wire shield embedded in semiconducting jacket on singles also available)
H—Fillers and binder tape: nonhygroscopic, moisture-resistant
I—Armor: interlocked—aluminum or galvanized steel; continuous welded and corrugated (CWC)—copper, stainless steel or aluminum
J—Jacket: normally PVC, can be color coded; CSPE, neoprene, and LSZH polyolefin are available.

Applicable standards: AEIC CS-5-1994 [B21] or AEIC CS-6-1996 [B22], ICEA S-66-524-1991 [B50] or ICEA S-68-516-1988 [B51], UL 1072-1995 [B89], CSA C68.3-97 [B42].

Conductor temperature: 90 °C wet or dry, 105 °C (normally EPR) available with limited jacket options.

Flame rating: Normally capable of passing 70 000 Btu/h flame test per UL 1581-1997 [B92] or IEEE Std 1202-1991 [B75]. CT use approval is required if installed in tray per UL 1072-1995 [B89] option. CT rating not normally available with PE jackets.

Applications: Direct burial, messenger, metal racks, troughs, tray or secured to supports not greater than 1.8 m (6 ft) apart subject to NEC and UL restrictions.

Remarks: Stress cone terminations are required.

Figure 17—5–35 kV Type MV-90 or Type MC, 3/C, shielded, armored

Construction:

A—Conductor: copper, bare, soft, stranded, normally compact round (can be concentric round or compact segmental)
B—Strand screen: carbon black paper tape
C—Insulation: paper tapes impregnated with a medium-viscosity dielectric fluid
D—Insulation screen: carbon black paper tape
E—Shield: copper-bearing alloy lead sheath
F—Jacket: normally polyethylene

Applicable standards: AEIC CS-1-1990 [B20], CSA C68.1-1992 [B41], CSA C170.2-1989 [B43].

Conductor temperature: In accordance with AEIC CS-1-1990 [B20].

Flame rating: Not applicable.

Applications: Raceways, ducts, direct burial, messengers.

Remarks: Indoor and aerial installations may not require a jacket. Lead exposed to the elements requires environmental considerations. Lead sheath provides substantial capacity for ground fault current. Separate ground is not needed. Consideration should be given to environmental issues when lead cable is used.

Figure 18—5–35 kV 1/C, paper insulated, lead covered

Construction:

A—Conductor: copper, bare, soft, stranded, normally compact round. Can be concentric round or compact sector.
B—Strand screen: carbon black paper tape
C—Insulation: paper tapes impregnated with a medium viscosity dielectric fluid
D—Insulation screen: carbon black paper tape
E—Shield: zinc alloy tape
F—Filler: impregnated paper
G—Binder: zinc alloy tape
H—Sheath: copper-bearing alloy lead
J—Jacket: normally polyethylene

Applicable standards: AEIC CS-1-1990 [B20], CSA C68.1-1992 [B41], CSA C170.2-1989 [B43].

Conductor temperature: In accordance with AEIC CS-1-1990 [B20].

Flame rating: Not applicable.

Applications: Raceways, ducts, direct burial, messengers.

Remarks: Indoor and aerial installations may not require a jacket. Lead exposed to the elements requires environmental considerations. Lead sheath provides substantial capacity for ground fault current. Separate ground is not needed. Consideration should be given to environmental issue when lead cable is used.

Figure 19—5–35 kV 3/C, paper insulated, lead covered

4. Application guidelines

In the design engineering of a new facility, certain basic electrical decisions have been made by the time selection of the power and control cables is needed. The size of the supplying electrical service along with its adequacy and continuity, the best system configuration to serve geographically situated loads, and distribution voltage levels are generally all known by this time. In most cases, on the basis of operational requirements, the system grounding type has been chosen. With proper consideration of the facility physical layout, its environmental requirements, and fire safety, the method of housing or supporting the cabling system can be determined. These factors should all be considered in the cable selection process since the foregoing basic data is necessary to make accurate decisions on the cable types. The integrity of the facility cabling system is of prime importance to continuity of operation and merits consideration equal to that given to the selection of switchgear and transformers. However, initial design considerations such as a designated plant short life cycle cost or strong economic restraints can be mitigating. When this occurs, full documentation is desirable.

4.1 Types of installations

Electrical cabling systems can be installed either overhead or underground. However, because of a greater number of enclosures or support and routing options, overhead systems are being selected more often. Since the primary function of cable is to carry energy reliably between source and utilization equipment, the enclosure or support option to best meet the physical characteristics of petroleum and chemical plants merits more than casual attention. Each system has its advantages and disadvantages, with the underground selection being the historical choice. As an example, the NEC did not officially recognize the use of overhead cable tray systems until 1975, even though significant numbers of chemical plants were already successfully using that support method.

Selection of the electrical cable system and its placement should include careful consideration of all criteria sensitive to economics, personal safety, physical location, and operational needs.

4.1.1 Underground cabling systems

Underground cabling systems consist of two basic types. One system utilizes conductors in metal or rigid nonmetallic conduit duct systems, commonly encased in concrete, with suitably located cable pits for installation and repair access. The other consists of suitably jacketed or sheathed cables, directly buried in designated trenches, backfilled with sand or other thermally conductive material, and with access generally restricted to supply and load termination points.

Underground installation has the advantages of placing the bulk of the electrical cabling system out of the way of surface construction, with the concurrent disadvantage of placing a physical concrete barrier in the path of other services requiring underground placement, such as water, sewer, natural gas, etc. It has the advantage of protection from explosions, hurricane force winds, and fire, with the concurrent disadvantage of exposure to groundwater and associated chemical spills. Its initial cost is higher than that of equivalent-capacity overhead systems and increased cable damage is more likely to occur during installation requiring cable jacketing with suitable physical abrasion-resistant properties. The cost of maintaining, repairing, and replacing cables is generally higher than that of equivalent overhead systems.

4.1.2 Overhead-supported electrical cabling systems

Overhead-supported electrical cabling systems are now selected for most installations because of the following advantages. They have lower initial cost coupled with lower maintenance and operation expense. During installation minimal damage to cable jacketing occurs, and if damage does happen, excellent visual accessibility for repair is a positive factor. Increased ampacity of conductors is achieved for a given size because of better heat dissipation. Additionally, routine operational visual safety and maintenance inspections are greatly improved. Such inspections are virtually impossible in the typical underground installation. Substantially improved personnel safety and better maintenance and repair economics are attainable when compared to the difficulties incurred in cable pit entry for equivalent functions.

The overhead system can be open, bare, or covered conductors placed on appropriately spaced insulation (knobs, pins, and tubes); covered and insulated conductors suspended by hangers on support structures (messenger supported); insulated conductors placed in cable trays; or hinged wireways located on support structures. Additionally, although most of the advantages noted are lost, insulated conductors may also be pulled into structure-supported metallic or nonmetallic duct systems. Regardless of the method chosen, each has the likely advantage of using a support structure placed for another purpose, such as a pipe rack or sleeper column.

The overhead system is likely to incur more damage to the electrical cabling as a result of a plant explosion, with resultant forces and flying debris exceeding the design considerations of the support systems; and it is more likely to suffer increased damage from surface fires. Hurricane-force winds with associated airborne debris could inflict much more damage than if the system were underground, while cranes and mobile elevated equipment can cause additional personnel and equipment damage if improperly used.

4.2 Electrical considerations

Electrical considerations that should be reviewed during the selection of the specific voltage class cable include the following:

a) Voltage class (rated operating and peak withstand), along with chosen insulation thickness;
b) The ability of the conductor to efficiently carry required load current, along with time-connected thermal stress resulting from short circuit currents;
c) Voltage stress associated with different methods of system grounding;
d) Electrostatic shielding; and
e) Fault current ratings.

Subclauses 4.2.1 through 4.2.5 highlight some of the more important aspects of each consideration.

4.2.1 Voltage

Resistance to voltage breakdown, due to peak transient voltages, of any electrical distribution system is a function of the design basic impulse level (BIL) of its equipment and its connecting cabling plus the thermal aging characteristic of the cable. The insulation of the cable selected, and its thickness, should be compatible with the rated operating voltage of the system as well as the BIL level of the source and utilization end equipment. Generally, the rated breakdown voltage of the cable insulation is greater than the connected equipment. The voltage rating of a cable is based, in part, on the insulation material and thickness and the type of electrical system to which it is connected. Switching surges and fault-interrupting equipment (relay-tripped switchgear, fuses, etc.) causing peak transient voltages, along with system physical parameters, should all be reviewed in the selection of the cable type and its insulation thickness.

There are three general insulation thickness levels for medium-voltage cable that should be taken under consideration, depending on the nominal system voltage. For additional information see 6.1.3 for typical insulation thicknesses, 12.4.1 of IEEE Std 141-1993[4], and the insulation level definitions following Table 310-64 of the National Electric Code® (NEC®) (NFPA 70-1999).

4.2.1.1 100% insulation level

Cables with 100% insulation level are permitted to be applied on grounded systems where the system is provided with relay or other device protection that will clear ground faults as rapidly as possible but in any case, within 1 min.

[4]Information on references can be found in Clause 2.

4.2.1.2 133% insulation level

Cables with 133% insulation level are permitted to be applied on ungrounded or resistance/impedance-grounded systems where the clearing time requirements of the 100% level category cannot be met. For use of this insulation level, there should be adequate assurance that the faulted section will be cleared within 1 h. Also, cables with this insulation level are permitted to be used where additional insulation strength over the 100% level category is desirable.

4.2.1.3 173% insulation level

Cables with 173% insulation level are permitted to be used on ungrounded or resistance/impedance-grounded systems where the time required to deenergize a grounded section is indefinite. Thus, if the 1 h maximum clearing time for the 133% level is likely to be exceeded, cables rated for the 173% level can be applied. However, this insulation level is seldom used in normal industrial practice.

4.2.2 Ampacity

Fundamental criteria needed to accurately assess the current-carrying capability of an insulated conductor consist of the following:

a) Conductor size and material
b) Insulation type, thickness and characteristics
c) Insulation rated wet/dry (i.e., XHHW-2) or dual rated
d) Maximum conductor temperature rating
e) Shield type and thickness
f) Armor type and thickness
g) Sheath type and thickness
h) Number of cables, ducts, conduits, etc.
i) Surrounding environmental conditions such as enclosed air (no circulation), plastic duct, metal conduit, concrete, sand, thermal fill, free air, sunlight, wind, etc.
j) Ac or dc voltage, frequency of ac
k) Wet or dry location
l) Maximum ambient temperature
m) Extraneous heat sources
n) Solar and wind exposure
o) Emergency overload
p) Phase orientation

As outlined above, there are a number of parameters to consider when calculating the ampacity of conductors. This analysis can range from being very simple for a small number of circuits to extremely complicated for large cable systems. The straightforward method is to use Tables 310-16–310-19 of the NEC to determine the allowable ampacities for circuits (usually a small number), rated 0–2000 V. Such circuits consist of single conductors in free air and three conductors in cable, raceway, or earth. For qualified users, the NEC permits the use of an alternative method for determining ampacity that more accurately takes into account the various conditions of use listed above. Under engineering supervision, ampacities may be calculated through the use of an equation that was published in Neher and McGrath [B15][5]. The NEC provides some additional ampacity tables for limited applications involving medium- and low-voltage circuits. These ampacities, based on the Neher-McGrath method, are found in Tables 310-67–310-86 for medium-voltage cables and in Appendix B for low-voltage cables. Tables comparable to those in the NEC may be found in CSA C22.1-98.

[5]The numbers in brackets correspond to those of the bibliography in Annex A.

Another source for determining power cable ampacity is IEEE Std 835-1994 [B70]. This standard and the previous IEEE Power Cable Ampacity Standard (IEEE Std S135-1962 [B76][6]) contain a comprehensive set of ampacity tables that were calculated using the Neher-McGrath method. This standard contains over 1200 ampacity tables that were calculated for the various conditions of use including duct banks, direct buried conduits, direct buried cable, horizontal conduit in air, free air (messenger), unventilated risers, buried pipes, and others.

Cable types covered are

Type 1: 600 V–5 kV, unshielded extruded dielectric
Type 2: 5–15 kV, two-conductor shielded URD single-phase extruded dielectric
Type 3: 5–46 kV, single-conductor extruded dielectric
Type 4: 69–138 kV, single-conductor, unfilled, cross-linked polyethylene
Type 5: 69–138 kV, single-conductor, filled, cross-linked polyethylene and ethylene propylene rubber
Type 6: 5 kV and 15 kV, three-conductor extruded dielectric
Type 7: 5–35 kV, single-conductor, paper-insulated, lead sheath
Type 8: 5–35 kV, three-conductor, paper-insulated, lead sheath, shielded
Type 9: 69–500 kV, single-conductor, self-contained, paper-insulated, liquid-filled
Type 10: 69 kV, three-conductor, self-contained, paper-insulated, liquid-filled
Type 11: 69–500 kV, high-pressure, paper-insulated, liquid-filled, pipe type
Type 12: 115–500 kV, high-pressure, laminated-paper, polypropylene-insulated, liquid-filled, pipe type
Type 13: 69–138 kV, high-pressure, gas-filled, pipe type

For large cable systems where the complexity and number of circuits exceed those listed in the NEC or IEEE Std 835-1994 [B70], the use of a computer program is recommended to determine cable ampacity. There are a number of commercially available power cable ampacity programs that can accomplish this task.

For the more complex configurations, the tables in the NEC and IEEE Std 835-1994 [B70] can be used in the initial stages of design to determine preliminary conductor sizes and to closely approximate ampacities. These preliminary cable sizes can then be used as the basis for a more rigorous computer analysis to determine the actual conductor sizes, temperatures, and ampacities in order to finalize the design.

4.2.3 Neutral, system, and equipment grounding

The selection of the neutral (grounded), grounding electrode, and equipment grounding conductor, whether insulated or bare, depends on the system configuration and method chosen for load distribution, ground fault interruption, and maintenance.

For most systems, the neutral conductor is sized the same as the phase conductors. The neutral conductor, however, may be larger or smaller depending on the calculated neutral current. Other conditions that affect neutral conductor sizing include high-resistance grounding, harmonic currents [such as those encountered with pulse-width-modulated (PWM) power supplies] or other rules set forth in the NEC.

Circuits and systems that require ground connections are defined in Article 250 of the NEC.

This article contains comprehensive data on selection of grounding electrode conductors as well as on equipment grounding conductors. Grounding electrode conductor size requirements are given in Table 250-66 of the NEC. Equipment grounding conductor size requirements are given in Table 250-122.

Special considerations should be given to paralleling phase, neutral, grounding electrode, and equipment grounding conductors including length, size, split of ampacity, and number in parallel.

[6] Also refer to IEEE Std 835-1994.

4.2.4 Fault current ratings of conductors and metallic shields

If proper consideration is not given to thermal effects generated during the time conductors are exposed to short-circuit currents available in the system, permanent damage may occur to the conductor insulation and shielding. Mechanical stresses beyond the design capabilities of the cable assembly may result in physical damage. In some cases, excessive thermal deterioration of the cable materials may result in ignition of surrounding materials. Also, refer to ICEA P32-382-1994 [B46] to cover short-circuit capability of conductors.

While not a thermal damage consideration, single conductor cables during short-circuit conditions are subject to strong mechanical forces that may displace and cause physical damage to the shielding and insulation, which can lead to unnecessary failures. Cables should be properly secured in place by physical positioning to cancel repelling forces or by physical restraint to prevent movement.

Equations for the calculation of required shield short-circuit capability may be found in ICEA P-45-482-1994 [B47]. However, this method does not take heat dissipation into account. Heat dissipation is an important factor that may increase shield ampacity by 25% or more.

Refer to Tables 12-3, 12-5, and 12-6 of IEEE Std 141-1993 for minimum insulated conductor sizes and temperatures for maximum operating, overload, and short-circuit conditions.

4.2.5 Shielding medium-voltage cable

The NEC, in Article 310-6, requires shielding on insulated conductors operated above 2000 V. There is an exception for cable listed by a qualified testing laboratory for use up to 8000 V where certain conditions are met.

Shielding of an electric power cable is the practice of confining the electric field of the cable to the insulation surrounding the conductor. This is accomplished with conducting or semiconducting layers, or most commonly both, that are in intimate contact with, or bonded to, the inner and outer surfaces of the insulation. In other words, the outer insulation shield confines the electric field to the space between the conductor shield and the insulation shield. The inner or conductor stress-relief layer is at or near the conductor potential. The outer or insulation shield, made up of semiconducting and metallic components, is designed to carry the charging currents and, in most cases, fault currents at low voltage potentials to ground. The conductivity of the shield is determined by its cross-sectional area and the resistivity of the metal tapes or wires employed in conjunction with the semiconducting layer.

The metallic shield, which is available in several forms, is generally designed to carry fault currents. The most common is the tape shield consisting of a copper tape, 0.076–0.127 mm (3–5 mils) thick, which is helically applied over the insulation shield.

A modification of the tape shield consists of a corrugated copper tape applied longitudinally over the semiconducting insulation shield. This permits full electrical use of the tape as a current-carrying conductor, and it is capable of carrying a greater fault current than a helically wrapped tape of the same thickness.

Another type is a wire shield, where copper wires are helically applied over the insulation screen with a long lay. Typically, heavy gauge #14 AWG and larger wires are designed for concentric neutral purposes. Smaller wires may not have the fault current-carrying capabilities as that of a copper tape shield. A variation of the wire shield is the use of corrugated drain wires that are embedded in an extruded semiconducting jacket. See Figure 12.

For further information on shielding, refer to Clause 7.

4.3 Mechanical and physical considerations

The sheaths or coverings used over other cable materials to protect the cable components from environmental and installation conditions can greatly affect the overall life cycle cost. Both metallic and nonmetallic coverings or a combination of both, are available to provide the protection needed for specific conditions. Some of these specific conditions are rodents, insects, abrasion, impact, moisture, and acids, alkalies, or other chemicals. The sheaths or coverings may be applied as protection over single conductors or over multiple conductors.

4.3.1 Metallic coverings

Metallic coverings are used where a high degree of mechanical, chemical, or short-time thermal protection of underlying cable components is required. These consist of interlocked galvanized steel, or aluminum armor; longitudinally applied, welded and corrugated aluminum or copper; flat or corrugated copper or bronze tapes; extruded lead or aluminum; wire braid; and helically applied armor wires. While improving physical protection, the use of metallic coverings does reduce flexibility and adds weight to the cable. Cost is usually increased significantly. Refer to Clause 10 for further information.

4.3.2 Nonmetallic coverings

The nonmetallic coverings consist primarily of either thermoplastic or thermoset (cross-linked) compounds. Examples of thermoplastics include PVC, TPR, LLDPE, and CPE. Examples of cross-linked compounds include chloroprenes, chlorinated polyethylene and chlorosulfonated polyethylene, and nonhalogen compounds. Other coverings include fiber braids of natural or synthetic materials. Refer to Clause 8 for further information.

4.3.3 Laminates or composite sheaths

A recent innovation that promises to maximize protection while optimizing cable performance involves metal-plastic laminates. These laminates allow a bond to the cable jacket thereby forming a composite sheath. Such laminates are particularly aimed at restricting permeation of water and chemical substances including solvents from the environment into the internal cable materials. These include laminated aluminum or copper tapes which are bonded to the overall jacket. These can be applied as smooth or corrugated constructions. In medium-voltage cable such laminates can function as the electrical shield as well as a moisture/chemical barrier. Refer to Clause 9 for further information.

4.4 Environmental considerations

The effect of the cable on its surroundings should be considered in response to environmental awareness. The potential for arc flash, explosion, fire propagation, smoke, and acid gas emissions or toxicity should be considered in the application and location of the cable. Also, the effect of the environment on the cable should be given consideration. Refer to 9.1 for further explanation.

4.4.1 Hazardous areas

Hazardous areas can be defined as locations in a manufacturing area where the environment is exposed to known hazards such as explosive mixtures of gases or liquids. See Articles 500, 501, 502, 503, and 505 of the NEC for hazardous (classified) locations.

The use of cables in these locations requires careful consideration of the environment in which they are installed. If the hazard encountered is vapor release, the cable terminations would require special termination glands, designed to prevent gas ingress into the cable. If the hazard encountered is a chemical spill, appropriate precautions are needed in protecting the cable from these substances. Verify that the jacketing compounds used are resistant to the hazard involved. In general, armored cables with protective jackets, both inside and outside the armor, are preferred for hazardous areas. Refer to 12.5 for further information on cables for use in hazardous areas.

4.4.2 Fire safety considerations

A vast majority of materials used in the insulation and sheathing (jacketing) of cables are based on polymeric compositions. They can contribute to the spread of combustion if exposed directly to a fire or be the cause of combustion in the case of an electrical fault. The problem is accentuated by the generation of smoke during a fire.

The reduction in the flammability or flame spread characteristics of polymers has been the subject of much research. Generally the use of halogen-containing polymers or the addition of halogen additives to the composition of the polymer have been used to reduce flame spread. More recent developments in fire safety have shown that, in addition to the reduction in flame propagation, the effects of the products of combustion on people and equipment are an equally important consideration. This has led to the formulation of materials with low or zero levels of halogens.

The choice of materials for cables with low combustibility will depend on the level of flame retardancy required and the smoke and toxicity levels of the products of combustion. The key characteristics that need to be considered in the selection of a flame-retardant cable are given in 4.4.2.1, 4.4.2.2, 4.4.2.3, and 4.4.2.4.

4.4.2.1 Flame spread

Flame spread is defined as the propagation rate of a flame under given burning conditions. Flame spread is an important characteristic, since it is a measure of the ease with which a fire can be spread along the length of a cable. The tests conducted to measure flame spread are reflected in the way the cable(s) are to be installed. Cables laid in vertical configurations are more susceptible than horizontal cable layouts.

Flame spread tests are conducted on single insulated conductors both in the horizontal and vertical modes and are referred to as the VW-1 test in UL 44-1999 [B85] and the FT1 test contained in CSA C22.2 No. 0.3-96, Section 4.11.1 [B33]. Grouped cable tests are generally more severe and the degree of severity is reflected in the end-use application. The most commonly used of these are found in IEEE Std 1202-1991 [B75], UL 1581-1997 [B92], and the FT4 test contained in CSA C22.2 No. 0.3-96, Section 4.11.4 [B33], all of which have been known as the “70 000 Btu/h vertical tray flame tests.” As metrification of standards is proceeding in North America, a more appropriate title is “20 kW (70 000 BTU/h) flame test.”

Flame propagation is determined by heat release from the burning cable, heat input from external ignition source, heat loss to the surroundings, available fuel, and oxidizer. As a minimum, cables selected should pass the UL 1581-1997 [B92] vertical cable tray flame test. The preferred choice is to select cables that pass the IEEE 1202-1991 [B75] and the CSA FT4 flame tests, which are also 20 kW (70 000 Btu/h) but have a more stringent pass/fail criteria.

4.4.2.2 Smoke measurement

Smoke is a complex mixture of solid and liquid particles released during combustion. It is quantitatively higher in situations of incomplete combustion, and can cause inhalation deaths due to obscuration of exits and escape paths in buildings during a fire. Halogenated polymers burn slowly and generate larger amounts of smoke. Halogenated additives dispersed in XLPE, ethylene vinyl acetate copolymers, and EPR also burn relatively slow and produce quantities of smoke. Materials formulated with only small amounts of halogens, or as nonhalogenated systems, have shown much reduced levels of smoke and are being specified in cables for use in areas occupied by large numbers of personnel. The exceptions are fluorocarbons that are heavily halogenated but generate very little smoke.

The most common smoke measurements are optical methods. The tests can be classified into two groups, namely, static and dynamic. The static methods use the NBS smoke chamber and are covered in the ASTM E 662-1997 [B32], NFPA 258-1997 [B83], and NES 711-1981 [B79]. The dynamic methods use a cone calorimeter and vertical cable burn tests and measure smoke generated or use the vertical cable tray flame test with optical smoke measurement as detailed in UL 1685-1997 [B93].

4.4.2.3 Corrosivity

The liberation of corrosive gases during the combustion of organic materials presents hazards to personnel and sensitive electrical and electronic equipment.

The acidic gases produced during the combustion of halogenated materials in combination with moisture are very corrosive. Nonhalogenated systems have very low corrosion effects.

Corrosivity of the combustion products can be measured by determining the acidity of the gases (pH), conductivity, or percent equivalent of hydrogen chloride as in MIL-C-24643 [B78], CSA acid gas test, IEC 60754-2-1991 [B55] and DIN VDE 0472 [B44], and DIN VDE 57472 [B45] acid gas tests. Actual corrosion measurements can also be made. In ASTM D 2671-1998 [B31] a copper mirror is used to observe corrosion, while the cone corrosimeter (ASTM committee D09.21) or the NBS radiant heat chamber (ASTM committee E5.21) uses metal loss of a circuit board coupon to assess corrosivity.

4.4.2.4 Toxicity

Chief among the hazards to human life in a fire situation are toxic gases. Most fatalities result from inhalation of toxic smoke. The gases are a mixture of carbon monoxide and several irritant gases most of which are acidic.

Toxicity measurements are quite controversial, and methods for determinations of the levels can be categorized into two types, namely, chemical analysis and animal toxicology.

The chemical analysis techniques used are spectroscopy, colorimetry, and chromatography. The NES 713-1985 [B80] test standard is one such method.

Animal toxicology tests such as the LC50–University of Pittsburgh tests use animals to try to differentiate material toxicity potency, but have been found inconsistent.

The most reliable technique is therefore by chemical analysis. The measurement, called a toxicity index, is a numerical summation of toxicity factors of 14 selected gases that have known human response to concentration of these gases.

4.4.3 Cold temperature installation

Since most cable products are based on polymeric materials, the most significant influence of temperature will be during the installation stage. The general tendency of polymeric materials is to increase in modulus or stiffness with decrease in temperature. Cables designed to operate at these temperatures and where movement is required are usually based on elastomeric/rubbery polymers. Fixed cable types, such as power cables, may have limitations on the installation temperatures. In addition to being stiffer, the cable insulation and jackets may have a tendency to crack. The key considerations in assessing the suitability of a cable design for installation at low temperature are its low-temperature brittleness value during bending over a specific radius of curvature and the impact strength at a given temperature. Current tests that have found favor in industry are the CSA –40 ˚C cold impact test, which tests cable samples with an impact load of 1.245 kg-m (9 ft-lb), and the –65 ˚C cold bend test. (See CSA C22.2 No. 0.3-96 [B33].) These tests are of primary importance in arctic installations.

4.4.4 Corrosion protection

The use of metals as conductors and as shielding or armoring in a cable can expose these components to corrosion when they are in contact with corrosive elements. Corrosion can lead to failure of the integrity of the cable and/or terminations and splices.

Copper-stranded conductors are often coated with tin to prevent corrosion during manufacture and in use, where the components of the cable insulation or jacket can emit corrosive by-products or the terminations are exposed to corrosive atmospheres. The metallic components of a cable can also be protected by the use of jackets, especially in buried cables and in hazardous environments. Corrosion of conductors is accelerated at higher temperatures, the biggest problem being oxidation. At temperatures higher than 200 ˚C only nickel-plated conductors can be used.

4.5 Other application considerations

The Occupational Safety and Health Administration (OSHA) mandates that electrical systems and equipment be installed safely in accordance with the NEC. OSHA further requires that electrical conductors and cables be acceptable for the installation. Acceptability is determined by a nationally recognized testing laboratory, by a manufacturer testing products in accordance with recognized standards, or by an authority having jurisdiction. At present Underwriters Laboratories (UL) and Electrical Testing Laboratories (ETL) are the most commonly recognized listing agencies for certifying cables to the requirements of NEC.

4.5.1 Designations

Most power, control, instrumentation, and remote signaling conductors and cables have recognizable designations in accordance with NEC Articles 310-13, 310-61, 326, 334, 340, 400-4, 402-3, 725-61, 725-71, 727, 760, 770-50, 770-53, 800-50, 800-53, 820-50 and 820-53.

4.5.2 Color coding and surface marking

The NEC provides guidance for much of the color coding and surface marking of conductors and cables. Section 310-11 of the NEC provides details for the required information and method of marking phase conductors. Section 310-12 of the NEC provides details for the identification of grounded and grounding conductors. UL has additional requirements for listed cables such as Types TC, PLTC, MV-90, etc. Also, refer to ICEA S-73-532-1990 [B52] for control cable.

4.5.3 Adherence to OSHA requirements

Adherence to the OSHA requirements for “Electrical Safety-Related Work Practices; Final Rule” demands that cables that are to be accessed for maintenance, while adjacent (nearby) cables are energized, be neatly racked and arranged as well as marked to facilitate identifying the conductors or cables to be worked upon, in addition to isolating all other cables while work is in progress.

4.5.4 Choice of cable

The choice of cable type and materials as well as location and support dictates initial conductor and cable integrity. The method of operation and conditions of testing performed throughout the life of the cable helps maintain its performance.

5. Conductors

The two most common conductor materials used are copper and aluminum. The NEC requires conductors to be stranded for sizes #8 AWG and larger. Stranded conductors are typically made more flexible by increasing the number of wires in the conductor. The size specified for the conductor in AWG, kcmil, or mm^2 denotes the total area of the conductor metal.

5.1 Copper

Copper is the most popular metal used for conductors in petroleum and chemical plant applications because of its electrical properties and chemical resistance. Copper is most often specified for its high conductivity, chemical resistance, and good connectibility. It is supplied in soft-drawn temper for installations that are not under tension and medium-hard or hard-drawn temper when installed under tension, where additional strength is required.

5.2 Aluminum

Aluminum is used because of its higher conductivity-to-weight ratio than copper and its lower cost. Two different aluminum alloys are used for insulated conductors. UL-listed conductors are required to be an Aluminum Association 8000 series alloy. Electrical utilities typically use 1350 aluminum alloy for their systems. In open air, aluminum develops a tough, protective oxide coating providing a degree of protection from corrosion.

The major drawback to using aluminum conductors in industrial applications is that aluminum requires a larger diameter for the same current-carrying capacity as a copper conductor. Also, an aluminum conductor can fail at a termination if the connectors are not suitable for use with aluminum. An aluminum conductor can also fail by ac electrolysis at low-voltage terminations where moisture and a leakage current are present.

5.3 Conductor stranding

Conductors are stranded to increase the flexibility of finished cables. Conductors are available as concentric round, compressed, compact, segmental, bunched, and rope lay. Compressed conductors have up to a 3% reduction in diameter from that of a concentric round and are common for insulated conductors. A cable specifier may choose to use a compact conductor, which has approximately a 9% reduction in diameter. A compact conductor is used in areas where the conductor diameter or duct fill is critical. Segmental conductors are typically utilized in very large conductor sizes and for paper-insulated, lead-sheathed cables (PILC).

5.4 Tinned- or lead-alloy-coated copper

A tin or lead-alloy coating on a copper conductor facilitates soldering and is required when sulfur-cured insulations are selected because of the possibility of sulfur attack on copper. A tinned conductor is normally electrolytically plated and is typically used with smaller wires such as flexible strand, instrumentation, and control cables. Lead-alloy conductors are usually hot-dipped in a lead-alloy bath. They are typically used for conductors that have larger wire strands.

5.5 Filled strand conductors

A conductor can be filled with materials during manufacturing that will block water and also act as a gas block. It cannot be assumed that a water-blocking material will also block gases. Water blocking can be accomplished by using a material that completely seals the strands, or a water swellable material can be used that prevents the flow of water through the conductor.

6. Insulation

6.1 Materials and thicknesses available

The most readily available insulations for low-voltage (600 V) and medium-voltage (5–35 kV) cables installed in petroleum and chemical plants are polyvinyl chloride (PVC), polyethylene (PE), cross-linked polyethylene (XLPE), tree-retardant cross-linked polyethylene (TRXLPE), and ethylene propylene rubber (EP, EPR, or EPDM). Chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), and polyamide (nylon) are sometimes used for the second layer in dual-layer insulations. The temperature rating of these materials is usually 75 °C for thermoplastic materials and 90 ˚C for thermoset.

For installation in areas with high ambient temperatures, cables with special high-temperature insulations are used. These cables carry temperature ratings ranging from 125–450 ˚C and beyond. High-temperature insulations include specially formulated EPR, cross-linked polyolefin, silicone rubber, various fluoropolymers, ceramic tapes, aramid fiber, and glass-reinforced mica tape. High-temperature cables are frequently constructed with a combination of one or more of the above materials. Common fluoropolymer insulations include fluorinated ethylene propylene (FEP), polytetrafluoroethylene (PTFE), and ethylene chlorotrifluoroethylene (ECTFE).

The insulation type and insulation thickness of wire and cable used in petrochemical plant applications are usually set by industry standards written by UL, CSA, or the ICEA. In the U.S., virtually all wire and cable used in petrochemical plants are required to be installed in compliance with the NEC. In Canada, it is required to be installed in compliance with the Canadian Electrical Code (see CSA C22.1-98). What this means, in a practical sense, is that the wire or cable is required to bear the proper UL or CSA marking for the application. It is required also to be installed in a manner consistent with the code requirements applicable to the particular facility in which the wire or cable is being used.

A broad overview of cable insulation types and some of their important electrical and physical properties are contained in IEEE Std 141-1993.

6.1.1 600 V multiconductor control cable

The thickness of most U.S. and Canadian 600 V control cable insulation is set by ICEA S-73-532-1990 [B52], UL 44-1999 [B85], UL 62-1997 [B86], UL 83-1998 [B87], UL 1277-1996 [B90], and CSA C22.2 No. 239-96 [B40] standards. The most common North American control cable insulations are EPR, XLPE, PVC, PE with a PVC covering, and PVC with a nylon jacket. Minimum insulation thicknesses for some of the most common cable constructions are summarized in Table 1, Table 2, Table 3, Table 4, and Table 5. Insulation thicknesses for other insulating materials, conductor sizes, and cable voltage ratings can be found in the referenced standards. It should be noted that industry standards do change. Thus, standards reissued subsequent to the issue date of this guide may call for revised insulation thickness contrary to those shown in the following tables.

Table 1—Insulation thicknesses for 600 V control cables with single-layer insulation per ICEA S-73-532-1990 [B52]

Conductor size (AWG)	XLPE and EPR		PVC	
	mm	mils	mm	mils
20–19	0.64	25	0.64	25
18–16	0.64	25	0.76	30
14–9	0.76	30	1.14	45

Table 2—Insulation thicknesses for 600 V control cables with dual-layer PE/PVC insulation per ICEA S-73-532-1990 [B52]

Conductor size (AWG)	PE inner layer		PVC outer layer	
	mm	mils	mm	mils
20–19	0.38	15	0.25	10
18–16	0.38	15	0.25	10
14–9	0.51	20	0.25	10

Table 3—Insulation thicknesses for 600 V control cables with PVC insulation and nylon jacket per UL 62-1997 [B86] and UL 83-1998 [B87]

Conductor size (AWG)	PE inner layer		PVC outer layer	
	mm	mils	mm	mils
18–16	0.38	15	0.10	4
14–11	0.38	15	0.10	4

Table 4—Insulation thicknesses for 600 V control cables with single-layer insulation per CSA C22.2 No. 239-96 [B40]

Conductor size (AWG)	XLPE, EPR, and PVC	
	mm	mils
18–10	0.76	30
9–8	1.14	45
6–2	1.52	60
1–4/0	2.03	80

Table 5—Insulation thicknesses for 600 V control cables with PVC insulation and nylon jacket per CSA C22.2 No. 239-96 [B40]

Conductor size (AWG)	PVC insulation		Nylon jacket	
	mm	mils	mm	mils
18–12	0.38	15	0.10	4
10 and 9	0.51	20	0.10	4
8–6	0.76	30	0.13	5
4–2	1.02	40	0.15	6
1–4/0	1.27	50	0.18	7

6.1.2 600 V single-conductor power cables

The insulation thickness of U.S. and Canadian 600 V power cables are also generally set by ICEA, UL, or CSA standards. In Canada, cables are frequently dual-rated for both 600 and 1000 V. The most common insulation materials include EPR, XLPE, PVC, PVC with an outer layer of nylon, and EPR with an outer layer of CSPE or CPE. Some common North American insulation thicknesses and applicable standards are shown in Table 6, Table 7, Table 8, and Table 9.

Table 6—Insulation thicknesses for single conductor 600 V power cables per UL 44-1999 [B85], UL 854-1996 [B88], and ICEA S-66-524-1991 [B50]

Conductor size (AWG or kcmil)	UL types XHHW and XHHW-2		UL types RHH, RHW, RHW-2, USE, and USE-2	
	mm	mils	mm	mils
14–10	0.76	30	1.14	45
8–2	1.14	45	1.52	60
1–4/0	1.40	55	2.03	80
250–500	1.65	65	2.41	95
750–1000	2.03	80	2.79	110

Table 7—Insulation thicknesses for single-conductor 1000 V power cables per CSA C22.2 No. 38-95 [B34]

Conductor size (AWG or kcmil)	CSA type RW90		CSA type RWU90	
	mm	mils	mm	mils
14–10	1.14	45	1.52	60
8	1.14	45	2.03	80
6–2	1.52	60	2.03	80
1–4/0	2.03	80	2.41	95
250–500	2.28	90	2.79	110
600–1000	2.28	90	3.17	125

Table 8—Insulation thicknesses for UL Type THHN/THWN 600 V power cables with PVC insulation and nylon jacket per UL 83-1998 [B87]

Conductor size (AWG or kcmil)	PVC inner layer		Nylon outer layer	
	mm	mils	mm	mils
14–12	0.38	15	0.10	4
10	0.51	20	0.10	4
8–6	0.76	30	0.13	5
4–2	1.02	40	0.15	6
1–4/0	1.27	50	0.18	7
250–500	1.52	60	0.20	8
550–1000	1.78	70	0.23	9

Table 9—Insulation thicknesses for UL Types RHH, RHW, RHW-2, USE, and USE-2 600 V power cables with dual-layer EP/CSPE insulation per UL 44-1999 [B85], UL 854-1996 [B88], and ICEA S-68-516-1988 [B51]*

Conductor size (AWG or kcmil)	EP inner layer		CSPE outer layer	
	mm	mils	mm	mils
14–10	0.76	30	0.38	15
8	1.14	45	0.38	15
6–2	1.14	45	0.76	30
1–4/0	1.40	55	1.14	45
250–500	1.65	65	1.65	65
550–1000	2.03	80	1.65	65

*These same thicknesses may also be used with an XLPE inner layer and a nonhalogen polyolefin outer layer if a low-halogen construction is required.

6.1.3 Medium-voltage cables

Insulation types and thicknesses for MV cables are set by UL, CSA, ICEA/NEMA, and AEIC standards.

The cable insulation level required for a medium-voltage application depends on the neutral grounding type (e.g., solidly or impedance grounded) and the intended mode of plant operation (e.g., maximum equipment protection with fast tripping, or minimum process interruption with time-delayed tripping). See 4.2 for information on 100%, 133%, and 173% insulation levels. On critical circuits where maximum reliability is required, the use of thicker insulation is recommended.

To prevent a single-phase-to-ground fault from escalating into a three-phase fault, medium-voltage systems in many plants are designed with an impedance-grounded neutral (i.e., to limit the fault current). Also, their medium-voltage feeders are protected by ground overcurrent relays that trip within a few cycles (i.e., to limit the fault energy). In this case, cables with a higher insulation level (i.e., 133%) are *not* needed, but are almost always recommended to assure long-term operating reliability.

However, some medium-voltage installations at 4160 V and higher allow the ground fault to continue for a long period of time. If that is the case, 133% and 173% insulated feeder cables are required in order to match the timing of the overcurrent protection device (see 4.2.1).

Some of the most common shielded MV cable insulation thicknesses and applicable industry standards are summarized in Table 10. Insulation thicknesses for nonshielded MV, other voltage ratings, and conductor sizes larger than 506.7 mm (1000 kcmil) can be found in the referenced standards.

It should be noted that the specified insulation thicknesses are not always identical among standards bodies. An example is 5 kV, 133% level where the UL standard calls for 2.3 mm (90 mils) while the AEIC standard calls for 2.9 mm (115 mils). Also, existing industry standards do not address all insulation levels—especially 173% levels. As a result, common industry practice has been to use the cable manufacturers' recommendations for insulation thickness when not otherwise specified. Typical thicknesses are shown in Table 11.

Table 10—Insulation thicknesses for shielded medium-voltage power cable per AEIC CS5-1994 [B21], AEIC CS6-1996 [B22], CSA C68.3-97 [B42], ICEA S-66-524-1991 [B50], ICEA S-68-516-1988 [B51], and UL 1072-1995 [B89] standards

Voltage rating (kV)	Insulation level %	UL and ICEA/NEMA		CSA		AEIC	
		mm	mils	mm	mils	mm	mils
5	100	2.29	90	2.3	90	2.29	90
	133	2.29	90	2.3	90	2.92	115
8	100	2.92	115	2.9	115	2.92	115
	133	3.56	140	3.6	140	3.56	140
15	100	4.45	175	4.5	175	4.45	175
	133	5.46	215	5.5	215	5.59	220
25	100	6.60	260	6.6	260	6.60	260
	133	8.76	345	8.8	345	8.13	320
35	100	8.76	345	8.8	345	8.76	345
	133	—	—	11.6	455	10.7	420

Table 11—Typical insulation thicknesses of shielded medium-voltage cables for use in industrial practice

Voltage rating (kV)	Insulation level %	Common industry practice	
		mm	mils
5	100	2.29	90
	133	2.92	115
	173	3.56	140
8	100	2.92	115
	133	3.56	140
	173	4.45	175
15	100	4.45	175
	133	5.59	220
	173	6.60	260
25	100	6.60	260
	133	8.13	320
	173	10.67	420
35	100	8.76	345
	133	10.67	420
	173	14.73	580

6.2 Performance requirements

Insulating materials have improved over the years and now provide the specifying engineer with a wide range of properties that enables an optimum match to a particular application. The choice of insulation will depend on many factors, such as the operating voltage and temperature, type (signal or power) and frequency of electric energy to be transmitted by the conductor, the type of outer protective covering for the insulation, the amount of flexibility desired, and outside chemical influences. Where a number of insulations are deemed suitable for an application, the selection may be made based on economic, maintenance, or other factors. In any case, it is important to consider the minimum acceptable performance characteristics of an insulation to assure the long-term reliability of an electrical system.

6.2.1 Dielectric strength

Dielectric strength of an insulation material is usually quoted as being so many volts per millimeter (volts per mil) of insulation thickness. This is simply the breakdown voltage in kilovolts divided by the insulation thickness, which is actually the breakdown gradient and not the dielectric strength. High dielectric strength is a desirable feature for any electrical insulation and even more so for medium- and high-voltage applications (1 kV and above). Stability of the dielectric strength over the life of an insulated conductor is highly desirable in essentially all applications.

In general, unfilled insulation formulations of high-molecular-weight polyethylene (HMWPE) and cross-linked polyethylene (XLPE) provide the highest level of dielectric strength. This does not, however, mean that any insulation will provide a stable dielectric strength over the life of a cable; especially in wet operating environments. Filled or chemically altered formulations such as ethylene propylene rubber (EPR) and tree-retardant cross-linked polyethylene (TRXLPE) maintain their dielectric strength better in wet locations involving medium-voltage cable designs. Where higher voltage withstand strength must be achieved because of electrical system demands (overvoltages, switching surges, excessive ground fault clearing time, etc.), increased insulation thicknesses such as 133% or 173% should be considered.

For communications cable and low-voltage power applications, unfilled insulations (excluding TRXLPE) may be used, but typically filled compounds are chosen for enhanced physical or thermal characteristics. This is acceptable because of the low operating voltage stress involved in these cable designs. Materials such as polyvinyl chloride (PVC), carbon black or mineral-loaded XLPE, silicone, and fluoropolymers are common insulations used in these designs.

To help assure that a given cable design has been manufactured with noncontaminated insulation of proper dielectric strength for its voltage class, the specifying engineer should require factory voltage withstand tests in accordance with industry standards (UL and ICEA-NEMA). For shielded medium-voltage insulated cables, the dielectric strength and maximum corona level requirements of the AEIC specifications should be invoked.

6.2.2 Capacitance

Insulated wire may be considered a cylindrical capacitor, where the center conductor and outer shield (or adjacent conductor) comprise the electrodes surrounding the dielectric (insulation). Capacitance, which is a measure of a dielectric's ability to store energy, increases in magnitude as the area of the electrodes increases and decreases as the insulation thickness increases (large-gauge conductors with thin insulation walls have higher capacitance than ones with small conductors and thick insulation). Capacitance also increases as the length of an insulated conductor increases. Beyond the influence of geometry, the capacitance of an insulated wire is dictated by the dielectric constant, i.e., the molecular structure of the insulation and its purity.

Temperature and the frequency of the applied voltage minimally affect insulation capacitance for most power applications. However, the effect may be significant in a few specialized power cable applications, some control and instrumentation cable applications, and in many communication applications.

In power cable designs it is desirable to have low capacitance, since it is a power cable's job to transmit, not store, energy. The preferred capacitance for instrumentation cables varies, depending on the circuit length, the desired accuracy and sensitivity of the electronic equipment, the equipment's internal ability to balance to the characteristic impedance of the cable, and the susceptibility of the circuit to traveling waves. Depending on the application, the desired capacitance of a control cable may follow that of either power or instrumentation cable. Capacitance is generally not an issue in cases of dc cable applications, nor is it an important consideration for circuit lengths less than 300 m (984 ft).

Industry standards and specifications such as ICEA S-82-552-1992 [B53] and UL 13-1996 [B84], which address instrumentation cables, do not include capacitance requirements because of the widely varying needs of the multitude of electronic equipment designs available to the industry. The purchaser of the cable should, therefore, include the requirement in the procurement specifications or purchase order for the cable.

For power cables and most control cables, capacitance is rarely specified. Rather, maximum percent change in capacitance at intervals during an elevated temperature water immersion test is set along with a maximum value for the insulations' specific inductive capacity (SIC), which is a parameter that can be easily converted to capacitance if the dimensions of the insulation are known. SIC, which is also sometimes referred to as dielectric constant or permittivity, is defined as the ratio of the energy that a capacitor's dielectric (insulation) can store to the energy stored by the same size capacitor (equal electrode areas and spacing) having its dielectric replaced with air under vacuum.

Industry standards and specifications created by ICEA, NEMA, UL, CSA, and AEIC include requirements for SIC and capacitance change during accelerated aging tests. By reference to one or more of these standards and specifications as applicable to the particular insulation type or cable design, capacitance will usually be adequately defined.

6.2.3 Thermal characteristics and heat dissipation

The thermal characteristics of an insulation should be specified in accordance with the anticipated temperature of the environment in which the cable will be operated. In addition, the planned temperature rise of the metallic conductor caused by electrical current flow should be considered along with excessive temperature conditions arising from emergency overloads or short-circuit current on a system. The minimum desired temperature of the cable at the time of installation should also be considered to prevent brittleness and subsequent fracturing of components due to cold. Restriction of the insulation's operating temperature to temperatures below its rating under ideal conditions may be required to prevent or reduce deterioration by oxidation or exposure to chemicals in the environment. Operation at less than the insulation's rated temperature may also be necessary to prevent problems with accessories caused by excessive thermal expansion or to avoid drying of the soil around an underground installation, which could result in cable destruction by thermal runaway. It is a good idea to identify, when known, any extreme environmental conditions in the specification for the cable, whether they are mechanical, thermal, or chemical in nature.

Heat losses originate from a number of sources within a cable system: one originating from the metallic components (phase, shield, and/or grounding conductor), and the other from the insulation itself. These losses should be considered when selecting the particular cable design and insulation, as they will dictate the temperature at which the insulation will operate. An increase in cable operating temperature increases the attenuation of the transmitted signal with instrumentation cables, and increases the voltage drop in power cables. High-temperature operation also adds an ongoing expense to the system by continuously dumping waste energy as heat into the environment. Such high-temperature operation may also ultimately reduce cable life expectancy.

The insulation's major contribution to heat loss arises from its natural electrical loss components when ac voltage is applied. Heat is produced by the work (or power) involved in charging and discharging the capacitance of a cable, which causes distortion and rearrangement of the insulation molecules as the polarity of the ac sine wave changes. Neher and McGrath (AIEE Paper 57-660) [B15] provides an equation that indicates that the heat produced (measured in watts) is directly proportional to the insulation SIC and dissipation (power) factor and varies as the square of the magnitude of the applied voltage. In normal operation, this power loss contributes as little as approximately 0.1 ˚C to as high as several degrees Celsius to the temperature rise of the system. This can result in an added cost range to operate a cable of approximately $1–10 per 305 m (1000 ft) conductor length per year. As such, the insulation for power applications should be specified to have SIC and dissipation factor characteristics that are as low as possible, especially where voltage stresses will be high.

See 6.2.4 for the almost insignificant heat loss due to direct insulation resistance.

The current, which flows through the metallic power conductor, and the electrical resistance of the conductor result in heat being generated. This is caused by friction between the moving electrons and the stationary conductor. The amount of heat that is generated is directly proportional to the resistance of the conductor, which increases as the conductor temperature increases, and increases as the square of the current (I^2R). Using low-resistance metal such as copper instead of aluminum, increasing the conductor size for a given current, or adding additional (paralleled) circuits will act to reduce this loss. There is good reason to attempt to do so, because in a typical fully loaded power cable, the annual cost of this type of power loss is in the range of $300 to $3000 per hundred meters of circuit length ($1000 to $10 000 per 1000 ft of circuit length), assuming 7¢/kWh.

In a single-conductor metallic shielded cable, where the shield is grounded at multiple points, an additional heat loss occurs. This loss is due to the current flow through the resistance of the metallic shield. The current is created as a result of magnetic coupling (transformer effect) between the shield and phase conductor. In general, shield losses increase when the shield cross section increases, as the phase conductor current level is increased, and when the distance between individual conductors of a three-phase installation is increased. Unless the cable shield is designed to handle high-magnitude fault currents or it is to be utilized as an active component in the electrical system (neutral conductor), low-cross-section shields should be specified for power cables to reduce shield losses. Such losses can cost as much annually as $3 000 per 100 m ($10 000 per 1000 ft) on a poorly designed, multiple-point grounded system.

ICEA specifications provide minimum requirements for wire and copper-tape shielding systems. For wire shields, ICEA states that the minimum copper cross section must be 0.1 mm^2/mm (5000 circular-mil/in) of insulated core diameter. ICEA requires copper-tape shields to be at least 0.064 mm (2.5 mils) in thickness, although the wire and cable industry standard is 0.127 mm (5 mils). The tape can be helically applied with an overlap that is typically 12.5% to 25% of the tape's width. Corrugated and longitudinally applied tape with an overlap of 9.525 mm (375 mils) is another common shield design. These cable shield designs will result in relatively low power losses costing annually in the range of $30 to $300 per 100 m of circuit ($100 to $1000 per 1000 ft of circuit) to operate.

To achieve optimum service life of an insulation it is better to design an electrical system and cable to operate at reasonably low temperatures; however, in the real world this is not always possible. Therefore, insulations that are suited for higher operating temperatures may have to be considered.

Insulating materials can be classified in two categories—thermoplastic and thermoset. Thermoset materials such as EPR and XLPE generally perform better in high-temperature environments than do thermoplastic materials such as HMWPE and PVC. This is because the molecular structure of thermoset insulations has been altered to make them resist flowing or melting at high temperature. There are, however, specialized thermoplastic insulations such as fluorinated ethylene propylene (FEP) that are designed for use in low-voltage, extremely high temperature environments. Typical maximum continuous operating temperature ratings for various insulating materials/systems are shown in Table 12.

Industry specifications such as ICEA S-68-516-1988 [B51], ICEA S-66-524-1991 [B50], AEIC CS5-1994 [B21], AEIC CS6-1996 [B22], UL 44-1999 [B85], and UL 1072-1995 [B89] address insulations that are rated for continuous operation at between 75 and 90 °C. In UL 44-1999 [B85], a means exists for specifying multiple operating temperature ratings of insulation (e.g., RHH/RHW, 75 °C wet and 90 °C dry; RHH/RHW-2, 90 °C wet or dry). The 1996 NEC was modified to recognize that thermoset insulations are available for use at 105 °C conductor temperature where design conditions require a maximum conductor temperature above 90 °C. ICEA S-19-81-1992 [B48] addresses insulations that are rated for operation at 60 to 125 °C.

Table 12—Typical maximum temperature ratings for common insulating materials

Material	Rated operating temperature (°C)	Emergency operation temperature (°C)
EPR	75–105	7130–140
XLPE	775–90	7130
TRXLPE	775–90	7130
PE	760–75	795
CSPE	790	N/A
Silicone	7125	200
PVC	760–105	N/A
FEP	7105–200	N/A
Mica	7450	N/A
Ceramic braid	71000	N/A
Aramid fiber	7250	N/A
Synthetic rubber	760–90	785–105
Natural rubber	760–75	785–95

UL 1581-1997 [B92] provides specifications for the properties of low-voltage insulations of various types rated for operation up to and including 250 °C. Additional specifications for insulation operating temperatures and special application wires may be found in UL and CSA documents frequently referred to as “style pages.” Style pages give details on hundreds of different appliance wiring material (AWM) types.

By selecting the best-suited insulation for a particular thermal operating environment and referencing one or more of the aforementioned specifications, the general minimum performance requirements for the material, including the temperature characteristics, should be adequately covered. However, additional or more stringent requirements may be in order for extreme conditions of operation. For instance, ICEA cold bend, CSA impact, or ASTM cold temperature brittleness tests may be specified for insulations that will be installed and operated in extremely cold environments. The temperature limit of such tests should be set at a level that is slightly lower than the anticipated cable environment with the understanding that cable components over the insulation may demand a more severe requirement, as they are stressed more during bending.

Since the rate of a chemical reaction approximately doubles for every 10 °C increase in temperature, evaluation of an insulation for compatibility with elements found in the installation environment in even low concentrations may be advisable for cables intended for use in high-temperature environments. Testing formats and judgment criteria for determining oil and gasoline resistance of some insulations are provided in UL specifications; however, the electrical industry does not define a standard test for determining compatibility of all polymers and chemicals. It is, therefore, up to the end user and supplier of the insulation to devise a test that best suits the application. Slightly elevated temperatures and chemical concentrations would be advised in such a test to accelerate the aging. Further, the pass/fail criteria for low-voltage insulations should focus on physical property retention and maximum volume swell.

For medium- and high-voltage insulations and in extreme conditions for low-voltage insulations, where the electrical integrity of the dielectric may be more critical, it may be advisable to simply eliminate the possibility of chemicals contacting the insulation. This can be accomplished by incorporating a lead sheath, metal-plastic laminated sheath, welded seam armor, and/or chemical resistant outer jacket (see Clause 9). This approach can also be used for protection against long-term exposure to water.

6.2.4 Power factor (dissipation factor), insulation resistance, and losses

Wire and cable insulations exhibit characteristics of capacitors, but not perfectly efficient ones. The theoretical 90˚ phase shift between the current and voltage across a perfect capacitor is never quite achieved and falls short of 90˚ by a factor called the phase defect angle. The tangent of the defect angle is called the *dissipation factor* (DF) and the more familiar term *power factor* (PF) is defined as the sine of this angle. As previously discussed in 6.2.3, the DF and SIC create losses and, as a result, heat is generated within the insulation when ac voltage is applied; therefore, low DF is a desirable characteristic. Stability of this parameter over the life of the cable is also important.

Very pure insulations like PE and XLPE exhibit very low DF values. TRXLPE has a slightly higher DF than XLPE, while materials like EPR, PVC, and CSPE have still higher DF values. However, both EPR and TRXLPE have acceptably low values for medium-voltage applications. DF tends to increase with increased temperature and with increased time in service in wet locations. It may also increase slightly with increased voltage stress. ICEA and AEIC both set maximum limits for DF using various types of performance tests under wet and dry conditions. However, AEIC addresses only shielded cables rated 5000 V and higher. Whether the insulation is intended for low-, medium-, or high-voltage applications, DF should be addressed by reference to the aforementioned specifications when the cable is intended for use in wet locations at elevated temperatures.

Insulation resistance (IR) is simply the electrical resistance measured between the conductor and the outer surface of the insulation, and is by convention referred to as a standard length of 300 m (1000 ft). The measurement is typically made using dc voltage and is expressed in megohms (MΩ). The measurement must be corrected to adjust for the length of the specimen under test because IR varies inversely with the length of the insulated conductor. In addition, since IR has a negative temperature coefficient (it decreases with an increase in temperature), test readings may need to be corrected to a common 16 °C (60 °F) reference temperature.

The least significant loss in a power cable is due to insulation resistance; the annual cost of this loss is only a few cents per 300 m (1000 ft), a small fraction of the costs incurred due to other internal cable losses. The low losses are attributed to the high insulation resistance constants (IRKs) available in current insulation formulations. IRK values, which can be translated to insulation resistance using the insulation dimensions, are specified by ICEA to be not less than 500–10 000 MΩ for 300 m (1000 ft) conductor lengths for low-voltage insulations, and not less than 20 000 MΩ for medium-voltage insulations. Actual values for IRK can, however, be greater than 100 000 MΩ for 300 m (1000 ft) lengths for pure, unfilled insulations like XLPE.

UL provides a long-term, elevated-temperature water stability test for IR. UL also provides tabled minimum IR values that vary according to the insulation type and UL type designation (wall thickness). Where IR is important to the functionality of an insulating system, the existing industry standards and specifications provide a means for control of the parameter and should be referenced.

6.2.5 Resistance to water treeing

Water treeing is the medium-voltage phenomenon that describes the appearance of treelike growths in polymeric dielectrics exposed to high electrical stresses in moist environments. This phenomenon is a problem particularly associated with medium-voltage direct buried cable. These structures, which start off looking like small bow-tie shapes, develop over time and under electrical stress into larger trunk-like electric trees, which lead to eventual breakdown of the dielectric medium.

Beginning in 1970 it was discovered that unjacketed high-molecular-weight polyethylene (HMWPE) and "unfilled" XLPE insulated cables utilized in the 15 kV class or higher voltage were prone to high failure rates due to incipient defects called "trees." These trees are microscopic voids in the insulation material, which tend to grow in a pattern similar to the branches of a botanical tree. They generally form at a contaminant or void, or at a point of high stress such as a protrusion of the semiconducting strand shield or insulation shield into the insulation. Their growth is accelerated by water and voltage stress and they can ultimately weaken the dielectric to the point of failure. This problem was so prevalent with the HMWPE material that it ultimately became unacceptable to users who had any concern for reliability. Since that time, steps have been taken to mitigate the effects of treeing. These include the implementation of dry curing techniques, improved methods of eliminating contaminants, use of strand filling, and the development of tree-retardant additives. As a result, the XLPE and TRXLPE cables of today are outperforming their predecessors. Trees have also been found in EPR/EPDM materials but appear not to be the major factor contributing to failures in these materials.

One of the most effective methods of preventing tree growth in cables is to surround the cable in a moisture-impervious sheath. This can be a seamless metallic tube, a longitudinally applied plastic/metal laminate with an overlapped seam, or a metal tape with either a welded seam or a polymer-sealed overlap. Refer to Clause 9 for further information on this subject. Where the cost of encasing cables in metallic sheaths is a deterrent, alternative moisture-resistant designs have been developed, which though not as effective, have provided varying degrees of resistance to tree growth.

The methods of reducing the initiation and growth of trees can be categorized into two groups. The first deals with the physical prevention of water ingress into the cable, while the second deals with chemical enhancements to the dielectric that retard the growth of trees within the dielectric. The use of a combination of these methods is often used to obtain the most satisfactory and cost-effective solution.

Of the physical methods used to prevent ingress of moisture, the most fundamental is the use of a polyethylene black jacket based on a linear resin system in the low- or medium-density range. The use of "strand blocking," which is a term used to describe the filling of the conductor strands with a semiconductive polymeric material, should prevent ingress of moisture through the conductor. Other physical enhancements applied in conjunction with the above are the use of water-swellable tapes or powders, which when placed under the cable jacket act as a secondary defense to any moisture that may enter the cable because of mechanical damage. Still another is to use closed barrel lugs with sealing from lug to insulation at cable terminations.

The second method of dealing with tree growth in cable dielectrics is the use of dielectric materials that have been chemically modified to retard the growth of trees, hence increasing significantly the life of the dielectric. This modification contributes to slightly higher electrical loss.

6.2.6 Physical properties, chemical resistance, and environmental considerations

The design and construction of a cable largely determine its physical properties. However the components of the design, and the materials used, also play a significant role in the overall physical properties of the cable.

The choice of materials for the cable design depends on the degree of abuse to which the cable is subjected, or the environment in which it is being designed to operate. However, the overriding choice of a specific material depends on its dielectric properties.

The use of XLPE is generally preferred where a tough, abuse-resistant material with excellent dielectric properties is required. EPR/EPDM is generally preferred where there is a need for a more flexible cable, but a less critical need for abuse resistance and electrical properties.

The selection of materials with respect to their resistance to chemical environments largely depends on the degree of exposure to these substances. In the case of occasional spills of hydrocarbon solvents, materials based on XLPE and EPR/EPDM would survive without significant loss in physical properties. However, if prolonged exposure is likely, the selection of materials based on chloroprene or chlorosulfonated polyethylene may be necessary. A metal or laminate protective sheath over XLPE or EPR/EPDM may be the only alternative where the electrical properties of the cable are critical under prolonged exposure.

6.3 Service history

The following discussion of the relative reliability and service history of present day insulation materials is based on the experience of 19 major industrial users in the U. S. and Canada. No attempt was made to establish a failure rate for each insulation type. These figures are often misleading because of major differences in the relative time periods that different materials have been installed as well as differences in installation conditions. Instead, general trends based on user experience have been cited which should guide the engineer in the proper selection of materials.

There is no comprehensive compilation of industrial cable failure rates in the U. S. However, the Insulated Conductors Committee (ICC) of IEEE, the Cable Committee of AEIC, and the Rural Utility Service (RUS) have all conducted extensive surveys of medium-voltage cable failure rates for electrical utilities (Bowles and Dedman [B9]; AEIC Report, 1992 [B97]). At least one paper has also been presented that reports the service history of medium-voltage cables at U.S. plant sites of a major industrial manufacturer from 1961 to 1990 (Arhart and Morrison [B1]). Although these results can be easily misinterpreted, there are general trends from which some conclusions may be drawn.

6.3.1 Low-voltage power, control, and instrumentation cables (150–600 V)

A common insulation system utilized for both single-conductor and multiconductor cables is thermoplastic PVC covered by a polyamide (nylon) jacket (e.g., UL cable Types THHN, THWN, TC and PLTC). In instrumentation cable applications, the use of PVC insulated/PVC jacketed cables is prevalent in both 600 V Type TC and 300 V PLTC ratings. These cables are cited as being cost-effective, but some problems have been reported because of poor flame retardancy; deformation—especially under short-circuit conditions; embrittlement; shortened life at elevated temperatures; problems withstanding voltage surge spikes; and problems associated with the outgassing of chlorine during fires. Failures have also been reported because of exposure to moisture and chemicals underground for periods of 15 years or more. A vast majority of failures, however, involve mechanical damage during or after installation.

One of the installation concerns with single-conductor power cables, such as Types THHN and THWN, is over the tendency of the thin nylon covering to wrinkle while bending back and forth and its subsequent hang-up at discontinuities in the raceway wall. It is felt that this mechanical problem is exacerbated by the combination of thin insulation walls and the fact that less care is taken with the installation of low-voltage cables as opposed to their medium-voltage counterparts. For this reason, some cost-conscious users prefer Type THW cables, particularly for larger conductor sizes, because of their heavier insulation walls.

Cross-linked polyethylene (XLPE) is another popular insulation material utilized in low-voltage applications (UL types XHHW, USE, and RHH/RHW). Although more costly, cables utilizing XLPE offer superior electrical and mechanical properties over the less expensive PVC alternative. The thermoset nature of these compounds also affords much better resistance to abrasion, compression, and deformation, thus reducing installation induced failures. They have the capability of being rated 90 ˚C in wet environments (XHHW-2 and USE-2) as opposed to the 75 ˚C wet rating for PVC. These designs also offer higher dielectric strength, superior flame retardancy, improved aging characteristics, and better resistance to the ingress of moisture and chemicals. As a result, few problems have been reported other than mechanical damage.

EPR/EPDM insulated cables with CSPE jackets (UL Types RHH, RHW, and USE) also offer high reliability and long life when compared to the PVC alternatives. Jacketed XLPE or EPR are preferred by some users for critical service applications—particularly in underground applications. They have exhibited excellent aging properties, high dielectric strength, flame retardancy, resistance to deformation, and resistance to moisture. However, EPR is more susceptible to degradation by the ingress of hydrocarbons than XLPE or PVC/polyamide alternatives. If this potential condition exists, some type of impervious sheath should be employed.

6.3.2 Medium-voltage cables

Although XLPE- and EPR/EPDM-insulated cables have been commercially available since the early 1960s and tree-retardant XLPE (TRXLPE) since 1981, almost all of these materials have undergone changes in composition and/or processing since that time. These changes deserve consideration since they most likely affect the performance of these materials.

One major fact derived from the combined ICC/AEIC failure data (AEIC Report, 1992 [B97]) is that more than half of the failures of utility cable systems are due to splice or termination failures. This appears to be a common occurrence for industrial systems as well. A greater potential for splicing and terminating problems exists for XLPE/TRXLPE cables than for those insulated with EPR/EPDM. During the manufacture of the cable, the insulation is extruded on the conductor under high mechanical stresses and at elevated temperatures. Because the conductor and insulation have different axial coefficients of thermal expansion, residual stresses can be “frozen in” when the cable is quenched or cooled after extrusion (Brown [B10]). These stresses are low in the case of EPR/EPDM because of its amorphous structure, and are typically relieved when the cable is cut (Occhini et al. [B16]). However, the crystalline structure of the XLPE/TRXLPE material may retain these stresses until the cable temperature is elevated. If not addressed, this can result in an appreciable amount of “shrink-back” away from a splice or termination component interface, creating voids. Corona discharges may be produced which can eventually result in failure. AEIC specifications have strict tolerances on shrink-back, which are being complied with by manufacturers of XLPE/TRXLPE as well as of EPR/EPDM cables.

Additionally, the radial coefficient of thermal expansion of XLPE/TRXLPE is nonlinear above 85 ˚C as the material changes from a crystalline to an amorphous state. Above this point, the expansion rate can vary significantly from that of premolded rubber components that most commonly are made of EPR/EPDM. This may create voids within some premolded splices or terminations after repeated cycles of heating and cooling.

Industrial users appear to experience a lower incidence of medium-voltage cable failure than their utility counterparts. This is probably due to almost universal use of jacketed cables, the use of thicker insulation walls, and the tendency of industrial users to install cables aboveground in cable trays or on aerial messenger. Virtually all of the utility cables studied were unjacketed and installed underground in conduit, or were directly buried and exposed to moisture.

With respect to EPR/EPDM materials, it should be noted that some users have reported major differences in the performance of cables from different manufacturers. This is particularly true of their relative resistance to moisture. Some manufacturers’ cables performed very poorly underground in ducts, while some provided many years of reliable service. This is undoubtedly because, unlike XLPE/TRXLPE materials, the mechanical, electrical, and chemical properties of the EPR/EPDM materials can and do vary significantly from supplier to supplier (Eichorn [B11]). Consequently, their relative performances with respect to thermal aging, voltage aging, impulse withstand, resistance to electrical discharge, and resistance to the effects of moisture will also vary. It is possible but difficult to effectively evaluate these differences on the basis of accelerated tests.

Additional improvements in both materials and manufacturing techniques promise improved performance for all types of insulations in the future.

7. Shielding

7.1 Selection and application criteria

7.1.1 Conductivity

Certain levels of conductivity may be required for the metallic shielding component of the cable, depending on installation and electrical system characteristics. Some system characteristics that should be considered are the functioning of overcurrent devices, required levels of fault or surge current, the manner in which the system may be grounded, desired levels of electrostatic protection, and environmental factors such as incidence of lightning. The type of metallic shield selected, its thickness or diameter, and operating characteristics as determined by the application of the shield to the cable (i.e., helical vs. longitudinal) all become factors in obtaining the desired levels of conductivity.

7.1.2 Conditions

Any of the following factors may require the use of metallic shielded cable:

a) Personnel safety;
b) Single conductors in wet locations;
c) Direct earth burial or damp conduits;
d) The cable surface may collect unusual amounts of conducting materials such as salts, soots, and the like;
e) Connections to aerial lines;
f) Transition from a conducting to a nonconducting environment such as from moist to dry earth;
g) Dry soil, such as in a desert;
h) Exposure to adverse levels of electrostatic or electromagnetic interference;
i) The cable needs protection from lightning or other induced surges;
j) Voltage buildup protection is required; or
k) High-speed PWM, IGBT-type ac drives.

7.1.3 Environmental considerations

There are environmental considerations that are important to overall cable operation and may have an effect directly or indirectly on the shielding. One of the key considerations is ambient temperature and its effect on current-carrying capacity. A second is location, i.e., indoors, outdoors, or underground. All three mediums have their specific thermal characteristics, which affect cable ampacity and potential shielding requirements. Specific environmental considerations affecting shielding choices are described in 7.1.3.1 and 7.1.3.2.

7.1.3.1 Corrosion

The potential for corrosion of the shielding material needs to be considered because any corrosion that decreases the thickness or width of the metallic shielding can have an adverse effect on shielding performance. In particular, loss of continuity can impair the ability of the shield to carry surge, fault, or lightning currents. Thinning or perforation of the shield can also affect its ability to carry transients as well as impair its ability to provide electrostatic protection.

7.1.3.2 Underground installation

Shielding for circuits operating at 2001 V and above is necessary for continuously wet or alternately wet and dry locations. Generally wet locations provide a certain degree of natural shielding. If the cable goes from a dry to wet area, there will be an abrupt change in voltage stress. The use of shielding can help control this stress to prevent accelerated degradation of the insulation of the cable. For direct buried systems, shielded or armored cable provides an exterior ground path for personnel safety in case of accidental dig-in.

7.1.4 Electrical considerations

There are several electrical system parameters to consider when using shielded cable is used. Among them are the parameters given in 7.1.4.1 through 7.1.4.6.

7.1.4.1 Fault currents

The shield can be damaged if exposed to excessive fault currents. The recommendation for ground fault current capability of the shield is 2000 A for 1/2 s (see IEEE Std 141-1993). A recommended practice is to limit the ground fault current exposure of the shield by employing resistance-grounded supply systems and suitably sensitive relaying. Without such limiting measures, the occurrence of a ground fault in a solidly grounded system could result in replacement of substantial lengths of cable. Grounding of the shield at all splice and termination points will direct fault currents into multiple paths and further reduce the possibility of shield damage.

7.1.4.2 Voltage considerations

A shielding system should be used on solid dielectric cables rated 5 kV and higher, unless the cable is specifically listed or approved for nonshielded use.

7.1.4.3 Splicing devices and techniques

For shielded cables the splice is in the direct line of the shielding system. The continuity of the shield must be ensured at the splice. The device(s) used to make the shield electrically continuous must be capable of handling the ground or fault currents that may pass through the shielding system. Likewise, the connectors used at termination points also ensures electrical continuity and must be capable of carrying the anticipated ground or fault currents. They should have an ampacity no less than that of the shield.

7.1.4.4 Grounding of shields

The shields and metallic sheaths of power cables must be grounded for safe and reliable operations. Grounding is necessary to prevent the shields or metallic sheaths from operating at a potential considerably above ground. Hazards to personnel could occur as well as potential degradation of the jacket or covering, or other materials interposed between the shield and ground. The shield can be grounded at one or both ends. When grounded at one end, fault currents traverse the length from the fault to the grounded end. This may impose a high current on the shield, potentially damaging the shield. There will be a voltage buildup on the sheath which could create an unsafe condition. With grounding at both ends, the full fault current should divide and flow to both ends, potentially reducing duty on the shield and subsequent damage. Multiple grounding is the grounding of cable shield at all access points and can limit shield damage. Grounding at both ends or multiple grounds tend to limit voltage buildup. Grounding at both ends also provides shielding against induced electromagnetic interference transients originating from lightning or faults.

7.1.4.5 Shield losses

Metallic shields grounded at more than one end usually have circulating currents flowing in them. The magnitude of the currents depends on the mutual inductance to other cables, the current in the conductors, the voltage on the system, and the resistance of the shield. The effect of the circulating currents is to heat the shield. This can reduce the effective current-carrying capacity of the cable when the shield loss exceeds 5% of the copper conductor losses.

7.1.4.6 Insulating barriers in shield

Where a balance of shield grounding points are required to prevent voltage buildup due to circuit length, overlapping shields separated by an insulation medium can be applied. This method eliminates circulating shield currents. The procedure must be done properly to prevent danger to personnel.

7.2 Semiconducting materials

The formulation of semiconductive materials requires the use of large amounts of conductive carbon black, which is usually dispersed in a polyethylene copolymer. In addition to the principal constituents, minor amounts of proprietary additives are included to aid dispersion, heat stability, and adhesion to the insulation.

These materials are manufactured on a continuous basis or, in the case of some EPR formulations, in a batch process. Semiconductive materials based on carbon black are prone to absorb moisture. They are pelleted and packaged in a dry condition in metallic-foil-lined packages to provide moisture protection.

There are some rubber-based semiconductive insulation shield materials for use on EPDM insulations that cannot be made in a pelleted form and are produced in strip form.

7.2.1 Strand shielding

Strand shield materials are rather stiff with excellent adhesion to the insulation layer. The base polymers used are ethylene ethyl acrylate (EEA) for compounds used on copper conductors and ethylene vinyl acetate (EVA) for compounds used on aluminum conductors. EPR strand shield materials may also be used with EPR insulation.

These materials are extruded as a continuous layer, and for highest quality the strand shield is combined with the insulation and insulation shield in a common extruder head during extrusion of the cable (true triple extrusion).

The critical characteristics of a strand shield are good conductivity and surface smoothness. The extent of its conductivity is usually defined in terms of its volume resistivity with typical values being between 1000 and 100 000 Ω·m at room temperature. The surface smoothness is important in terms of limiting the electrical stress concentration at the interface between insulation and semiconducting layers in a cable.

7.2.2 Insulation shielding

Insulation shield compositions are more flexible and should be strippable from the insulation. They are generally based on polyethylene vinyl acetate polymers, or in the case of EPR systems, may be based on ethylene propylene rubbers.

The key characteristics in the insulation shield layer are the conductivity, as expressed in terms of its volume resistivity, and the force required to strip the insulation shield from the insulation layer during termination, without leaving a residue of semiconductive material on the insulation that cannot be removed by a solvent wipe.

7.3 Metallic shielding materials

7.3.1 General

Cable shields are nonmagnetic metallic materials. The two materials typically used for metallic shields are aluminum and copper. Aluminum requires a larger diameter as a wire or a thicker cross section as a tape to carry the same current as copper. At equivalent current-carrying capacity, an aluminum shield will be lighter in weight but about 40% larger in its dimensions. Therefore, a cable with aluminum shielding would be larger in diameter than a cable with an electrically equivalent copper shield. Typically aluminum shields are used for instrumentation control and communication cables. Copper shields are used typically with medium- and high-voltage cables.

There is also a difference in the conductivity of the oxide layers on the surface of aluminum and copper. The aluminum oxide forms rapidly and builds up over time and is essentially insulating. Copper produces an oxide layer relatively slowly and its oxide layer is relatively conducting. As a result there normally needs to be a difference in connector designs between those used for aluminum and those used for copper shielding.

The metallic shield needs to be electrically continuous over a cable length to adequately perform its functions of electrostatic protection, electromagnetic protection, and protection from transients such as lightning and surge or fault currents.

Various types of shields can be used as described in 7.3.2 through 7.3.7. These types of shields may be used in combination provided they are compatible within the cable sheath construction. A nonmetallic covering or jacket may be used over the shield for mechanical and corrosion protection. The covering should prevent exposure of the metallic shield during handling and installation. Metallic components need to be applied to the cable in a way that maintains electrical continuity. It is important to ensure that continuity will not be broken during handling, installation, or operation.

7.3.2 Helically applied shields

A helical or spiral shield consists of a copper tape (generally) applied in a helical fashion over the cable core. Normally the width of the tape is 25–37 mm (1–1.5 in). The tape is applied with an overlap that can range from 10% to 25% of the tape width. The overlap allows the cable to be bent. Normally a spirally applied shield yields a high degree of cable flexibility. The width of the overlap is the key parameter in the bend performance of the cable. The width of the overlap determines the degree to which the cable can be bent without the edges slipping over each other. If one edge passes another edge, distortion or damage may occur. If it is severe enough, it can penetrate the insulation of the conductor(s) and lead to premature cable failure.

Under certain conditions, the helical shield can have a resistance that approaches that of a helix. This will limit the fault current capacity to a lower value than if lap conduction is present. If corrosion between the laps or very high frequencies (megahertz range) are being considered, the area at the spiral overlap may have a contact resistance that tends to resist the flow of current through this area. The use of a tin-coated copper tape and/or a metallic sheath may reduce the corrosion possibility between the lap. Helically applied shields that are 0.025 mm (1 mil) or less in thickness are regarded as electrostatic shields, i.e., may effectively block the electrical field. The fault current capacity may be increased by wider overlaps, thicker tapes, or intercalated (double-layer) tapes.

7.3.3 Corrugated longitudinally applied shield

This shield tape is obtained by taking a smooth metallic tape, corrugating it in line during the cable manufacturing process, and then folding it longitudinally around the cable core with a single overlap. With this design, the corrosion and high-frequency issues, if present, are eliminated.

7.3.4 Laminated longitudinally applied shield

A laminated aluminum or copper shield can also be used for electrostatic and electromagnetic protection, particularly on instrument and control cables. By grounding the shield at both ends, a countercurrent is generated in the shield during exposure to transients, such as nearby lightning strokes, or continuous waves, such as power line interference. The countercurrent effectively cancels the interference on the signal conductors. This shielding function depends on the transformer effect. This shield is generally of a relatively greater thickness than the commonly used foil shields over individual pairs or wrapped over the cable core. These are normally grounded only at one end for electrostatic protection. Because of this thickness difference [typically 0.125 mm (0.005 in) for copper or 0.2 mm (0.008 in) for aluminum] the shield is able to carry the induced current necessary to provide protection from transients or power line interference (see 9.3.)

7.3.5 Wire shield

A wire shield consists of copper wires that are helically applied over the cable core. The wires can be sized to handle the anticipated level of fault current that may be expected in the power systems. A cable jacket or outer covering generally is extruded over the wire shield, providing protection against corrosion, as well as protecting the wires from mechanical damage.

The use of wire shields in petrochemical plants is limited because they do not provide 100% coverage of the semiconducting layer. A tape shield has the advantage of completely surrounding the cable core, thereby providing for 100% ground coverage over the semiconducting layer. However, with currently utilized semiconducting shielding materials, a wire shield is generally adequate for most power cable applications. Both wire and tape shields are used to control electric stress, to provide a ground plane for charging current, and to provide a path to ground in the event of insulation failure.

A modification of the wire shielding system consists of corrugated copper drain wires that are embedded in an extruded semiconducting jacket compound based on chlorinated polyethylene (CPE). The CPE compound has good chemical resistance and is classified as a deformation resistant thermoplastic (DRT). This jacket material plus the drain wires provide a combination shield and jacket as well as a continuous ground over the length of the cable. Thus, the semiconducting jacket plus the wires provide a completely conducting sheath over the insulated core.

7.3.6 Lead sheath

An extruded lead sheath is used in petrochemical plants as a combination shield and mechanical covering. Often a plastic jacket or outer covering is extruded over the lead to provide the sheaths with an increased level of corrosion protection. The jacketed lead can be used in direct burial or underground applications (duct or conduit) to provide chemical and moisture protection to the cable core.

The thickness of the lead can be varied to provide the desired cross-sectional area to carry the required fault currents, dissipate transients such as lightning, and provide electrostatic protection as well as electromagnetic protection.

Lead is under increased scrutiny for its impact on both the environment and worker's health. OSHA Regulation 29 CFR Part 1926.2 [B100] contains employee protection requirements for construction workers exposed to lead. Every employee working with hot lead is required to undergo an annual medical surveillance for monitoring blood lead level. EPA regulations, such as those prompted by the Safe Water Drinking Act, cover lead sheaths and compounds containing lead additives.

Older cables made with high-purity lead sheaths have exhibited low fatigue resistance and have developed cracks due to expansion and contraction of the cable during load cycles. This made the cable susceptible to leaking. Leaking oil may present an environmental discharge problem. Water pumped out of a manhole may contain oil and be subject to EPA regulations. To improve fatigue and creep resistance, hard arsenical alloys were developed and various types are used today. The lead sheath can provide a complete chemical and moisture barrier when protected from corrosion. Often lead sheaths are protected from corrosion through the use of cathodic protection. This may be a costly procedure; however, cathodic protection is enhanced through the use of protective jackets. Lead has a few other disadvantages besides fatigue and flexing resistance. One is its weight; another is that it is often difficult to remove old lead cables and then dispose of the used cable.

7.3.7 Corrugated metal sheath

The sheath is made from a metallic strip or tape that is longitudinally formed around the cable core. The edges of the tape are butted together and then welded together to form a continuous metal cylinder. The cylinder can be corrugated during manufacture (corrugations formed perpendicular to the cable axis) for flexibility and increased radial strengths. An extruded plastic jacket must be used over the metal sheath for direct burial or underground applications or other areas where corrosive conditions may prevail. The sheath may be regarded as impervious to moisture, liquids, and gases.

The metal sheathing material may be aluminum, copper and its alloys, stainless steel, or a bimetallic composition with the choice of materials determined by what would be best to meet the intended service. The aluminum or copper sheathing material may also be used as the equipment grounding conductor, either alone or in parallel with the grounding conductor in the cable.

In recent years, it has been found that the high-frequency shielding properties of a continuously corrugated aluminum sheath is recommended for many high-speed ac drive application (see Bentley and Link [B5]).

7.4 Current-carrying capability

7.4.1 Shield current

The ability of a metallic shield or sheath to carry current is a function of its resistance. The lower the resistance, the more current it can handle at a given temperature. Guidelines for the minimum amount of shielding allowed are given in ICEA standards. Standards such as ICEA S-68-516-1988 [B51] and ICEA S-66-524-1991 [B50] require a 0.0635 mm (2.5 mil) tape minimum thickness. Copper wires, straps, or sheaths must have a minimum area of 0.1 mm^2/mm (5000 cmil/in) of insulated conductor diameter. Other nonmagnetic metals can be used provided they have equivalent conductance. This particular shielding requirement is strictly for electrostatic shielding. To meet short-circuit requirements, additional shield conductance may be required.

Shield current results from several factors. The cable’s insulation capacitance (charging current) and insulation resistance results in a current flow. These currents are a result of the dielectric losses of the insulation material. The shield provides a path for these currents to flow to ground. They are proportional to the square of the voltage and are present regardless of current flow in the conductor.

When shields are grounded at more that one point, circulating currents occur. Circulating currents are a result of magnetic coupling of the shield with the phase conductor. The shield circulating current is directly proportional to the phase current, shield conductance, and phase separation. To minimize circulating shield/sheath currents, the phase conductors should be kept close together in equilateral form, the phase conductor should be as large as practical, and the shield cross-sectional area should be as low as possible, provided it meets any short-circuit requirement.

Shield current is also generated by eddy currents. Eddy currents in the shield are present for either single-point or multipoint grounded shields. When compared to circulating current, eddy currents are generally low, especially for tape-shielded designs. They begin to have more significance in sheathed cable designs where the shield resistance is relatively low.

7.4.2 Short-circuit current

It is necessary to consider the short-circuit current (capacity) of the shield to assure the cable will not be damaged by the heat generated during a short circuit. The shield must be large enough to carry the short-circuit current for a sufficient length of time to permit the system protection devices to operate before the shield is heated to the point where it would damage the cable. Short-circuit capabilities for various shield and sheath designs and methods of calculation are given in ICEA P-45-482-1994 [B47].

Note that the NEC does not permit use of the shield as an equipment-grounding conductor.

7.4.3 Single conductors in separate conduits

Power cables in ac circuits should not be installed with each phase in separate magnetic conduits under any circumstances. Because of the high inductance under such conditions, this results in a serious derating of the ampacity and is not a practical application for this type of installation.

All three phases of a circuit should be installed in the same conduit. When it is necessary to run only one phase per conduit, then nonmetallic or nonmagnetic metallic conduit should be used. If nonmagnetic metallic conduits are used, the reduction of cable ampacity due to conduit heating should be considered. Also, no magnetic metal, such as clamps or reinforcing bar, should form a closed ring around the conduit.

7.5 Induced shield voltage

Circuits that employ shielded, single-conductor cable carrying alternating current usually have a voltage buildup on the shield if the shield is grounded at only one point. Refer to Table 13 for formulas used to calculate the induced shield voltage for several cable arrangements. Under normal operating conditions, a maximum voltage of 25 V is a commonly accepted limit. However, a maximum of 50 V is often considered acceptable. Surge arrestors may be used at the ungrounded end to mitigate high voltages at the open end of the shield. The use of triplexed cables minimize these problems and voltage buildup.

7.5.1 Mutual reactance and shield resistance

To facilitate calculating the mutual reactance and shield resistance, the following formulas, which neglect proximity loss, may be used with Table 13 for practical purposes. The set of formulas for use with metric units is given first, followed by the set of formulas to be used with customary (inch-pound) units.

$$X_M = 2\pi f\left(0.4606 \log_{10} \frac{S}{r_m}\right) \ \mu\Omega/\text{m}$$

$$a = 2\pi f\,(0.4606 \log_{10} 2) \ \mu\Omega/\text{m}$$

$$b = 2\pi f\,(0.1404 \log_{10} 5) \ \mu\Omega/\text{ft}$$

$$R_s = 159\,000 \cdot \frac{\rho}{r_m t} \ \mu\Omega/\text{m}$$

where

- X_M is the mutual inductance of shield and conductor, in μΩ/m,
- a, b are the mutual inductance correction factors, in μΩ/m
- μΩ is the symbol for micro-ohm,
- R_S is the resistance of the shield in, μΩ/m**,**
- t is the thickness of metal tapes used for shielding, in mm,
- f is the frequency, in Hz,
- S is the spacing between cable centers, in mm,
- r_m is the mean radius of shield, in mm,
- ρ is the apparent resistivity of the shield, in $\Omega\cdot\text{mm}^2/\text{m}$, at operating temperature (assumed 50 ˚C). This includes allowance for the spiraling of the tapes or wires.

Typical values of ρ, in $\Omega \cdot mm^2/m$:

Overlapped helical copper tape	0.050
Lead sheath	0.25
Aluminum sheath	0.033
Bare copper wires	0.0176
Overlapped brass tape	0.116
Overlapped monel tape	4.16
Overlapped ambrac tape	0.58
Aluminum interlocked armor	0.047
Galvanized steel armor wire	0.170
50-52 aluminum alloy	0.050
Galvanized steel Interlocked armor	0.116

For 60 Hz:

$$X_m = 174 \log_{10} \frac{S}{r_m} \ \mu\Omega/\mathrm{m},$$

$a = 52.3\ \mu\Omega/\mathrm{m}$,
$b = 121\ \mu\Omega/\mathrm{m}$.
It is assumed that the cables are carrying balanced currents.

The following formulas are to be used with inch-pound units:

$$X_M = 2\pi f\left(0.1404 \log_{10} \frac{S}{r_m}\right) \mu\Omega/\mathrm{ft}$$

$$a = 27\pi f\,(0.1404 \log_{10} 2)\ \mu\Omega/\mathrm{ft}$$

$$b = 27\ \pi f\,(0.1404 \log_{10} 5)\ \mu\Omega/\mathrm{ft}$$

$$R_s = \frac{\rho}{8 r_m t}\ \mu\Omega/\mathrm{ft}$$

where

X_M is the mutual inductance of shield and conductor Ω/ft,
a, b is the mutual inductance correction factors, in Ω/ft,
μΩ is the micro-ohm, $\Omega \times 10^{-6}$,
R_S is the resistance of shield, in μΩ/ft,
t is the thickness of metal tapes used for shielding, in inches,
f is the frequency, in Hz,
S is the spacing between center of cables, in inches,
r_m is the mean radius of shield, in inches,
ρ is the apparent resistivity of shield, in Ω-cmil/ft, at operating temperature (assumed 50 ˚C). This includes allowance for the spiraling of the tapes or wires.

Typical values of ρ, in Ω-cmil/ft:

Overlapped helical copper tape	30
Lead sheath	150
Aluminum sheath	20
Bare copper wires	10.6
Overlapped brass tape	70
Overlapped monel tape	2500
Overlapped ambrac tape	350
Aluminum interlocked armor	28
Galvanized steel armor wire	102
50-52 aluminum alloy	30
Galvanized steel Interlocked armor	70

For 60 Hz:

$$X_m = 52.92 \log_{10} \frac{S}{r_m} \ \mu\Omega/\text{ft}$$

$a = 15.93$ μΩ/ft
$b = 36.99$ μΩ/ft
It is assumed that the cables are carrying balanced currents.

7.5.2 Cables in conduit

For cables installed three per conduit, use Arrangement II in Table 13. The spacing, *S*, is equal to the outside diameter of the cable increased by 20% to allow for random spacing in the conduit.

7.5.3 Maximum cable lengths with single-point shield grounding

Table 14 gives the maximum lengths of single-conductor cable with shields grounded at one point to stay within the 25 V maximum for the specific conditions stated. Other conditions permit different lengths. For example, cables operated at less than rated ampacity allow longer lengths.

8. Cable jackets

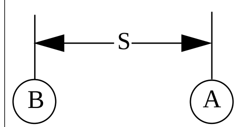
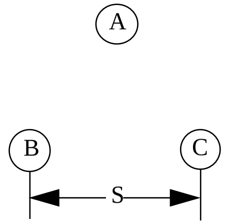
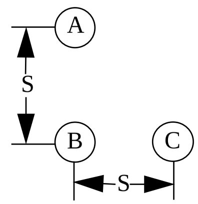
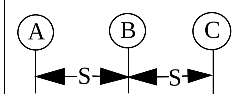
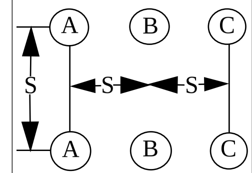
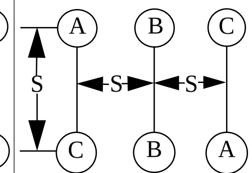
8.1 General

Cables in petrochemical plants are exposed to many different environments. Thus, the function of a jacket is to protect the underlying cable components from one or a number of exposures including mechanical abuse, chemicals, flame, moisture, sunlight and other radiation. See Table 15 for basic properties of jackets used on cables in the petroleum and chemical industry.

8.2 Jacket thickness

The thickness of cable jackets depends primarily on the type of cable and diameter of the core. In general, jacket thickness is specified in the applicable industry standards (CSA, ICEA, UL, NEC, etc.) for the type of cable being specified. Reduced wall jackets in accordance with UL requirements are available when required. Refer to the appropriate standard for specific information.

Table 13—Formulas for calculating induced shield voltages for single conductor cables

Cable arrangement number and diagram	I One phase	II Equilateral	III Rectangular	IV Flat	V Two circuit	VI Two circuit
						
Induced shield voltage to neutral–shields open circuited–μV/m or μV/ft, according to definitions chosen from 7.5.1						
Cable—A Cable—C	IX_M	IX_M	$\frac{1}{2}\sqrt{3Y^2 + \left(X_M - \frac{a}{2}\right)^2}$	$\frac{1}{2}\sqrt{3Y^2 + (X_M - a)^2}$	$\frac{1}{2}\sqrt{3Y^2 + \left(X_M - \frac{b}{2}\right)^2}$	$\frac{1}{2}\sqrt{3Y^2 + \left(X_M - \frac{b}{2}\right)^2}$
Cable —B	IX_M	IX_M	IX_M	IX_M	$I\left(X_M + \frac{a}{2}\right)$	$I\left(X_M + \frac{a}{2}\right)$
Shield loss–shields solidly bonded–μW/m or μW/ft, according to the definitions chosen from 7.5.1						
Cable—A Cable—C	$I^2R_s \frac{X_M^2}{R_s^2 + X_M^2}$	$I^2R_s \frac{X_M^2}{R_s^2 + X_M^2}$	$I^2R_s \left[\frac{(P^2 + 3Q^2) + 2\sqrt{3}(P-Q) + 4}{4(P^2+1)(Q^2+1)}\right]$			
Cable—B	$I^2R_s \frac{X_M^2}{R_s^2 + X_M^2}$	$I^2R_s \frac{X_M^2}{R_s^2 + X_M^2}$	$I^2R_s \left[\frac{1}{Q^2+1}\right]$			
Total Loss	$2I^2R_s \frac{X_M^2}{R_s^2 + X_M^2}$	$3I^2R_s \frac{X_M^2}{R_s^2 + X_M^2}$	$3I^2R_s \left[\frac{P^2 + Q^2 + 2}{2(P^2+1)(Q^2+1)}\right]$			
	$P = \frac{R_2}{Y}$	$Y =$	$X_M + \frac{a}{2}$	$X_M + a$	$X_M + a + \frac{b}{2}$	$X_M + a - \frac{b}{2}$
	$Q = \frac{R_s}{Z}$	$Z =$	$X_M - \frac{a}{6}$	$X_M - \frac{a}{3}$	$X_M + \frac{a}{3} - \frac{b}{6}$	$X_M + \frac{a}{3} - \frac{b}{6}$

***I* = conductor current (amperes)**

Note—This table is adapted from IEEE 525-1992 [B68]. See also Okonite Bulletin [B99].

Table 14—Maximum lengths for single-conductor cables operating at rated ampacity with single-point shield grounding and with induced shield voltages of 25 V

Conductor size	One cable per duct (see Note 1)				Three cables per duct (see Note 2)			
	Copper		Aluminum		Copper		Aluminum	
	Amperes	meters/feet	Amperes	meters/feet	Amperes	meters/feet	Amperes	meters/feet
1/0	249	447/1465	194	572/1875	214	1513/4965	167	1114/3655
4/0	371	322/1055	290	411/1350	278	1076/3530	248	1366/4480
350	496	250/820	387	320/1050	418	796/2610	329	1009/3310
500	608	212/695	472	271/890	504	671/2200	400	844/2770
750	762	181/595	601	229/750	626	549/1800	497	689/2260
1000	890	172/565	707	216/710	—	—	—	—
2000	1237	128/420	1022	155/508	—	—	—	—

NOTES
1—Single conductor, 15 kV cables in ducts on 0.19 m (7.5 in) centers operating at 75% load factor with 90°C conductor temperature, 20°C earth temperature, earth thermal resistivity of 90 ˚C·cm/W (90 rho), and 1.27 m (50 in) buried depth. The unit of earth (thermal) resistivity, rho, is defined in the NEC as the reciprocal of thermal conductivity, normally expressed in °C-cm/W. For additional information on determining earth resistivity, see IEEE Std 442-1981 [B64].

2—Three single conductor, 15 kV cables in one duct operating at 75% load factor. The length listed is the duct length. Other conditions same as NOTE 1.

8.3 Electrical properties

8.3.1 Dielectric strength

Cable jackets may be semiconducting or insulating. If insulating, a fair range of dielectric strengths are available. The continuous grounding afforded by semiconducting jackets on metallic-shielded cables directly buried in earth may offer some advantages with respect to safety or adequacy of surge (such as lightning) protection. Intermittent ground contacts with semiconducting jackets might result in jacket punctures under surge or fault conditions. For nonshielded cables and the majority of metallic-shielded cables, insulating jackets are preferred. In general, the dielectric strength of the insulating jacket is not a major consideration. However, where repeated surges are expected or the operation of single-point grounded shields or sheaths is involved, dielectric strength of the jacket is a major consideration. Jacket puncture in these cases is a serious concern.

8.3.2 Discharge resistance

When a nonshielded cable rests upon, or comes into contact with, a ground plane, the ground plane acts as the outer plate of the capacitor made up of the conductor, insulation, and the ground plane. Contact with the ground plane may be intermittent and at high levels (generally 2001 kV and above) result in discharges that normally occur at and near the point(s) of contact. Such discharges may cause erosion of the jacket material. Some materials are more resistant to deterioration due to discharges. The use of discharge-resistant jackets should be considered for nonshielded cables depending on operating voltage (typically 5–8 kV), electrical stress level, cable configuration, and operating environment.

8.3.3 Tracking resistance

As with discharge resistance, the operation of a nonshielded cable in the presence of a ground plane or with surface contamination results in voltage gradients on the cable surface. These gradients result in current flow on the cable jacket surface, depending on the surface resistance (and/or contamination). This surface current flow is commonly known as tracking. Some materials have higher surface resistance and are therefore more resistant to tracking. However, if surface contamination is involved, it overcomes any benefits achieved by the use of track-resistant material.

Table 15—Properties of cable jackets

Properties	Thermoplastic			Thermoset	
	PE	PVC	CPE	CSPE/NEO	CPE
PHYSICAL					
Toughness	Excellent	Good	Excellent	Excellent	Excellent
Flexibility	Poor	Good	Good	Excellent	Excellent
Ease of installation	Good	Excellent	Excellent	Good	Good
THERMAL					
Thermal rating, dry	75 °C	60–90 °C	60–90 °C	90 °C	90 °C
Thermal stability	Poor	Good	Good	Excellent	Excellent
Heat resistance	Good	Excellent	Excellent	Excellent	Excellent
CHEMICAL RESISTANCE					
Acids	Excellent	Excellent	Good	Excellent	Excellent
Alkalines	Excellent	Excellent	Good	Excellent	Excellent
Organic solvents	Excellent	Poor	Good	Good	Good
Oil	Poor	Fair–good	Fair–good	Good	Good
Water	Excellent	Good	Good	Good	Good
SPECIAL PROPERTIES					
Flame resistance	Poor	Good–excellent	Good–excellent	Excellent	Excellent
Weather resistance	Excellent	Good	Excellent	Excellent	Excellent
NOTE—These comparisons are general in nature. Specific formulations and compound variations of these materials will change the performance criteria to some extent.					

8.4 Physical properties

8.4.1 Toughness

Toughness is a relative matter and not easily defined. Abrasion resistance, puncture resistance, tear strength, crush, and deformation are all attributes that might define toughness. However, these attributes are a function of the cable design as well as the jacket material.

Other attributes include tensile strength, elongation, retention of properties with aging, heat distortion, cold impact, and cold bending properties.

Except for special cases of severe duty, which would be applicable to portable cables, all of the commonly used jacket materials have adequate strength for petrochemical plant applications.

8.4.2 Flexibility

Flexibility is a consideration to some degree in all installations. In general, the flexibility of cables is dependent on the design and each component in the cable. However, because it is the “outer” member, the jacket can have considerable impact on flexibility. There are often trade-offs to be faced. Those material properties that enhance surface hardness for abrasion and impact resistance often are at the expense of flexibility. Increasing the number of conductor strands in conjunction with the use of other flexible materials has the greatest impact on cable flexibility.

8.5 Thermoplastic vs. thermosetting jackets

A major consideration in selecting a jacket is whether a thermoplastic or thermosetting material is required. In many cases a thermoplastic jacket is less expensive. However, thermoplastics melt at some elevated temperature (different for each thermoplastic material) and could run or drip from the cable under extreme conditions. This may be unacceptable in many applications.

Thermoset materials will not melt and run or drip at elevated temperatures.

8.6 Chemical and environmental properties

8.6.1 Chemical resistance

The resistance of jacket materials to various chemicals can be of major importance. This is a very complex matter as chemical resistance is generally a matter of concentration and temperature as well as the chemical(s) involved, their state (vapor or aqueous), and the time of exposure. See Table 15 for performance of cable jackets exposed to oil and chemicals.

8.6.2 Moisture resistance

Moisture is a major consideration in all underground installations and many other plant locations. Fortunately, these are often locations including enclosed terminations where fire/flame is not a major consideration. Often, materials with the highest degree of moisture resistance are not particularly flame-resistant. Where installations include both underground and overhead (aerial or cable tray) cable, the user may specify a premium cable jacket that optimizes flame and moisture resistance. A second option would be to transition from the moisture-resistant jacketed cable to a flame-resistant jacketed cable by splicing the two types of cables.

8.7 Fire and smoke considerations

8.7.1 Flame resistance

The relative degree to which a jacket material will burn is an important consideration. The importance is dependent on the application.

Cables directly buried or in ducts underground may not require a flame-resistant jacket, depending on where the cables are terminated. Cables entirely contained in conduits may also not require a high degree of flame resistance. Cables in trays or ladders, or run exposed in walls, require a higher resistance to flame. Cables run in plenums or other air-handling spaces should have the highest degree of flame resistance as well as low smoke. Refer to 4.4.2 for further information.

Another consideration is the critical nature of the circuit. Power, control, and signal circuits required to shut down operations safely in the event of fire should maintain integrity with long exposure to flame/fire.

8.7.2 Smoke density

Obscured vision due to smoke generated by a fire can hinder escape and fire-fighting efforts. This can be a major consideration in work areas, control rooms, or where the public congregates. New and improved materials are now available that have low or limited smoke emissions when burned. Their use is growing rapidly.

8.7.3 Toxicity

Many common materials emit toxic substances when burned. This can also reduce escape potential of persons in the area of the fire. While they may not be more toxic than many other substances, halogenated materials have come under special scrutiny. There is somewhat of a trade-off, as halogens are excellent flame retardants. Low- or zero-halogen flame-retardant compounds are available to address this problem.

8.7.4 Corrosivity

Many materials emit corrosives when burned. This may be further complicated if the corrosives react with fire-fighting agents such as water to form acids or bases. One such well-known reaction involves the combination of hydrogen chloride with water to form hydrochloric acid. This is another reason why halogenated materials (especially containing chlorides) have come under scrutiny.

8.8 Special considerations

One issue that must be considered is the future disposal of used cables. This may be impacted by the materials, including jackets, that are used. Some compounds contain varying quantities of ingredients such as lead that may present future disposal problems (see Barras et al. [B2]).

9. Moisture and chemical protection

9.1 General

There is a need for chemical and moisture protection for cables used in petrochemical plants. The environment in these plants can have an adverse effect on cable materials, potentially leading to less-than-expected performance. The various methods used to provide chemical and moisture protection are described in this clause. These methods are summarized as follows:

a) Choice of jacketing materials;
b) Use of chemical/moisture barrier (CMB) cables with laminate sheaths;
c) Use of metallic sheaths as chemical and moisture barriers;
d) Use of water-blocking materials in cables.

When metallic shields and armors are used for moisture protection, protective jackets over the shield are required to provide corrosion protection. Alternatively, protective coatings on the shielding materials and/or cathodic protection (see Bayer et al. [B3]) may be considered. Corrosion can generate pin holes and/or other openings in the metallic sheath (see Bow [B98]). These openings greatly compromise the chemical or moisture barrier.

9.2 Moisture/chemical resistance of jackets

9.2.1 Moisture resistance of jackets

No plastic material can absolutely prevent the permeation of moisture. All have a defined moisture permeability, which depends on the composition of the jacket and the materials that are used as additives or fillers to the jacket. Data from the field indicates that, over time, moisture can penetrate many jacketing materials and enter into the core of the cable, where it can cause deterioration of electrical properties and, in the case of medium-voltage cable, result in initiation and growth of trees. Jacket materials with improved moisture resistance have been developed, but such materials cannot be classified as moisture impervious. See 8.6.2 for further information.

9.2.2 Chemical resistance of jackets

The effects of chemicals and oils can cause hardening, softening, swelling, and/or cracking of polymeric jackets. The hardening appearing on PVC is often caused by extraction of plasticizers, oils, or chemicals. Swelling is observed on PVC, elastomeric, and filled polyethylene jackets. Excessive swelling can result in cracks or splitting of the jackets. Cracking can be accelerated by heat. Stress cracks are accelerated by contact with certain chemicals and oils. See Table 15 for chemical performance ratings of jackets.

9.3 Laminate sheaths as chemical/moisture barriers

The heart of the chemical/moisture barrier (CMB) is plastic-coated metallic tape. The tape may be coated on one or both sides. It can be applied either smooth or corrugated. Prior to the jacketing process, the tape is longitudinally formed in-line and folded over the core with an overlap at the edges. During the jacket extrusion process, the polymer at extrusion temperatures melts the coating, thus creating a bond between the coating and the overlying jacket. The heat from the extrusion process also melts the coatings in the overlap area and seals them together.

Selection of a suitable overall jacket is a primary consideration in specifying CMB cable constructions. The jacket should have bonding compatibility with the coating on the metallic tape. Another key consideration is the degree of ignition suppression required for the cable. Unfilled thermoplastic polyethylene jackets, in a variety of densities and types, are chosen when flame resistance is not a consideration. Thermoplastic elastomeric-filled chlorinated polyethylene is selected when flame and chemical resistance are required. Zero-halogen jackets are selected when there is an additional need to minimize the emission of smoke and corrosive fumes. Polyvinyl chloride (PVC) jackets are chosen for general-purpose applications where ignition suppression and lower cost are the main considerations. Physical properties of the jacketing materials should also be considered.

The CMB tape is composed of aluminum-, copper-, or chrome-coated steel tape. The tape is coated with a plastic layer that forms a highly moisture resistant bond to the metal tape. A family of coated aluminum, copper, or steel tapes has been developed that is adhesively compatible with PVC jackets; low-, linear low-, medium-, and high-density polyethylene jackets; chlorinated polyethylene (CPE); and zero-halogen jacketing materials.

As noted, the primary component of the chemical/moisture barrier is the metallic tape. The key to performance is to incorporate the tape into the sheath through adhesive bonding. The seal at the overlap becomes a "tortuous path" that prevents chemicals or moisture from entering the cable core. This seal is not 100% diffusion proof. However, tests published in the literature indicate very low diffusion rates (see Poulsen et al. [B17] and [B18]). The referenced calculations indicate that the rate is low enough to be equivalent to a lead sheath in performance (see Iwawaki et al. [B12]). The degree of barrier depends on the length and thickness of the coatings used to seal the overlap. The coatings on the metallic tape normally self-seal under proper extrusion conditions. However, a hot-melt adhesive can be inserted into the overlap area to aid the sealing of the seams. The use of hot-melt adhesives provides a reliable method of sealing the overlap during continuous cable manufacture. The adhesive provides assurance that the overlap is sealed completely without skip or pinholes. The insertion of the adhesive can be electronically monitored for continuity. The use of a hot melt is particularly recommended when one-side-coated or corrugated tapes are used.

The main benefits of using a laminate with a relatively thicker metallic sheet (as opposed to a foil) are greater mechanical strength and assurance of a pinhole-free moisture barrier. Bonding the laminate to the cable jacket provides a moisture block in the tape-jacket interface and gives the cable improved mechanical properties such as bend performance, impact or crush resistance, and improved sidewall pressure capabilities (see Bow et al. [B8]). The use of sheet thicknesses of 0.125 mm (0.005 in) and greater insures that pinholes and defects from the metal rolling process are relatively improbable and provide a metallic/plastic laminate of sufficient thickness to achieve improved mechanical performance.

The use of water-swellable tapes over the core of medium-voltage cables allows for a longitudinal water block at the moisture barrier–shield–core interface. The water-swellable tape can also serve as a cushion layer to handle thermal expansion. Typically, a hot-melt adhesive is placed in the overlap to insure a sufficient seal. This blocks both radial and longitudinal moisture flow through the overlap. Powders and water swellable yarns can also be used. See 9.5 for further information on methods of water blocking.

The use of corrugated tape in medium-voltage cable has the following benefits. First, the mechanical properties of the cable, bend performance in particular, are significantly improved vs. bare metal by bonding a plastic coated, corrugated shield to the jacket. Second, the longitudinally applied corrugated shield provides electrical and mechanical improvements over helically applied copper-tape shields (see Lukac et al. [B13]). Third, the field experience in power cable with the corrugated shield has exceeded 20 years. This experience has been excellent. Fourth, hot-melt adhesives have been developed that allow the overlap to give (move) during thermal loading to accommodate some of the thermal expansion of the core.

9.4 Metallic sheaths

Extruded lead and aluminum sheaths can be used as moisture or chemical barriers. Metallic sheaths with welded seams and lateral corrugations have also been used (see Clause 10).

9.5 Water blocking

9.5.1 Powders

Swellable powders are used as longitudinal water blocks in cables to prevent longitudinal water penetration. These powders swell and expand sufficiently upon contact with water to form a gel-like material to block the flow of water. The cable design may have to be modified to hold the swellable powders in place. It is possible for the powder to migrate during cable handling and leave areas within the cable unprotected.

9.5.2 Water-blocking tapes

A water-blocking tape is usually a nonwoven synthetic textile tape impregnated with, or otherwise containing, a swellable powder. Upon contact with water, the powder swells into the interstices and forms a jelly-like longitudinal water block. The tape may be semiconducting or nonconducting, depending on the cable type and design. The tape may be applied helically or longitudinally into the areas of expected airspace. Tapes used for power cables can be omnidirectional and swell on both sides upon contact with water. The factors affecting the ability of the tape to swell are primarily dimensional. The space to be filled must be small enough to allow sufficient pressure to build up in the gel to block the flow of water. Water-blocking tapes are useful as longitudinal water blocks.

9.5.3 Sealed overlap

To ensure a seal of the overlap, hot-melt adhesives can be used. These adhesives can be extruded or pumped into the overlap seam of a longitudinally formed metallic tape before the seam is closed during cable manufacture. They should be capable of sealing to bare metal and be adhesively compatible with the material chosen as the cable jacket. Hot-melt adhesives are useful as radial and longitudinal water blocks.

9.6 Gas blocking

Seals are required in the cable to prevent the passage of a hazardous atmosphere along the wiring system from one division to another or from a Division 1 or 2 hazardous location to a nonhazardous location. The use of multiconductor cables with a vaportight continuous outer sheath can significantly reduce the sealing requirements in Class 1, Division 2 hazardous locations (see Clauses 10 and 12.5).

10. Metal armors

10.1 General

Metallic armored cables (metal clad) are used to provide additional mechanical protection, increased resistance to flame propagation and a barrier to the intrusion of moisture and chemicals. The self-contained cable system of metal-clad cable provides a "factory-installed" system without subjecting the individual insulated conductors to the possible mechanical damage of installation as they would be if pulled as single conductors into a conduit or cable tray.

Metal-clad cables (Type MC) are detailed in Article 334 of the NEC. Canadian armored cables are manufactured and tested in accordance with CSA C22.2 No. 131-M89 [B37]. For UL label requirements, the constructions for 600 V and 2000 V cables are given in UL 1569-1995 [B91]. Armored medium-voltage cable is covered by UL 1072-1995 [B89]. Typical requirements for sheaths, interlocked armor, flat-tape armor, and round-wire armoring, including required bedding and covering, appear in specifications such as ICEA S-68-516-1988 [B51]. Cables for use in Class 1, Division 1 hazardous areas have specific requirements as set forth in UL 2225-1996 [B95] and CSA C22.2 No. 131-M89 [B37].

The various types of metal armors along with descriptions, applications and materials are listed in Table 16. The key features for each type of armor are shown in Table 17.

10.2 Applications for Type MC metallic armored cable

Type MC cable is suitable for use in the following areas and must be applied in accordance with Article 334 of the NEC:

a) Services, feeders and branch circuits;
b) Power, lighting, control and signal circuits;
c) Outdoors or indoors;
d) Where exposed or concealed;
e) Direct burial;
f) In cable trays;
g) In any raceway;
h) Aerial on a messenger;
i) In hazardous locations (see Articles 501, 502, 503, 504 and 505 of the NEC); and
j) In wet locations where specific conditions are met.

Table 16—Armor types, descriptions, applications, and materials

Type of armor	Description	Application	Most common materials	Other materials
Continuous corrugated sheath	Continuous solid metal wall is either extruded or welded over the cable core. The metal is corrugated for flexibility.	Various. See 10.2	Aluminum	Copper, bronze, stainless steel
Smooth sheath	Continuous solid metal wall, either extruded, welded, or swedged over the cable core.	Where a very rigid cable is required. See also 10.2	Aluminum	Copper, stainless steel
Interlocked armor	A flat metal tape is preformed with a die into an approximate S shape, then helically applied over the cable core so that the formed edges lock together.	Various. See 10.2	Galvanized steel or aluminum	Stainless steel, bronze, brass, or monel
Round wire	Individual round wires are helically wrapped around the cable core.	Submarine, vertical riser, and other special applications.	Galvanized steel or aluminum	Stainless steel
Flat metal tape	Single or double tapes are helically wrapped around the cable core.	Direct burial and other special applications.	Galvanized steel	Stainless steel

Table 17—Key features for each type of armor

Type of armor	Features
Continuous corrugated sheath	Provides a gas/vaportight sheath with a solid metal wall. Can be used as the equipment grounding conductor. With UL 2225-1996 [B95] listing, can be used in Class I, Division I hazardous locations. Excellent electromagnetic shielding and good performance on harmonics problems associated with pulse-width-modulated variable-frequency drives. Continuously corrugated sheath without a jacket is suitable for plenum use per NEC.
Smooth sheath	Very rigid (for such applications as high bay lighting). Provides a gas/vaportight sheath with a solid metal wall. Can be used as the equipment grounding conductor. Excellent electromagnetic shielding and good performance on harmonics problems associated with pulse-width-modulated variable-frequency drives.
Interlocked armor	Flexible. Does *not* provide a gas/vapor tight sheath. May *not* be used as the equipment grounding conductor, as there is no requirement for armor conductivity.
Round wire	Very high tensile strength for submarine cable, borehole applications, and such applications as long vertical installations or other specialty applications where high tensile strength is important. Not approved by UL as Type MC.
Flat metal tape	Double or single armor. Widely used internationally for direct burial. Not approved by UL as Type MC.

11. Cable quality and testing considerations

11.1 Quality principles for wire and cable

Historically, general design parameters for wire and cable were developed by cable manufacturers and users. Currently, readily available specifications based upon industry and national standards provide the design parameters and quality requirements. Comprehensive designs utilizing strand filling, supersmooth semiconducting screens, extra-clean insulation, swellable moisture-sealing materials, and metal/plastic laminate shielding and sheathing are extending cable life.

Quality assurance principles used in the wire and cable industry provide a basis for evaluating acceptable electrical, chemical, and physical properties for these products. As a result, quality assurance programs influence and impact the design, manufacture, installation, and expected service life of power and control cables.

Quality assurance during the manufacture of any cable or cable assembly is dependent upon use of quality materials and processes for such items as

a) Raw materials;
b) Handling;
c) Compounding;
d) Extrusion technology;
e) Curing processes; and
f) Acceptance testing.

Quality assurance programs are normally adopted by a manufacturer to ensure full conformance to applicable standards. Standards for quality assurance and testing are published by various organizations, which include AEIC, ANSI, ASTM, CSA (Canada), ICEA, IEEE, ISO, MIL, NEMA, NFPA, and UL.

Special considerations for determining design and qualification tests required to measure quality are dependent upon supplemental specifications such as AEIC CS5-1994 [B21] and AEIC CS6-1996 [B22] covering XLPE- and EPR-insulated shielded medium-voltage power cable. Production sampling tests may be desired at various steps in the manufacturing process to verify quality during the construction of complex cables or multiconductor assemblies, such as direct buried or armored-type cables.

Clause 2 and Annex A contain a partial list of reference standards and technical papers applicable to cable manufacture and use. Quality assurance and testing considerations for a specific cable type can be identified from the publications listed in this document and other sources. The reliability and expected service life of installed cables is dependent in part on assuring quality in manufacturing. Establishment of a methodology and testing program for the manufacture of quality cables is recommended to help assure a reliable and uninterrupted service life.

Qualification of a manufacturer should include review of an established quality assurance and testing program. Independent third party certification of the manufacturer’s quality assurance program and testing capability is available under guidelines published by CSA, ISO, ASTM, and NIST through the National Voluntary Laboratory Accreditation Program (NVLAP).

11.2 Application of standards

Standards applicable to cable manufacture are generally specific as to a certain type of cable construction or classification. The standard specifies tests applicable to a type of cable for chemical, electrical, and physical properties. Standards and specifications for cable assemblies are published by organizations such as AEIC, CSA, ICEA, IEEE, MIL, NEMA, and UL. Tests for conductors, insulation, shielding, coverings, fillers, semiconducting layers, jackets, and other materials are covered by these standards. Manufacturers normally perform design tests and production tests as required by the standards and specifications. The end user should specify at time of purchase all tests required in addition to standard production tests. Consult the manufacturer for tests available and copies of test results.

Certain factors govern acceptable use of cable including the NEC, NFPA requirements, and industry standard practices and guidelines. For specific use, such as below grade, direct burial, and tray cable, the cable selected should be listed or otherwise approved for that specific application. Approval for use is generally based upon satisfactory completion of applicable performance tests and is evidenced by marking on the outer jacket and a listing label where available. Where listing is not available on special-use cable assemblies, consult with the authority having jurisdiction on an acceptable test program based on national standards as a basis for approval.

11.3 Testing requirements and program

Test results can be evaluated on the basis of absolute criteria, pass or fail, generally acceptable criteria, or results evaluated in combination to arrive at a conclusion. The first step in establishing a testing program is to refer to applicable standards. Next, research applicable standards to identify tests to be performed by the manufacturer and tests to be performed by the installer or an independent test lab after installation. Finally, periodic maintenance tests conducted during scheduled outages may be desirable depending on system reliability requirements. Refer to Clause 2, Clause 3, and Annex A for applicable standards, and also 12.11.4 of IEEE Std 141-1993.

11.3.1 Factory tests

Factory tests consist of design and production sampling tests as illustrated in AEIC CS6-1996 [B22], Appendix 3, for medium-voltage cable. In addition, the manufacturer should conduct acceptance tests on raw materials for use in cable assemblies as part of the quality assurance program.

Tests required for materials include the following, based upon the applicable standards referenced:

a) *Conductors.* Elongation, finish, coating, diameter, tensile strength, stranding, conductor size, dc resistance per unit length, volume resistivity, conductivity.
b) *Insulation.* Percent carbon black, contaminants, porosity, water content, thickness, brittleness, tensile strength, elongation, oven aging, resistivity, insulation resistance, water absorption, partial discharge, dielectric strength, specific inductive capacitance, flame tests, toxicity tests.
c) *Shielding and coverings.* Oven aging, brittleness, elongation, volume resistivity, thickness, width, tensile strength, tension for removal, absorption coefficient, heat distortion, cold bend, irregularities, application, lay and spacing, torsion, adhesion, flame tests, toxicity tests.
d) *Completed cable.* Corona discharge.
e) *Completed cable.* AC and dc high potential tests.

All factory tests prescribed by the specifications are to be made by the manufacturer.

Certified copies of tests: If requested by the purchaser at the time of inquiry, the manufacturer can furnish the purchaser with certified copies of the results of tests required by specifications, including qualification and production tests.

11.3.2 Field acceptance tests

Cable tests performed “after installation” are recommended by the manufacturer and specified by the end user. The types of tests conducted depend on cable type, rating, and application. System reliability considerations may also influence testing requirements. Field tests are performed to determine adequacy of workmanship of installation, and condition of cable and accessories upon installation. Additional information on field testing of installed cable systems is contained in 12.11.4 of IEEE Std 141-1993. Also refer to IEEE Std 400-1991 [B62]. IEEE Std 400 is under revision at the time of this writing (August 1999) and should subsequently become an omnibus standard covering all feasible test methods. The new title is “IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems.” The major divisions of the revised standard will be as follows:

a) IEEE Std 400: Overview
b) IEEE Std 400.1: Direct Current (dc)
c) IEEE Std 400.2: Very Low Frequency (VLF)
d) IEEE Std 400.3: Partial Discharge (PD)
e) IEEE Std 400.4: Dissipation Factor (DF)
f) EEE Std 400.5: Power Frequency (PF)
g) IEEE Std 400.6: Oscillating Wave (OW)

This revision is under the auspices of the Insulated Conductors Committee of the IEEE Power Engineering Society, Project 12-50. Those involved in field testing of medium-voltage cable should make use of this standard when published. However, continued coordination with the cable manufacturer on acceptable field test methods and voltages is recommended.

IEEE Std 141-1993 and IEEE Std 400-1991 [B62] also address some issues related to conducting field acceptance and maintenance tests and the basis, method, interpretation and conclusions related to cable tests. Test voltage levels and frequency of tests are generally determined on the basis of level of performance and reliability required.

Field acceptance tests can be performed on cable systems upon receipt of cable prior to installation, upon installation and prior to splicing or terminating, or upon completion of splices and terminations prior to energization. Field acceptance tests should detect gross defects from manufacture, improper handling during shipment and installation, and poor workmanship on splicing or terminating.

Field acceptance tests include the following:

a) Visual inspection for physical damage, bends at less-than-minimum bending radius, phase identification, fireproofing, proper shield grounding, cable supports, and termination connections, along with required size and rating per design drawings and proper separation of power, control, instrumentation, and emergency circuits.
b) Electrical tests including dc high potential, ac overpotential, dissipation factor, capacitance, dc insulation resistance, conductor resistance/continuity, conductor phasing, shield resistance/continuity and time-domain-reflectometer (TDR) trace. There may be practical limits in performing field tests due to site conditions, availability and quality of test power, and test equipment availability and portability. These limitations should be considered.
c) Resistance of neutral wires and tapes.

11.3.3 Maintenance tests

Maintenance tests are beyond the scope of this guide. The user should refer to NFPA 70B-1998 [B81] and IEEE Std 400-1991 [B62] for further information.

11.3.4 Special tests

The electrical tests described or referenced in this clause are all applicable to petroleum and chemical plant environments. In addition, special considerations need to be given to petroleum and chemical plant environments regarding tests to be performed at the time of manufacture or installation. The specifier should be prepared to provide the supplier a list of known or anticipated conditions and chemicals likely to be present. Special consideration should be given to tests required to assure that materials used in manufacture are suitable for chemical, thermal, physical, and operational conditions. Clause 2 and Annex A list standards and references applicable to specific components and assemblies.

Tests for flammability and flame propagation of material, water-blocking assemblies, gas/vaportight cable assemblies, oil- and gas-resistant insulation and jacket materials, corrosion-resistant conductors, and chemical-resistant shield jackets and armors have been established to determine suitability. Proof of suitability can be evidenced by listing or labeling with the approved application embossed on the outer jacket or included in manufacturer's literature. The manufacturer should be consulted on cable application and suitability.

11.3.5 Reports and documentation

Reports and documentation on completed tests are critical to the approval and acceptance of cable. This is particularly applicable to medium- and high-voltage cable. Complete documentation provides the basis for acceptance by manufacturer, specifier, end user, and inspector or authority having jurisdiction. When specifying a cable, the specifier should request the manufacturer’s test reports. The tests may include design test data for a particular cable assembly type, which should be compared to applicable standards to verify compliance. The manufacturer tests normally include production tests and any special tests required by the end user. Manufacturer's tests can be factory-certified or witnessed by a third party.

The end user may also require field testing. Test requirements are usually included in construction specifications or referenced to industry standards or project specifications. Field tests are completed by an installer, owner's representative, or independent test laboratory. Minimum requirements for documentation should be established to ensure useful information is received. Items to note on a field test report include date, time, circuit designation, cable rating, manufacturer, cable type, length, test data, test equipment used and calibration date, test technician, ambient conditions, temperature correction factors, project reference, result concluded from test data, chart or graph of incremental data, and notes and comments related to condition of cable or points of interest noted during test. Test forms should be prepared and accepted prior to conducting tests.

11.4 Interpretation of results

Results of tests in some cases can be evaluated in absolute terms based upon specific criteria where results are quantifiable. Examples of quantifiable results would be micrometer measurements compared to a minimum or maximum thickness requirement.

Results of tests in some cases are subject to rules of thumb or should be evaluated with other factors being considered that can be subjective. Comparative methods can also be used as a basis for evaluating results.

Interpretation of test results may be simplified by comparison of test results for specimens of equal length or by using a control specimen of known length to establish base parameters. Examples of application of this technique would be conductor and shield resistance tests. TDR measurements also lend themselves to comparative evaluation.

Cable suppliers are sources of information for evaluation of field test results. Manufacturers of field test equipment are also sources of information. In recent years, many field testing companies have been formed to provide field testing services and are capable of evaluating test results.

Suppliers of cable often assist the end user in evaluating factory test results, and most standards-writing organizations will normally assist with regard to the application of standards to the evaluation of test results. In performing tests such as capacitance and dissipation factor, it may be necessary to consult the manufacturer in order to interpret results. The same would apply to partial discharge and very low frequency testing.

12. Special-purpose cables

12.1 Instrument cable

12.1.1 Scope

The scope of 12.1 includes single- and multiconductor instrumentation cables as well as thermocouple extension cables. Instrumentation cables are either single- or multiconductor cables, the latter comprised of twisted pairs or triads, that convey low energy or power-limited electrical signals from field devices to process analyzers, controllers, or some form of distributed control system (DCS). These signals are used to control and monitor equipment in process facilities and electric power systems. They function as the electrical pathway for connecting the nonmechanical elements of the feedback control loop to the input and output devices.

12.1.2 Circuit classifications

12.1.2.1 Class 1 circuit conductors

Class 1 circuit conductors can be applied on power-limited, remote control, and signaling circuits in accordance with Article 725, Part B of the NEC. Power-limited circuits are defined as having a rated output of not more that 30 V and 1000 V-A. Remote-control and signaling circuits are not to exceed 600 V and are not required to be limited. Wiring methods, rules for mixing different circuits, approved conductor types and cables, ampacity, and the number of conductors in cable tray and raceway are also included in Article 725, Part B. The installation of Class 1 circuit conductors and cables are to be in accordance with the appropriate Articles in Chapter 3 of the NEC. This allows for installation in raceway, underground duct, direct buried, aerial messenger, and cable tray.

12.1.2.2 Class 2 and 3 circuit conductors

Class 2 and 3 circuit conductors can be applied on circuits that are inherently limited by the power source or by a combination of the power source and current limitation. Class 2 and 3 power sources are listed in Article 725-41 of the NEC. Cable types permitted for use on Class 2 and 3 circuits need to be listed and marked in accordance with Article 725-71 of the NEC as follows: CL3P, CL2P, CL3R, CL2R, PLTC, CL3, CL2, CL3X, and CL2X. The uses, permitted cable substitutions, rules for mixing different circuits, and other application information can be found in the NEC, Article 725, Part C. In general, Class 2 and 3 circuit conductors and cables can be installed in plenums, risers, raceways, cable tray, hazardous locations, and other areas where approved for such use.

12.1.3 Cable descriptions and types

12.1.3.1 300 V power limited tray cable, Type PLTC

Power-limited tray cable is for use on power-limited circuits as described in Article 725-71(e) and (h) of the NEC. These cables are to be constructed in accordance with the UL 13-1996 [B84]. Such cables are for nonplenum and nonriser circuits, in general, and for use in trays. They can be installed in Class 1, Division 2 hazardous areas in accordance with Article 501-4(b) of the NEC. PLTC cables with intrinsically safe circuits must be separated from nonintrinsically safe circuits by the methods described in Article 504-30 of the NEC. Conductors can range in size from #22 AWG to #12 AWG.

12.1.3.2 300 V instrumentation tray cable, Type ITC

Instrumentation tray cable is used for circuits described in Article 727 of the NEC. This article permits an alternative wiring method for circuits that do not exceed 5 A (3 A for #22 AWG) and 150 V, such as those found in distributed or nonlimited process control systems. Type ITC cables are to be constructed in accordance with UL 2250-1998 [B96]. These cables may be dual-rated PLTC/ITC at the option of the manufacturer provided that the cable meets all requirements of UL 13-1996 [B84] and UL 2250-1998 [B96]. This would allow the cable to be used for either type of circuit. However, Article 727 of the NEC precludes the intermixing of instrument power circuits, intended for use with Type ITC cable, with intrinsically safe or power-limited circuits, intended for use with Type PLTC cable. Cables for intrinsically safe circuits should be separated from nonintrinsically safe conductors by the methods described in Article 504-30 of the NEC. Thus, a dual-rated PLTC/ITC cable could be used with either type of circuit. However, installers should be careful not to use such cables for both types of circuits in the same tray without a barrier in order to comply with the NEC.

In accordance with Article 727 of the NEC, Type ITC cable can be installed only in industrial facilities where the conditions of maintenance and supervision ensure that only qualified persons service the installation. Installation of ITC cable is permitted in cable trays, in raceways, in hazardous locations, as open wiring for cables with and without metallic shields, as aerial cable on a messenger, direct buried where identified for the use, and under raised floors. Type ITC cable, with a continuous corrugated metallic sheath and overall jacket, may also be installed in Class 1, Division I and Zone 1 locations when listed and approved for this purpose.

12.1.3.3 600 V tray cable, Type TC

Type TC cable is for use in cable trays per UL 1277-1996 [B90] and Article 340 of the NEC. Also refer to ICEA S-82-552-1992 [B53], which is specific to instrumentation applications, and ICEA S-73-532-1990 [B52], which is specific to 600 V cables. Such cable is designed for non-power-limited applications but may also be used in power-limited circuits. Conductors can range in size from #18 AWG to 506.7 mm^2 (1000 kcmil). See 3.3.1 and Figure 5 for typical construction and applications.

12.1.3.4 Thermocouple extension cable, Types PLTC, ITC, and TC

Thermocouple extension cable conductors are composed of alloys that, when joined to dissimilar alloys found in the thermocouple, create a naturally occurring current. When the junction is subjected to fluctuations in temperature, the current flow changes in distinct and measurable amounts. Thermocouple extension cables carry this current from a point outside the area of temperature measurement to the instrument panel where it is read and/or recorded by the operator. Detailed information regarding thermocouples including principles, applications, materials, and sources of error can be found in ASTM Book of Standards [B24], and ISA MC 96.1-1982 [B77].

12.1.4 Conductors

12.1.4.1 Instrument cable conductors

Conductors used in instrument cable are annealed-copper-insulated wire arranged in twisted pairs and triads. Conductors are available in sizes from #12 to #24 AWG; however, the most common are #16, #18, and #20 AWG. They may be either coated or uncoated copper in accordance with ASTM B 3-1995 [B25] (uncoated) or ASTM B 33-1995 [B27] (coated). The conductors are 7- or 19-wire, concentric stranded per ASTM B 8-1995 [B26] and ICEA S-82-552-1992 [B53]; however, solid conductors may be used. Stranded conductors allow for greater flexibility and ease of installation.

12.1.4.2 Thermocouple extension cable conductors

Conductors used in thermocouple extension cable are insulated metallic alloy arranged in twisted pairs that range in size from #14 to #20 AWG. The conductors are solid alloy wires, thermocouple extension grade, per ISA MC96.1-1982 [B77]. The most common cable alloys and ANSI color codes are shown in Table 18.

Table 18—Thermocouple extension cable alloys and colors

ANSI type	Positive conductor		Negative conductor		Overall
	Alloy	Color code	Alloy	Color code	Color
JX	Iron	White	Constantan	Red	Black
KX	Nickel/chromium	Yellow	Nickel/alumel	Red	Yellow
TX	Copper	Blue	Constantan	Red	Blue
EX	Nickel/chromium	Purple	Constantan	Red	Purple

12.1.5 Insulation

Common insulations along with operating temperature ranges and their respective properties are listed in Table 19. For insulation thicknesses, refer to Table 3-1 of ICEA S-82-552-1992 [B53].

NOTE—The temperatures shown are not applicable for installation.

Table 19—Properties of insulating materials used in instrument cable

Material	Temperature		Flexibility	Resistance to					Flame retardance
	Max. (°C)	Min. (°C)		Abrasion	Acid	Base	Solvent	Moisture	
PE	75	–62	Excellent	Good	Good	Good	Fair	Excellent	Poor
FR-EPR	105	–40	Excellent	Good	Good	Good	Fair	Excellent	Good
XLPE	90	–62	Excellent	Good	Good	Good	Fair	Excellent	Good
PVC	105	–10	Excellent	Good	Good	Good	Fair	Good	Good
Nylon	125	–54	Good	Excellent	Poor	Good	Good	Fair	Poor
Teflon-FEP	200	–166	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Silicone rubber	200	–73	Excellent	Fair	Poor	Good	Fair	Fair	Good
Aramid fiber	250	–73	Good	Excellent	Excellent	Excellent	Excellent	Poor	Excellent
Glass	450	–73	Good	Poor	Excellent	Excellent	Excellent	Poor	Excellent

12.1.6 Shielding

Shielding is used to reduce electrical and magnetic noise picked up by instrument and control circuits either between conductors or groups of conductors within a cable (individual pair/triad shields) or from outside interference (overall shield). In instrumentation and thermocouple extension cable, the most common shielding material is aluminum foil tape bonded to a polymer film in continuous contact with a stranded tinned copper drain wire. This shielding system, when applied with 25% overlap, provides for 100% shield coverage, and the drain wire allows for easy connection to a grounding terminal.

12.1.6.1 Unshielded instrument pairs and triads

May be used in metallic conduit or where no interference either from within or outside the cable is anticipated.

12.1.6.2 Overall foil shield

Provides protection against electrostatic noise from external sources. For use where signals are transmitted in excess of 100 mV except in areas where high voltage and current sources create excessive noise interference.

12.1.6.3 Individually shielded with overall foil shield

For use where optimum protection from noise interference caused by either cross talk or common mode noise from adjacent pairs or triads as well as from outside interference is desired.

12.1.6.4 Overall all-purpose shield

A relatively thick metallic shield (0.125 mm or 0.005 in copper or 0.2 mm or 0.008 in aluminum) is used when protection is required from surges induced by lightning or electrical faults. This shield provides electromagnetic protection and should be grounded at both ends. It also provides a high level of electrostatic protection. A metal/plastic laminate, bonded to the jacket, is often used for this purpose (see Clause 9).

Four types of noise that may interfere with signal integrity, and the shielding most often used for each, include:

a) *Electrostatic.* Aluminum/polymer tape shielding of individual pairs and/or the overall cable core protects against electrostatic interference.

b) *Electromagnetic.* The twisting of pairs inherently resists electromagnetic interference. Other excellent shields against electromagnetic interference are galvanized steel metal armor, metal conduit or overall shields with tapes of copper, aluminum, or steel.

c) *Common mode.* Aluminum/polymer tape shielding of individual pairs and the overall cable core. A particular problem in thermocouple circuits.

d) *Cross talk.* Staggered lay of pairs or triads for unshielded pairs or triads. Aluminum/polymer tape shielding also prevents cross talk.

12.1.7 Communication wire

A stranded or solid copper, orange-insulated communication wire offers a means to perform circuit checks during installation and maintenance.

12.1.8 Jackets

Comparative properties of jackets commonly used for instrument cables are listed in Table 15. Refer to 4.2.1 of ICEA S-82-552-1992 [B53] for jacket thicknesses.

12.1.9 Metallic coverings

Metallic coverings may be used for protection or shielding purposes. Overall outer jackets may be applied over metallic coverings to give corrosion protection or extra protection against environmental attack. Metallic coverings recognized by ICEA S-82-552-1992 [B53] are

a) Interlocked metal-tape armor. Galvanized steel and aluminum are the most commonly used. Galvanized steel is especially efficient in electromagnetic shielding.

b) Galvanized steel wire armor.

c) Flat metal tape armor.

d) Continuously corrugated metal armor.

See Clause 10 for further information on armors.

12.1.10 Applications of Class 2, Class 3, and PLTC cables

a) *Plenum.* Article 725-61(a) of the NEC. Cables installed in ducts, plenums, and other spaces used for environmental air shall be type CL2P or CL3P.

b) *Riser.* Article 725-61(b) of the NEC. Cables installed in vertical runs shall be CL2R or CL3R.

c) *Cable trays.* Articles 725-61(c) and 727 of the NEC.

    1) Cables installed in cable trays shall be type PLTC or ITC.

    2) Class 2 and Class 3 circuits cannot be placed in cable trays with Class 1 cables.

    3) Class 2 and Class 3 circuits if placed in cable trays must be separated by 2 in and have a barrier. See exception.

d) *Hazardous locations.* Article 725-61(d) of the NEC. Also see 12.5. Cables installed in classified locations shall be type PLTC or ITC in accordance with Articles 501-4, 502-4, and 504-20 of the NEC.

e) *Other wiring within buildings.* Article 725.

f) *In locations other than the above.* Use CL2 or CL3 cables.

12.1.11 Application considerations

Consider the following environmental factors when specifying cable components:

a) Temperature
   1) During normal operating conditions
   2) Potential heating under emergency conditions
   3) Ambient temperature
b) Presence of moisture and or chemicals
   1) Concentration
   2) Temperature
   3) Length of time of exposure
c) Potential mechanical/physical abuse
d) Flexing during normal use
e) Required degree of flame resistance
f) Critical circuit—is circuit integrity during fire conditions required?
g) Susceptibility to and/or emission of electromagnetic and electrostatic interference. Installation considerations:
   1) In trays
   2) In conduit
   3) Direct buried
   4) In proximity to possible signal interfering factors such as high-voltage lines

Refer to Clause 4 for further application guidelines.

12.2 Fiber-optic cables

Fiber-optic cables have been developed in recent years and have gained rapid acceptance. Now such cables are in demand as a necessity for high-speed communication and data transmission. Fiber-optic cables have properties that are very different, and superior in many respects, when compared to metallic conductor cables.

12.2.1 Construction

To fully understand fiber-optic cable construction it is necessary to understand the behavior of light in a medium, in this case glass. Fiber-optic construction consists of a central transparent core region. Surrounding the core is a cladding layer. It is because the fiber core has a higher refractive index than the surrounding cladding that allows light [usually generated by a laser diode or light -emitting diode (LED)] to be reflected down the fiber cable.

The core and the surrounding cladding are usually made of pure silica glass. There are other materials that can be adapted to fiber-optic usage, but they are not as good as the all-glass fiber. After manufacture of the core and cladding a primary coating is applied to give the hair-thin fiber-optic cable added strength to endure the cabling process and installation handling. Surrounding the primary cladding is a buffer tube. This buffer tube is designed to provide mechanical protection and isolation. There are two types of buffer tubes: tight and loose buffers.

Tight buffer tubes are characterized by a thick coating that is applied directly to the fiber. This coating provides excellent protection. There are several types of loose buffer tubes. The most common type has the fiber in a tube whose diameter is considerably larger than that of the fiber. This allows the fiber to move freely. To sheath the fiber cable, strength members are added and covered by the overall jacket. The tight buffer tube design is used only indoors and is generally rated for an ambient temperature no lower than –20 ˚C. Loose buffer tube design is primarily for outdoors use, with the cable rated for ambient down to –40 ˚C. It can also be used for intrabuilding applications. Because of their inherent delicate nature, fiber cables should be treated with respect before and during installation. There are special tools to perform all handling functions, so correct installation is not a problem.

12.2.2 Core/cladding design

There are three types of core/cladding design used to carry light through the fiber. They are

a) *Multimode step index.* Normally utilizes a fiber about 50 µm in diameter. Light passing down this cable can be directed to travel down the center or be directed to travel a path that requires the light ray to be reflected from side to side. The different path lengths result in different arrival times at the cable end. This difference in arrival times is called *modal dispersion.* This is an undesirable characteristic and means that this type of cable has limited use.

b) *Single-mode step index.* To improve fiber cables from the multimode step-index design, the diameter of the fiber is reduced to 8–10 µm. At this diameter the only light rays to pass through the fiber are those that pass along the cable axis. So light rays start and end virtually at the same time. Therefore, modal dispersion is all but eliminated.

c) *Multimode graded index.* To find a happy medium, a system has been developed that uses several cladding layers, each of which has a continuously decreasing refractive index relative to the core. Now, the light ray paths that are longer travel faster than those rays that pass down the cable axis. This results in the light rays arriving at the end nearly at the same time and with limited modal dispersion.

12.2.3 Terminations

Cable terminations are always points of concern and care. Fiber-optic cables are no exception. The only difference is that fiber optic cables contain very small fibers that demand special care and attention. Fiber-optic cables also require connectors and splices. The connector is designed to terminate the cable and is usually a removable type of connection. The splice is a permanent connection of two fibers. It is possible to connect two connectors in such a way that it becomes a nonpermanent splice. The difference in splices lies in the fact that in a permanent splice the fiber ends touch and in a nonpermanent splice they do not.

To terminate a fiber the end must be flat with no optical flaws. This quality of fiber end is usually achieved by placing the fiber in a polishing plate or jig which holds the fiber in place as it is rubbed over a set of progressively finer abrasive sheets until the fiber end is buffed to a mirrorlike finish. To determine if the fiber end has reached the desired finish, a microscope with 200X magnification provides a quick and easy method to make a head-on inspection of the fiber. To achieve the desired quality of termination, this inspection is necessary. The fiber end must have no flaws. Any flaw will act like a diffuser in a light fixture, thus causing light to scatter.

12.3 Coaxial cables

Coaxial cables consist of a conductor centered inside a metallic tube or shield separated by a dielectric. The inner conductor is typically referred to as the conductor or center conductor. The outer conductor is typically referred to as the shield. Coaxial cables typically have a jacket over the shield. Coaxial cables are normally used for closed-circuit TV systems, computer network cables, security systems, etc.

The center conductor is typically copper and may be solid or stranded. The copper conductor can be bare, tinned or silver coated. The conductor can also be copper-clad aluminum or copper-clad steel. The conductor is typically #18–22 AWG, but can be as large as #11 AWG or as small as #30 AWG.

The dielectric is typically made from polyethylene or teflon. It may be either a solid or foam dielectric.

The shield is usually either a woven metallic braid or wrapped foil shield. Woven braided shields are normally bare or tinned copper. Sometimes, aluminum- or silver-coated copper is used. Foil shields are often aluminized mylar. For more effective shielding, combinations of a braid shield over a foil shield or a braid shield over a braid shield are used. Some trunk or broadband network coaxial cables have solid shields. The solid shields are typically smooth aluminum, but may be copper and may be corrugated.

There are a number of available jacket materials. PVC is probably the most common, but polyethylene, CPE, fluoropolymers, and others are available. Refer to Clause 8 for further information on jacketing materials.

The nominal impedance of coaxial cables can vary from 35 Ω to185 Ω, but 50 Ω, 75 Ω, and 95 Ω cables are the most common.

12.4 Voice and data cables

12.4.1 Premise cables

Premise telephone and data cables are generally supplied with 2, 3, or 4 conductor pairs for runs to individual telephones or with 25, 50, 100, or 200 pairs for distribution purposes. Cable construction generally includes twisted pair, #22 or #24 AWG solid, bare copper conductors; color-coded, polyethylene insulation; and a PVC jacket. For plenum use, fluoropolymer materials are utilized to minimize fire risk.

12.4.2 Outside plant cables

Outside plant cables are generally installed aerially, in ducts or direct buried, and provide the means for connecting central office switching facilities to buildings and plant facilities throughout the complex. Such cables are often referred to as exchange cables. Frequently, they are furnished and installed by local telephone companies. There are many types such as air core; filled core; self support; and (aluminum, steel, polyethylene (ASP)) sheath. Presently, it is beyond the scope of this guide to provide details of the many constructions available and their application.

12.4.3 Intercom and audio cables

Intercom and audio cables are available in several constructions. The typical types are one or two pairs, one through eight individual conductors, and some combination of pairs and individual conductors. Some of the individual conductor cables may have different-size conductors within the same cable.

The conductors are typically tinned copper, but in some cases are bare copper. Conductors are generally stranded, but are sometimes solid. They are commonly #18 AWG, #22 AWG, and #25 AWG.

The most common insulation is PVC. Polyethylene and polypropylene are occasionally used for insulation. The insulation is available with voltage ratings from 90 to 400 V. The most common is 300 V insulation.

These cables are available with or without a shield. When a shield is present, it is typically aluminum polyester.

The jacket is most often PVC for normal cable construction, but other materials are available where increased fire retardancy is a factor (see Clause 8).

12.4.4 Special considerations

Most types of voice and data cables are available with plenum ratings for installation inside ducts, plenums, and other air-handling spaces. For specific requirements refer to the NEC articles on wiring methods for such spaces.

12.5 Cables for hazardous areas

12.5.1 General

In the petroleum and chemical industries, hazardous materials are predominantly flammable or combustible gases, vapors, and liquids. Hence, any reference to hazardous locations in this clause will be limited to Class I, Division 1 and Division 2; and Class I, Zone 0, Zone 1, and Zone 2 per NEC and CEC. (Refer to 4.4.1 and the NEC for further information on hazardous areas.)

The acceptability of cables in hazardous areas depends not only on the type of cable (see 12.5.2), but also on the type of circuit they support (see 12.5.3) and the type of installation method employed (see 12.5.4). Each of these types is discussed in their respective clauses.

12.5.2 Types of cables

In hazardous areas, the main underlying goal of electrical installations is to reduce the risk of explosion or fire. A way to accomplish this in cable installations is to use cables with a gas/vaportight continuous sheath, coupled with suitable termination seals, or a core design that blocks the passage of flammable or combustible gases, vapors, and liquids through the cable core. (Another way is to eliminate the ignition source and this is covered in 12.5.3.) However, most cables are not designed to prevent flammable or combustible gases, vapors, or liquids from traveling through cable fillers and between conductors from a hazardous location to a nonhazardous location. Sealing requirements differ depending upon the type of cable selected. Refer to NEC Article 501-4 for further information on cable constructions and installation methods suitable for such applications in both Class I, Division 1 and Class I, Division 2 hazardous areas. Also refer to Article 501-5 for further information on sealing requirements for specific cable constructions.

12.5.2.1 Mineral-insulated cables

Mineral-insulated, metal-sheathed, Type MI, cable is a factory assembly of one or more conductors insulated with highly compacted mineral insulation and enclosed in a seamless, liquid and gastight continuous copper or alloy steel sheath. MI cable, because of its construction, has an inherent ability to block gases, vapors, and liquids. It is approved for installation in Class I, Division 1 and Division 2, and Zone 1 and Zone 2 hazardous areas without the use of conduit and conduit seal. An approved fitting for terminating the cable ends is a requirement for installation in a hazardous area.

MI cable is hygroscopic and moisture can be a problem when the ends are left exposed during installation. Sealing the end fittings as soon as possible is imperative in preventing the accumulation of moisture.

12.5.2.2 Metal-clad cables

The metal-clad (MC) cable is a factory assembly of one or more insulated circuit conductors enclosed in a metallic sheath of interlocking tape, or a smooth or corrugated tube, with or without an overall jacket of suitable polymeric material and separate grounding conductors. Conventional Type MC cable is permitted in Class I, Division 2 and Zone 2 hazardous areas. Type MC-HL (hazardous location) is permitted in Class I, Division 1 and Zone 1 applications in industrial establishments with restricted public access where the condition of maintenance and supervision ensure that only qualified persons should service the installation. The cable must be listed for use in such hazardous locations and terminated with approved cable fittings.

Refer to 3.3.1 and Figure 8, for additional information on MC cable. Other cable constructions that employ a continuous corrugated metal sheath with an overall jacket, such as Type ITC, can be used in Class I, Division 1, and Zone 1 installations when specifically approved for such use. For example, in the U.S., such cables must be Listed as Type MC-HL in accordance with UL 2225-1996 [B95].

12.5.2.3 Other cables

Unlike Type MI mineral-insulated cable, other types of cables do not block the passage of flammable or combustible gases, vapors, or liquids. (Refer to Clause 3 for the various types and constructions of cables.) Therefore, conduits and seals, to meet NEC requirements, must be used on cables to prevent passage of such gases, vapors, and liquids. Cables must be installed in an approved wireway and must be sealed with an approved sealing method when used in hazardous locations. (Refer to 12.5.4 for installation methods used in the hazardous areas.)

12.5.3 Types of circuits

Sometimes, it is the type of circuit a cable supports that determines whether a cable is suitable for installation in the hazardous areas. Two basic types of circuits exist: a circuit type that has enough energy to ignite flammable or explosive gas or vapor mixture during faulted conditions and a circuit type that does not have enough energy to ignite hazardous gas or vapor mixture during faulted conditions. Circuit types that do not have enough energy to ignite are called intrinsically safe and nonincendive circuits.

12.5.3.1 Intrinsically safe circuits

The ***i**ntrinsically safe circuit* is defined by the NEC as a circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air. An intrinsically safe circuit is incapable of starting a fire or an explosion during normal operating conditions and by means of diverting excess energy to the system ground through energy-limiting devices (so-called intrinsically safe barriers) during abnormal operating conditions. Since the available energy during a faulted condition is not sufficient to ignite a flammable or combustible gas or vapor mixture, any cable used for intrinsically safe circuit is suitable for installation in Class I, Division 1 and Division 2, and Zone 0, Zone 1, and Zone 2 hazardous locations employing simply the nonhazardous location installation methods. Intrinsically safe circuits are the only type that is allowed in Zone 0 hazardous areas. Conduit seals and cable seals should be used on cables supporting the intrinsically safe circuits to block passage of flammable or combustible gas, vapor, and liquid.

12.5.3.2 Nonincendive circuits

The *nonincendive circuit* is defined by the NEC as a circuit in which any arc or thermal effect produced, under intended operating conditions of the equipment or due to opening, shorting, or grounding of field wiring, cannot ignite the flammable gas or vapor mixture. A nonincendive circuit is incapable of starting a fire or an explosion during normal or abnormal conditions. Thus, a cable supporting such circuits is approved for installation in Class I, Division 2, and Zone 2 hazardous locations. Similar to the cables supporting the intrinsically safe circuits, conduit seals and cable seals should be used on cables supporting the nonincendive circuits to block passage of flammable or combustible gas, vapor, and liquid.

12.5.4 Types of cable installation methods

When the type of cable (as contained in 12.5.2) or the type of circuit it supports (as described in 12.5.3) does not qualify for installation in a hazardous area, other means of reducing the risk of starting a fire or an explosion are used. Typically, if the cables are not suitable for installation in hazardous areas, they must be installed in conduit and properly sealed with approved fittings.

Some cable types, however, are approved for installation in Class I, Division 2, and Zone 2 hazardous areas without conduit when an approved cable termination fitting is used on each end of the cable. These types include medium-voltage (Type MV), metal-clad (Type MC), power and control tray cable (Type TC), power-limited tray cable (Type PLTC), and instrument tray cable (Type ITC). Refer to Articles 501 through 505 of the NEC and Section 18 of the CEC for further information.

12.6 Cablebus

The most common busway used in the petrochemical industry is nonsegregated-phase, metal-enclosed bus, commonly called *bus duct*. This bus duct is normally utilized for connection between transformers and switchgear and interconnection of switchgear to other switchgear and other motor control centers. However, when the bus duct runs are long and the currents high, the costs and installation of the bus duct including supports has proved to be expensive compared to other cable installation methods.

As defined by the NEC, cablebus is an approved assembly of insulated conductors with fittings and conductor terminations in a completely enclosed, ventilated, protective metal housing. The assembly is designed to carry fault current and to withstand the magnetic forces of such currents.

A cablebus is different from metal-enclosed bus in several important ways. Cablebus is more of a hybrid between cable tray and busway. It uses insulated conductors in an enclosure that is similar to cable tray with covers. Cablebus is normally furnished as components for field assembly, but can be furnished as factory-assembled sections. The use of factory-assembled sections is recommended when the run is short enough so that splices may be avoided.

The conductors are normally spaced at least one cable diameter apart so that the cable ampacity rating in free air may be maintained. This spacing is also close enough to provide low reactance, resulting in minimum voltage drop. The conductors are standard single-conductor insulated power cables. The normal insulating material is either XLPE or EPR. The most common jacketing materials are PVC, CSPE, and CPE. The power conductors are individually supported by factory-installed nonmetallic support blocks at required intervals [typically 900 mm (36 in) horizontal and 450 mm (18 in) vertical spacing] inside the structural enclosure. Cablebus is generally not subject to expansion or contraction problems. The enclosure is normally manufactured from aluminum or steel and resembles a cable tray with ventilated bottom and top covers as seen in Figure 20.

Figure 20—Cablebus section view

There are normally parallel conductors (more than one per phase) spaced about 76.2 mm (3 in) apart. This spacing allows for minimum current unbalance in the conductors and also permits ampacity calculation based on the free-air rating of the conductors. The correct phasing arrangement of the parallel conductors should be verified by computer-generated inductive and reactance analysis calculations by the manufacturer. The manufacturers of the cablebus systems provide test data on the current carrying capacity of the various conductor configurations. The current-carrying capacity of cablebus is generally higher than that of an equivalent size cable tray installation with unspaced multiple conductors.

In addition to the other technical requirements, the cablebus system should be designed to withstand the available short-circuit current. The user specification for cablebus should provide the manufacturer the maximum available short circuit current, so that the supplied system can withstand such mechanical forces. This is not normally a problem. Another issue not to be overlooked is grounding. The cablebus enclosure must be grounded according to the requirements of the NEC.

In conclusion, cablebus is a safe and reliable system used for transmitting large amounts of power over relatively short distances. It is a more economical replacement for conduit or busway systems but normally more expensive than cable tray. It is suitable for either indoor or outdoor use. It is normally provided as a complete system including all necessary fittings, enclosure connectors, entrance/termination fittings, electrical connectors, terminating kits, and other accessories as required.

13. Cable Installation

13.1 Types of installations

There are various considerations in installing electrical cables. Cables installed underground may be direct buried or pulled into underground conduit. Cables above ground may be installed in conduit, cable tray or on an aerial messenger wire. For details on types of installations, refer to IEEE Std 576-1989 [B69].

13.2 Installation overview

Whichever method of installation is chosen, consideration should be given to pulling tension, minimum bending radius, and sidewall pressure.

13.2.1 Pulling tension

Using a pulling eye attached to a copper conductor, the maximum pulling tension divided by the area of the conductor should not exceed 70 N/mm^2 (0.008 lbf/cmil). When a pulling eye is attached to an aluminum conductor, the maximum tension divided by area should not exceed 52 N/mm^2 (0.006 lbf/cmil). The maximum tension for a single conductor should not exceed 22 kN (5000 lbf), and for multiconductor cables, should not exceed 44 kN (10 000 lbf). When using pulling grips on an outer sheath, the maximum pulling tension should not exceed 4.4 kN (1000 lbf).

13.2.2 Bending radius

There are minimum values for bending radius for training of cables during installation. These limits do not apply to cable under tension around conduit bends, sheaves, or other curved surfaces during installation. Larger-radius bends may be required for such conditions. It should be noted, however, that the utility industry makes use of bending radius standards that are less conservative than those minimum values that follow. If in doubt, consult with the cable manufacturer.

13.2.2.1 Nonshielded cables

Minimum bending radii are 4 to 8 times cable diameter depending upon insulation thickness and cable diameter.

13.2.2.2 Shielded cables

Minimum bending radius is 12 times cable diameter for single conductor or 7 times overall diameter on multiconductor cables.

13.2.2.3 Metallic sheath cables

Minimum bending radius is 7 to 15 times the cable diameter, depending upon metal armor construction.

13.2.3 Sidewall pressure

Sidewall pressure is the force exerted on the insulation and sheath of the cable at a bend point when the cable is under tension. Sidewall pressure is the ratio of the tension out of a bend divided by the radius of the bend. This pressure should be kept as low as possible to prevent damage when a cable is pulled around a bend under tension. Maximum sidewall pressure is 446–744 kg/m (300–500 lb/ft) of bend radius. Specific sidewall pressure limitations are dependent upon cable construction.

13.3 Conduit installation

For groups or combinations of cables, it is recommended that the conduit be properly sized so that individual cables will not exceed the recommended percent fill. Maximum conduit fill for various cables ranges from 31 to 53% of internal area of the conduit. The total cross-sectional area of the cable divided by the cross-sectioned area of the conduit is the percent fill. Proper conduit sizing can also prevent jamming when three cables lay side by side in a flat plane. Cable can become wedged during pulling and damage can occur. The ratio between the conduit inside diameter and a single conductor overall diameter is the jam ratio. The critical range to be avoided is 2.8–3.0. Installation of cable in conduit should be in accordance with appropriate articles of the NEC.

13.4 Direct burial installation

Installation practices should be considered in installing direct burial cable. Trenching, laying of cable, and backfill material are important to prevent damage to cable. Cable and installation should comply with Articles 300, 310, and 710 of the NEC.

13.5 Cable tray installation

Consideration should be given to length of runs and number and size of bends. Proper sheaves and rollers are necessary during installation to prevent excess tensions and cable damage. Cable tray installation should be in accordance with Article 318 of the NEC.

13.6 Aerial installation

Aerial cable consists of cable bound to and supported by a messenger. The type and size of messenger vary according to length of spans, weight of cable, and weather conditions. Proper sheaves and rollers are necessary during installation to prevent excess tensions and cable damage. Aerial installation should be in accordance with Article 321 of the NEC.

13.7 Splicing, terminating, and grounding

13.7.1 Splicing

These general guidelines are offered for splicing cables. However, because of the variety of cables and methods of splicing, they are not intended as a detailed set of instructions. Most manufacturers have instructions for specific cable constructions and the type of splice being used, and these instructions are to be followed. There are many different splices available, such as premolded rubber, heat shrink, cold shrink, resin and tape. This clause will describe these different splices. For additional installation details concerning the different types of splices, refer to IEEE Std 576-1989 [B69]. It is recommended that whichever method of splicing is chosen, it meet the requirements of IEEE Std 404-1993 [B63].

The objective is to make a joint in a power cable that is electrically equivalent to the cable. Splices essentially rebuild the cable, where it has to be cut. Splices consist of a connector, which connects the conductors and carries current, a conductive electrode or stress grading material, around the connector, insulation, and insulation shield. The cable should be prepared according to the manufacturers instructions before any accessory is installed.

In selecting a splice, the type of environment it will be installed in should be considered, as well as the environmental seal and the compatibility of the rejacketing material to the environment. The following is a brief description of each of the different types of splices.

13.7.1.1 Premolded rubber splices

These splices are normally used on shielded cable and typically consist of a one-piece molded body that has an electrode, insulation, and insulation shield all molded into the one body. The electrode typically covers the connector and extends onto the cable insulation. Since the electrode is semiconductive and touches the connector, a Faraday cage is created under the electrode where everything is at the same potential and there is no electrical stress. This serves the same purpose as the strand shielding on the cable. The insulation is next and insulates the high voltage from ground, just as the cable insulation does. The semiconductive insulation shield is on the outside of the insulation and typically comes in contact with the cable insulation shield and extends it over the splice. The cable metallic shield must be extended over the splice externally and be in contact with the insulation shield of the splice to insure that it is at ground potential. These splices are 100% factory tested before being sold to meet the requirements of IEEE Std 404-1993 [B63]. These splices are usually slid into place over the prepared cable using silicone grease to lubricate the cable and to fill in the semiconductive step of the cable.

13.7.1.2 Heat shrink splices

These splices can be used on shielded or nonshielded cable and typically consist of a stress-control mastic that is applied over the connector and onto the cable insulation. A stress-control tube is then shrunk over the mastic and onto the cable. Sealing mastic is then applied at the end of the stress control tube and an insulating tube is shrunk over the stress-control tube and the sealing mastic. Again, the cable metallic shield must be extended over the splice and be in contact with the insulation shield on the outside of the insulating tube, if a shielded cable is being spliced. This insures the splice shield is at ground potential. These splices are positioned over the prepared cable and then shrunk with heat.

13.7.1.3 Cold shrink splices

These splices can be used on both shielded and nonshielded cable. For shielded cable, they are typically molded with an electrode, insulation and an insulation shield, just like premolded rubber splices. These splices functionally rebuild the cable just like a molded rubber splice. They are also 100% factory tested.They are stretched and loaded on a removal core. The splice is positioned over the prepared cable, the core is removed and the splice shrinks into place. The cable metallic shield must be extended over the splice, and in contact with the splice insulation shield.

13.7.1.4 Tape splices

Tape splices can be used on shielded or nonshielded cable and again rebuild the cable components. These splices are very flexible, but require a much higher skill level than the other splices discussed. The tape must be stretched and applied in half-lapped layers. An electrode is made by applying semiconductive tape over the connector and onto the cable insulation. The insulation is made with rubber insulating tape, and the insulation shield with semiconducting tape. Again, the cable metallic shield must be extended over the splice.

13.7.1.5 Resin splices

These splices are typically used on nonshielded cable up to 5000 V. Normally a mold is placed over the prepared cable and the mold is filled with resin. The cable jacket should be roughed up with sand paper so the resin will adhere to it.

13.7.1.6 Miscellaneous

Most splices offer a rejacketing method of some kind for environmental and physical protection of the splice. Especially with jacketed cable, it is recommended that rejacketing be applied to the splice. Paper-insulated lead-covered (PILC) cable requires special treatment, and can be handled in one of two ways:

a) The splice can be taped with an oil-impregnated tape or an oil-compatible insulating tape and covered with a lead sleeve that is soldered onto the lead jacket of the cable on each end. The lead sleeve is then filled with either oil or a hot compound.

b) An oil stop can be applied to the lead cable to contain the oil and keep moisture out, over which a standard accessory is then applied.

13.7.2 Terminating

Cable terminations are required when connecting insulated shielded power cables to uninsulated conductors such as a busbar or uninsulated overhead lines. When a shielded power cable is ended or terminated, and the outer cable shield is stopped on the cable insulation, there is a very high concentration of electrical stress at this point. These terminations contain a method of controlling this high stress (stress cone or stress grading material), an outer nontracking surface, and a means of providing an environmental seal to prevent moisture ingress. There are many different types of terminations available, such as premolded rubber, porcelain, heat shrink, cold shrink, and tape. It is recommended that whichever method of terminating is chosen, it meet the requirements of IEEE Std 48-1996, Class I [B56].

For nonshielded cable, environmental sealing of the connector to the jacket is advantageous to keep out water, and an outer insulating track-resistant covering minimizes the possibility of a failure due to surface discharge.

For general installation guidelines on terminations, refer to IEEE Std 576-1989 [B69]. Most manufacturers have instructions for specific cable constructions and the type of termination being used, and these instructions are to be followed. The objective is to make a termination in a power cable that will last as long as the cable. In selecting a termination, the type of environment it will be installed in should be considered, as well as the environmental seal, the track resistance of the material, the UV resistance, and weatherability of the material. A brief description of each of the different types of terminations is given in 13.7.2.1, 13.7.2.2, 13.7.2.3, and 13.7.2.4.

13.7.2.1 Premolded rubber

These terminations are typically a molded, one-piece body that usually incorporates geometric stress control as part of the termination. They are usually slid into place over the prepared cable, using grease to lubricate the cable and to fill in the step of the semiconductive layer of the cable.

13.7.2.2 Heat shrink terminations

These typically consist of a stress-control mastic applied at the step of the semiconductive layer of the cable to control the electrical stress. Then an insulating/stress control tube is positioned and shrunk by heat over the mastic. Skirts are then positioned and shrunk by heat.

13.7.2.3 Cold shrink terminations

These typically consist of molded skirts and a high-dielectric stress-control tube loaded onto a removable core. Some have a high-dielectric stress-control mastic and sealing mastic built into the termination, while others have grease applied to the cable semiconductive step as a void filler. The termination is positioned over the prepared cable and shrunk by removing the core.

13.7.2.4 Tape terminations

These are typically made using a combination of hand-applied tapes, and are normally used indoors, since they have no skirts. The electrical stress control is accomplished with either a high-dielectric stress-control tape over the cable semiconducting layer or using rubber insulating tape and semiconducting tape to make a geometric stress cone. Silicone rubber tape is usually used on the outside of the termination for an environmental seal, track resistance, UV resistance, and weatherability.

13.7.3 Grounding

When an external ground is to be attached to the cable shield at a splice or termination, there are several things that should be considered. First, if possible, all of the ground connections that tie into the same cable should come from the same ground grid. This reduces the possibility of circulating ground currents in the cable shield.

Second, when an external ground is attached to the cable shield at a joint or a termination, care should be taken to keep water out of the accessory and the cable. Where the ground exits the accessory and the protective covering, mastic or some similar material must be used to keep moisture from running down the ground conductor into the accessory. If the ground leaving the accessory is not a solid strap or solid bare conductor, the ground must be solder-blocked either at the factory or in the field to prevent moisture ingress through the strands of the external ground.

Annex A

(informative)

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