

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

Approved 26 June 1999

IEEE-SA Standards Board

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

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Copyright © 1999 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 31 August 1999. Printed in the United States of America.
2nd Printing, January 31, 2012. Corrections made to Table 19 on page 61, and the 2nd paragraph on page 65.

Print: ISBN 0-7381-1757-9 SH94762
PDF: ISBN 0-7381-1758-7 SS94762

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

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 these industries, including such environmental effects as chemical atmospheres, hazardous areas, contamination, corrosion, and fire.

Participants

At the time this guide was completed, Working Group P1242 had the following membership:

Donald A. Voltz, *Chair*

Joseph H. Snow, *Vice Chair*

Roger E. Barras
Michael G. Bayer
Justo Benitez
Kenneth E. Bow
Robert R. Brown
Robert Bryce
Thomas G. Campbell
John Cancelosi
Eli Contreras
James M. Daly
Kevork G. Dekmezian
Robert Edwards

Douglas E. Effenberger
Rodney E. Ginger
Barbara Jensen
Lawrence J. Kelly
Robert Konnick
Sunita Kulkarni
Vincent C. Kwon
Carl C. Landinger
Mark T. Leyton
Mark E. Lowell
Wayne Madden
L. Bruce McClung
David C. Mercier

W. G. Morrison
C. R. (Dick) Porcaro
Franklin W. Roberts
Gary Savage
Robert Schoolcraft
Edward H. Shuler
Joseph P. Stees
H. R. Stewart
Bill Taylor
Jan Visser
Craig M. Wellman
William D. Wilkens

The following members of the balloting committee voted on this guide:

George P. Alexander
J. Kirk Armintor
Andrew Bagley
Frederick Bried
Robert R. Brown
Malcolm M. Cameron
William F. Casper
James M. Daly
John Davis
Frank DeWinter
Gary Donner
Richard L. Doughty
Marcus O. Durham
John B. Dwyer
Thomas E. Dye
Hal B. Dygert
Kimberly Eastwood
William F. Ecton
Richard Epperly

C. James Erickson
Eugene J. Fagan
H. Landis Floyd
Stephen W. Hagemoen
Paul S. Hamer
Frank P. Hogan
Richard H. Hulett
John Hus
Ben C. Johnson
John H. Kassebaum
P. Michael Kinney
William H. Levers
Wayne Madden
George Mahl
William E. McBride
Bill McCarty
Bob McDaniel
Ed F. Merrill
Paul W. Myers

Lorraine K. Padden
Tom P. Pearson
John E. Propst
Sam L. Ralston
Milton H. Ramsey
Quentin Reynolds
James F. Rozsits
Chet Sandberg
Scott W. Shannon
Tom Shaw
Paul J. Skobel
Andrew W. Smith
H. R. Stewart
Jay A. Stewart
Frank Stone
Donald A. Voltz
Barry M. Wood
Bob Zahn
Donald W. Zipse

When the IEEE-SA Standards Board approved this guide on 26 June 1999, it had the following membership:

Richard J. Holleman, *Chair*

Donald N. Heirman, *Vice Chair*

Judith Gorman, *Secretary*

Satish K. Aggarwal
Dennis Bodson
Mark D. Bowman
James T. Carlo
Gary R. Engmann
Harold E. Epstein
Jay Forster*
Ruben D. Garzon

James H. Gurney
Lowell G. Johnson
Robert J. Kennelly
E. G. “Al” Kiener
Joseph L. Koepfinger*
L. Bruce McClung
Daleep C. Mohla
Robert F. Munzner

Louis-François Pau
Ronald C. Petersen
Gerald H. Peterson
John B. Posey
Gary S. Robinson
Akio Tojo
Hans E. Weinrich
Donald W. Zipse

*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Robert E. Hebner

Yvette Ho Sang
IEEE Standards Project Editor

Contents

1.	Overview	1
1.1	Scope	1
1.2	Purpose	1
2.	References	2
3.	Typical constructions	2
3.1	General comments	2
3.2	Acronyms	2
3.3	Low-voltage cables	3
3.4	Medium-voltage cables	8
4.	Application guidelines	13
4.1	Types of installations	14
4.2	Electrical considerations	15
4.3	Mechanical and physical considerations	19
4.4	Environmental considerations	19
4.5	Other application considerations	22
5.	Conductors	23
5.1	Copper	23
5.2	Aluminum	23
5.3	Conductor stranding	23
5.4	Tinned or lead-alloy-coated copper	23
5.5	Filled strand conductors	23
6.	Insulation	24
6.1	Materials and thicknesses available	24
6.2	Performance requirements	29
6.3	Service history	35
7.	Shielding	37
7.1	Selection and application criteria	37
7.2	Semiconducting materials	39
7.3	Metallic shielding materials	40
7.4	Current-carrying capability	42
7.5	Induced shield voltage	43
8.	Cable jackets	45
8.1	General	45
8.2	Jacket thickness	45
8.3	Electrical properties	47
8.4	Physical properties	48
8.5	Thermoplastic vs. thermosetting jackets	49

8.6	Chemical and environmental properties	49
8.7	Fire and smoke considerations.....	49
8.8	Special considerations.....	50
9.	Moisture and chemical protection.....	50
9.1	General.....	50
9.2	Moisture/chemical resistance of jackets	51
9.3	Laminate sheaths as chemical/moisture barriers.....	51
9.4	Metallic sheaths	52
9.5	Water blocking.....	52
9.6	Gas blocking	53
10.	Metal armors	53
10.1	General.....	53
10.2	Applications for Type MC metallic armored cable	53
11.	Cable quality and testing considerations.....	54
11.1	Quality principles for wire and cable.....	54
11.2	Application of standards	55
11.3	Testing requirements and program	56
11.4	Interpretation of results	58
12.	Special-purpose cables.....	58
12.1	Instrument cable.....	58
12.2	Fiber-optic cables.....	63
12.3	Coaxial cables	64
12.4	Voice and data cables.....	65
12.5	Cables for hazardous areas.....	66
12.6	Cablebus.....	68
13.	Cable Installation	69
13.1	Types of installations	69
13.2	Installation overview.....	69
13.3	Conduit installation.....	70
13.4	Direct burial installation	70
13.5	Cable tray installation	70
13.6	Aerial installation.....	70
13.7	Splicing, terminating, and grounding.....	71
Annex A	(informative) Bibliography	74

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)

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

²IEEE 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/>).

³The 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 polyolefin (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-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: 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.

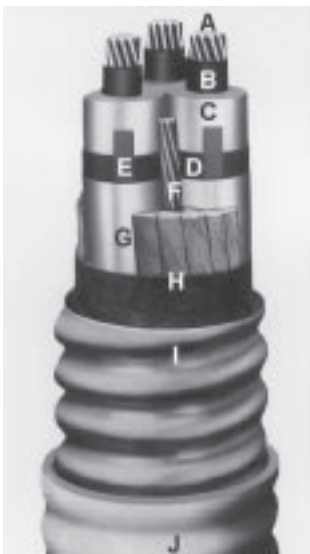


Figure 17—5-35 kV Type MV-90 or Type MC, 3/C, shielded, armored

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 141-1993⁴, 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.

⁴Information 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.

⁵The 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.

⁶Also 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.