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IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems

IEEE Industry Application Society

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IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems

Sponsor

Petroleum and Chemical Industry Committee
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IEEE Industry Application Society

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Abstract: Recommendations are provided for selection, application, and installation of electrical power, signal, control, data, and specialty marine cable systems on shipboard.

Keywords: cable application, cable installation, cable selection, cable systems, control cable, data cable, IEEE 45.8™, offshore drilling and production platforms, power cable, shipboard systems, signal cable, specialty marine cable

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Introduction

This introduction is not part of IEEE Std 45.8-2016, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems.

IEEE Std 45.8 is a member of the IEEE Std 45™ series of documents. Although intended to provide a consensus of recommended practices for cable systems on shipboard, this document may also be of benefit for information purposes in the proper selection and installation of wire and cable in commercial or military coastal vessels, or offshore drilling and production platforms. These cables include low-voltage cables, medium voltage cables, and specialty cables.

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1. Overview

IEEE Std 45.8 is a member of the IEEE Std 45™ series of documents. Although intended to provide a consensus of recommended practices for cable systems on shipboard, this document may also be of benefit for information purposes in the proper selection and installation of wire and cable in commercial or military coastal vessels, or offshore drilling and production platforms. These cables include low-voltage cables, medium voltage cables, and specialty cables.

1.1 Scope

The scope of this document is to provide recommendations for selection, application, and installation of electrical power, signal, control, data, and specialty marine cable systems on shipboard. These recommendations include the present day technologies, engineering methods, and engineering practices.

1.2 Purpose

IEEE Std 45.8 is intended to provide a consensus of recommended practices for the selection, application, and installation of electrical power, signal, control, data, and specialty marine cable systems on shipboard.

1.3 Application of various national and international standards

It is recognized that various national and international standards for equipment and installations are not identical. However, it is recognized that mixing of standards is occasionally necessary. Therefore, the application of any of these standards is the choice of the user, authority having jurisdiction, and classification society.

1.4 Equipment construction, testing, and certification

Electrical apparatus and equipment should be constructed and tested in accordance with the requirements of appropriate national and international equipment standards. Standards specifically addressing marine requirements should be used whenever applicable. Many appropriate standards are referenced in this document. All electrical equipment should be tested and certified, with labeling and follow-up services (i.e., listed) by a recognized independent laboratory acceptable to the authority having jurisdiction.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/NEMA WC-58-2008/ICEA S-75-381, Portable and Power Feeder Cables for Use in Mines and Similar Applications.[1]

API RP 14F Ed. 5 (2008/2013), Design and Installation of Electrical Systems for Fixed and Floating Offshore API Petroleum Facilities for Unclassified and Class I, Division 1 and Division 2 Locations.[2]

API RP 14FZ Ed. 2 (2013), Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Zone 0, Zone 1, Zone 2 Locations.

ASTM B3-13, Standard Specification for Soft or Annealed Copper Wire.[3]

ASTM B355-11, Standard Specification for Nickel Coated Soft or Annealed Copper Wire.

EN 50288-7:2005, Multi-element Metallic Cables Used in Analog and Digital Communication and Control. Sectional Specification for Instrumentation and Control Cables.[4]

CSA C22.2 No 239-09 (R2014), Control and Instrumentation Cables.[5]

CSA C22.2 No. 245-95 (R2014), Marine Shipboard Cable.

[1]ANSI/NEMA publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).
[2]API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC
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[4]EN publications are available from Thomson Reuters, http://www.techstreet.com
[5]CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3 (http://www.csa.ca/).

ICEA P-32-382, Ed. 7, Short Circuit Characteristics of Insulated Cables.[6]

ICEA P-45-482, Ed. 13, Short Circuit Performance of Metallic Shields and Sheaths on Insulated Cables.

IEC 60079-11 Ed. 6.0, Explosive atmospheres—Part 11: Equipment protection by intrinsic safety "i".[7]

IEC 60079-14 Ed. 5.0, Explosive atmospheres—Part 14: Electrical installations design, selection and erection.

IEC 60079-28 Ed. 1.0, Explosive atmospheres—Part 28: Protection of equipment and transmission systems using optical radiation.

IEC 60331-11 Ed. 1.1, Tests for electric cables under fire conditions—Circuit integrity—Part 11: Apparatus—Fire alone at a flame temperature of at least 750 °C.

IEC 60331-21 Ed. 1.0, Tests for electric cables under fire conditions—Circuit integrity—Part 21: Procedures and requirements—Cables of rated voltage up to and including 0.6/1.0 kV.

IEC 60331-23 Ed. 1.0, Tests for electric cables under fire conditions—Circuit integrity—Part 23: Procedures and requirements—Electric data cables.

IEC 60331-25 Ed. 1.0, Tests for electric cables under fire conditions—Circuit integrity—Part 25: Procedures and requirements—Optical Fibre cables.

IEC 60794-2 Ed. 3.0, Optical Fibre Cables—Part 2: Indoor Cables—Sectional Specifications.

IEC 60966-1 Ed. 2.0, Radio frequency and coaxial cable assemblies—Part 1: Generic specification—General requirements and test methods.

IEC 61914, Cable cleats for electrical installations.

IEEE Std 45.7™-2012, IEEE Recommended Practice for Electrical Installations on Shipboard—AC Switchboards.[8, 9]

IEEE Std 48™-2009, IEEE Standard for Test Procedures and Requirements for Alternating-Current Cable Terminations Used on Shielded Cable Having Laminated Insulation Rated 2.5 kV through 765 kV or Extruded Insulation Rated 2.5 kV through 500 kV.

IEEE Std 515™-2011, IEEE Recommended Practice for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications.

IEEE Std 1202™-2006, IEEE Standard for Flame-Propagation Testing of Wire & Cable.

IEEE Std 1580™-2010, IEEE Recommended Practice for Marine Cable for Use on Shipboard and Fixed or Floating Platforms.

IEEE Std 1717™ -2012, IEEE Standard for Testing Circuit Integrity Cables Using a Hydrocarbon Pool Fire Test Protocol.

[6]ICEA publications are available from the IHS Standards Store, https://global.ihs.com/

[7]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/).

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Foundation™ Specification—H1 Cable Test Specification FF-844" Rev. FS.12- Jan. 6, 2011.

MIL-DTL-17H, Military Specification: General Specification for Cables, Radio Frequency, Flexible and Semirigid.[10]

MIL-DTL-915G, Detail Specification: General Specification for Cable, Electrical, For Shipboard Use.

MIL-DTL-24640C, Detail Specification: General Specification for Cables, Light-Weight, Electric, For Shipboard Use.

MIL-DTL-24643C, Detail Specification: General Specification for Cables, Electric, Low Smoke Halogen-Free For Shipboard Use.

MIL-HDBK-299, Military Handbook: Cable Comparison Handbook Data Pertaining To Electrical Shipboard Cable.

MIL-PRF-85045G, Performance Specification: Fiber Optic, General Specification For.

NFPA 70, National Electrical Code® (NEC®).

UL 13, Ed. 3, July 23, 2007 Standard for Safety for Power-Limited Circuit Cables.[11]

UL 44, Ed. 18, February 9, 2014, Standard for Safety for Thermoset-Insulated Cables.

UL 60079-11 Ed. 6.0, Explosive atmospheres—Part 11: Equipment protection by intrinsic safety "i" .

UL 62, Ed. 19, March 14, 2014, Standard for Safety for Flexible Cords and Cables.

UL 486A-486B, Ed. 2, January 11, 2013, Standard of Safety for Wire Connectors.

UL 486E, Ed. 4, May 7, 2009, Standard for Safety for Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors.

UL 1277, Ed. 5, April 21, 2010, Standard for Safety For Electrical Power and Control Tray Cables with Optional Optical-Fiber Members.

UL 1309, Ed. 2, April 5, 2011, Standard for Safety Marine Shipboard Cable.

UL 1569, Ed. 4, November 23, 2014, Standard for Safety for Metal-Clad Cables.

UL 1651, Ed. 3, July 8, 2008, Standard for Safety for Optical Fiber Cable.

UL 2196, Ed. 1, March 30, 2012, Standard for Safety for Tests for Fire Resistive Cables.

UL 2225, Ed. 4, September 30, 2013, Standard for Safety for Cables and Cable-Fittings for Use in Hazardous (Classified) Locations.

UL 2250, Ed. 2, April 3, 2006, Standard for Safety for Instrumentation Tray Cable.

UL 2556, Ed. 3, March 22, 2013, Standard for Safety for Wire and Cable Test Methods.

[10]MIL publications are available from Customer Service, Defense Printing Service, 700 Robbins Ave., Bldg. 4D, Philadelphia, PA 19111-5094 (http://store.mil-standards.com).
[11]UL standards are available from Underwriters Laboratories standards website (www.ulstandards.com).

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[12]

accommodation spaces: Spaces provided for passengers and crew members that are used for berthing, dining rooms, mess spaces, offices, private baths, toilets and showers, lounges, and similar spaces.

adjustable speed drive (variable frequency drive): A converter using solid state switching devices that has the capability of adjusting the frequency and voltage of the output waveform to provide speed and torque control of motors.

communication and electronics circuits: Electrical circuits supplying equipment and systems for voice, sound, or data transmission, such as telephone, engine order telegraph, data communication, interior communication, paging systems, wired music systems, fire and general alarm systems, smoke and fire detection systems, closed circuit television, navigational equipment, and microprocessor-based automated alarm and control systems.

deluge: A condition where equipment is exposed to an abnormal volume of water during extreme weather, testing, maintenance, or fire suppression.

double banked: The arrangement of cables in a cable tray or raceway wherein the cables are stacked in two layers.

feeder: A cable or set of conductors that originates at a main distribution center (main switchboard) and supplying secondary distribution centers, transformers, or motor control centers. (Bus tie circuits between generator and distribution switchboards, including those between main and emergency switchboards, are not considered as feeders.)

hydrocarbon pool fire: A fire that occurs when a flammable liquid leaks from a vessel or pipeline to form a fluid reservoir, which then ignites.

intrinsically safe circuit: A circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under prescribed test conditions.

lug: A wire connector device to which the electrical conductor is attached by mechanical pressure or solder.

machinery spaces: Spaces that are primarily used for machinery of any type, or equipment for the control of such machinery, such as boiler, engine, generator, motor, pump, and evaporator rooms.

multicable penetrator (multicable transit MCT): A device consisting of multiple nonmetallic cable seals assembled in a surrounding metal frame, for insertion in openings in decks, bulkheads, or equipment enclosures and through which cables may be passed to penetrate decks or bulkheads or to enter equipment without impairing their original fire or watertight integrity.

NRTL: A nationally recognized testing laboratory as recognized by the U.S. Occupational, Safety, and Health Administration (OSHA) or the Authority Having Jurisdiction.

single banked: The arrangement of cables in a cable tray or raceway wherein the cables are installed in a single layer with a spacing of less than one cable diameter.

switchboard: A metal-enclosed panel or assembly of panels that may contain molded case, insulated case or power circuit breakers, bolted pressure contact or fusible switches, protective devices, and instruments. These devices may be mounted on the face or the back of the assembly. Switchboards are generally accessible from the rear as well as from the front; however, they can be front accessible only.

[12] *IEEE Standards Dictionary Online* subscription is available at: http://ieeexplore.ieee.org/xpls/dictionary.jsp.

triplex cable assembly: A cable assembly composed of three insulated single conductor cables twisted together.

variable frequency drive (VFD): A converter using solid state switching devices that has the capability of adjusting the frequency and voltage of the output waveform to provide speed and torque control of motors. *Syn:* **adjustable speed drive.**

vital services: Services normally considered to be essential for the safety of the ship and its passengers and crew. These usually include propulsion, steering, navigation, firefighting, emergency power, emergency lighting, electronics, and communications functions.

4. Cable types

Cables for installation on shipboard shall be listed as marine shipboard cable, Navy cable, or other cable as described in this clause.

Various cable constructions are detailed in IEEE Std 1580, permitting a selection of conductor insulation types, jacket types, armor, and ampacities. Cable constructions intended for specific applications and different voltages are also included. The application of each respective type is defined in the following paragraphs of this subclause.

4.1 Marine shipboard cable

Marine shipboard cables shall be listed as Marine Shipboard Cable by a Nationally Recognized Testing Laboratory (NRTL). These cables should meet the performance and construction requirements of IEEE Std 1580, UL 1309, or CSA 22.2 No. 245.

4.1.1 Power cables

4.1.1.1 Low-voltage cables (600 V to 2000 V)

These cables should be used for the distribution of power up to their voltage rating throughout the system, and they may be used in lighting, communication, control, and electronic circuits as desired.

4.1.1.2 Medium-voltage cables (2001 V to 35000 V)

These cables should be used for the distribution of power up to their voltage rating. Distribution cables rated 2001V and above shall be shielded.

4.1.1.3 Variable frequency drive (VFD) cables

These cables should be used for AC adjustable speed drives (ASD). In the absence of drive manufacturer's recommendations, refer to IEEE Std 1580 for specific cable construction.

4.1.2 Control and signal (Instrumentation) cables

4.1.2.1 Signal (Instrumentation) cables (300 V, 600/1000 V)

These cables should be used for signal transmission where twisted groups of conductors are desired. Individual or overall group shielding may be provided by means of a polyester/metal laminate tape and drain (ground) wire or a tinned copper braid, or a combination of both to prevent electrostatic or electromagnetic interference.

4.1.2.2 Control cables (600/1000 V)

These cables should be used for control, communication, indicating, electronic, and similar circuits.

4.2 Navy cable

Navy cables manufactured and tested in accordance with U.S. Navy military specifications MIL-DTL-24640C , MIL-DTL-24643C, MIL-DTL-915G, or MIL-PRF-85045G may also be used, provided they meet the IEEE Std 1202 or UL 2556 FT-4 Vertical Flame Test.

4.3 Data and communication cables

Data cables designed for use onboard ships and other areas such as drilling and production platforms, and on drillships, should be "ruggedized" to meet the operating conditions in such areas. These cables include, but are not limited to, Controller Area Network (CAN) cables; Category Cables; Low Voltage Differential Signaling Cables (LVDS); Differential balanced lines like RS-485; unbalanced (Single Ended) unidirectional cables like RS-232; Fieldbus and Profibus cables; Optical Fiber Cables; Composite Cables for CCTV, Coaxial Cables; Triaxial Cables; Mineral Insulated Cables, etc.

These data cables shall be constructed in accordance with their applicable standards and, when possible, meet the flammability requirements of IEEE Std 1202. It should be noted that data and communication cables may not meet the flame test of IEEE Std 1202. Where these cables do not comply with the IEEE Std 1202 flame test, the installation is to be provided with suitable fire stop arrangements meeting statutory and classification requirements.

In view of the wide variety of data cables, only some of them are highlighted in this subclause. Additional data cable types can be added as they find wider use in the maritime applications.

4.3.1 Fieldbus cables

Fieldbus cable is a Local Area Network cable for use in industrial automation applications establishments for process control. Fieldbus cable provides two-way communication protocol for devices such as actuators, transmitter and flame detectors, temperature and pressure measurement, motor starters, and limit switches.

4.3.2 Profibus cables

Profibus cables are designed for low level serial communication. The generic name Profibus is derived from the term "Process Field Bus". It utilizes an application independent communication protocol. It allows for communication between devices of different manufacturers without the need of any special interface adjustments. For further information, refer to IEC 61158-2.

4.3.3 Optical fiber

Transmission medium using ultra-pure silica glass or plastic to transmit pulse light signals for control, signaling, and communications. These type cable systems are used where an all-dielectric construction is preferred or for transmitting high capacity digital circuits such as Synchronous Transport Signal (STS), high resolution Closed Circuit Television (CCTV) camera systems, or for Programmable Logic Controller (PLC). Transmission of data through optical fiber cables is free from some of the detrimental effects inherent with copper cables, such as crosstalk, noise, lightning, and electromagnetic interference (EMI) problems.

Loose tube construction fiber contains individual fibers populated inside a colored furcation tube, and then may be impregnated with a water blocking material. Multiple tubes lie symmetrically around a central strength member. The strength member can be constructed from stranded steel (with a protective coating) or fiberglass, to offer rigidity during extended runs. Aramid yarn might be used as filler and provide tensile strength over the length of the cable.

Tight buffered construction consists of individual fibers directly buffered with acrylate and an additional synthetic substance such as nylon. The strength member can be constructed from stranded steel (with a protective coating) or fiberglass, to offer rigidity during extended runs. Aramid yarn might be used as filler and provide tensile strength over the length of the cable.

These cables should be selected in accordance with MIL-PRF-85045G, UL 1651, or IEC 60794-2.

4.3.4 Coaxial cables

These cables should be selected in accordance with MIL-DTL-17H or IEC 60966-1.

4.4 Specialty cables

4.4.1 Circuit integrity cable

4.4.1.1 Critical circuit cables

Cable for use in critical circuits (otherwise referred to as critical circuit cable, fire rated cable, or fire rated circuit integrity cable) should be selected based the type of potential fire exposure and fire endurance (heat flux).

4.4.1.2 Fire rated cables

Some applications that should be considered for the use of circuit integrity cable include critical communication, fire alarms or detection, non-fail safe critical devices, electric motor operated shutdown valves, or electric fire pumps. Cables that are required to operate under fire conditions and are subject to potential fire exposure and serve critical applications determined by the operator should be tested by a NRTL to the applicable test conditions as shown in 4.4.1.3 or 4.4.1.4.

4.4.1.3 Fire resistance tests

Cables designated as circuit integrity cable, in addition to meeting the flame test of IEEE Std 1202, should also meet the minimum circuit integrity flame test for 90 minutes at 1000 °C (1832 °F) with the equipment of IEC 60331-11 and the procedures of IEC 60331-21 for cables rated to and including 1000 V; IEC 60331-23 for electric data cable; or IEC 60331-25 for optical fiber cable. Cables that pass the UL 2196 per ASTM E119-14 [B1] test for two hours may also be identified as circuit integrity cable.

4.4.1.4 Hydrocarbon pool fire

For the specific applications that involve circuit integrity cables in an area that may be subjected to a hydrocarbon pool fire, the cable should be shown to comply (or listed by a NRTL) with the test criteria in IEEE Std 1717. Fire conditions resulting from a fire fueled by a hydrocarbon fuel source can achieve 1093 °C (2000 °F) in 5 minutes with a heat flux of 204 ±16 kW/m^2 (65000 ±5000 Btu/ft^2-hr).

4.4.2 Flexible cables and cords

Flexible cables used for special applications such as elevators and cranes should meet an appropriate recognized commercial standard (e.g., UL 62 or IEEE Std 1580), Military Specification (e.g., MIL-DTL-24643C), or ANSI/NEMA WC 58. Flame-retardant versions of these cables should be used where possible.

4.4.3 Mineral insulated cable

MI cable as defined by the National Electrical Code® (NEC®) may be used where there are requirements for circuit integrity or fire resistance, high power output, high exposure temperatures, or where environmental corrosives are present. Some applications may warrant the use of mineral insulated cables for power and data fire alarm cables rated up to 600 V.

4.4.4 Electrical resistance heat tracing cable (trace heating)

Heat tracing systems should be designed, installed, and operated in accordance with IEEE Std 515. For shipboard applications of heat tracing, ground fault protection is required.

4.4.5 Switchboard wiring

For recommendation concerning switchboard wiring refer to 6.4 of IEEE Std 45.7-2012.

4.4.6 Portable cords

Portable cords may be used in applications requiring temporary or portable power and shall be listed by a NRTL.

These cords and cables should be used only for connection of portable lamps and appliances and other equipment not suitable for fixed wiring and should conform to the requirements of the NEC, Article 400, for hard usage and extra hard usage. Portable cords and cables may also be used, as specified by MIL-DTL-24643C or MIL-DTL-915G.

Ampacities of cords and cables should be as defined by the NEC or MIL-HDBK-299, as applicable.

4.4.7 Equipment grounding conductors

Equipment grounding conductors may be bare or insulated. When insulated, the insulation shall be green or green/yellow. Equipment grounding conductors shall not be used as phase or neutral conductors.

5. Cable applications

5.1 AC applications

In general, multiple conductor cable should be used for all alternating current lighting and power circuits. All phase conductors of a circuit should be contained in a single cable to minimize inductive currents.

If the rating of any circuit is such that the current is greater than the rated capacity of any one conductor of the multiple conductor cable, then two or more multiple conductor cables of identical conductor size may be connected in parallel. One conductor of each phase of the circuit should be contained in each cable, and the power cables shall be routed to minimize circuit length differences.

Where the use of multiple conductor cable involves a difficult or undesirable arrangement, or where the use of single conductor cables will not incur heating of adjacent equipment or structure, single conductor cables may be used. For service voltages above 2000 V, single conductor cables should be bundled in triplex circuit groups.

5.2 DC applications

In general, cables designed for ac applications, not containing silicone, may also be utilized in dc applications up to 2000 V dc. Thermoplastic insulation, where used on dc circuits in wet locations, may result in electroendosmosis between conductor and insulation which may result in premature failure. Typical current ratings of cables in dc applications will be slightly higher than ac applications due to the ac skin effect. However, these differences are not significant for conductor sizes below 750 kcmil. Refer to Table 4 for current ratings for cables rated 2000 V and below with conductor sizes 750 kcmil and larger.

5.3 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 thermal stress resulting from short-circuit currents and emergency overloads
c) Voltage stress associated with different methods of system grounding and transient overvoltages
d) Electrostatic shielding
e) Fault current ratings
f) Electromagnetic shielding, if required
g) Voltage drop

5.3.1 Insulation levels for cables rated 5000 V and above

5.3.1.1 100% 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.

5.3.1.2 133% 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 one hour. Also, cables with this insulation level are permitted to be used where additional insulation strength over the 100% level category is desirable.

5.3.1.3 173% Insulation level

Cables with 173% insulation level are permitted to be used on ungrounded or resistance/impedance grounded systems where the time required to de-energize a grounded section is indefinite. Thus, if the one hour maximum clearing time for the 133% level is likely to be exceeded, cables rated for the 173% level can be applied.

5.3.2 Neutral, system, and equipment grounding

The selection of the neutral (grounded), grounding electrodes, and equipment grounding conductors, 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 and the short-circuit fault current of a line to neutral (ground) fault. Other conditions that affect neutral conductor sizing include high-resistance grounding or harmonic currents (such as those encountered with an ASD).

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. Where cables are paralleled in the same circuit, the size of the equipment grounding conductors, when used, should be sized in accordance with Table 250.122 of the 2014 NEC. For equipment that operates at high switching frequencies (above 1 kHz), such as ASD, active filters, etc., refer to equipment manufacturer's recommendations for sizing the equipment grounding conductors.

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. In addition, short-circuit currents can result in mechanical stresses beyond the structural design capabilities of the cable assembly and may result in physical damage. Finally, in some cases, excessive thermal deterioration of the cable materials may result in ignition of surrounding materials. Also, refer to ICEA P-32-382 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. However, this method does not take heat dissipation into account. Heat dissipation is a factor that may increase shield ampacity by 25% or more. Refer to IEC 60949 Ed. 1.0 [B6] for additional information.

Refer to IEEE Std 141™ [B8] for additional information regarding minimum insulated conductor sizes and temperatures for maximum operating, overload, and short-circuit conditions.

5.4 Accommodation spaces/areas containing sensitive electronic equipment

Sound engineering judgment should be used in the selection of cables for accommodation spaces and in the vicinity of sensitive electronic equipment. The following guidelines are provided for the selection of these cables.

Cables installed in areas that contain sensitive electronic equipment, where a heightened concern exists with regards to potential damage due to corrosive gases evolved during a fire, should be constructed with low smoke halogen free materials. These cables should meet the performance requirements of IEEE Std 1580-2010, including Table 13 for insulations, and Table 17 for jackets.

In considering personnel safety in the event of a fire, the evaluation of the Available Safe Egress Time (ASET) is essential. This is dependent on the time to activate the alarm, which in turn is a function of the detector. The appropriate detection system shall accommodate the type of cables and their location. For example, some ionization or photoelectric alarms may not provide maximum ASET when low smoke halogen free cables are under fire conditions. These considerations should be taken into account when selecting cables that meet the performance and construction requirements of IEEE Std 1580.

5.5 Variable frequency drive applications

Cables for variable frequency drive (VFD) applications require special consideration because of large change in voltage with respect to time (dV/dt), harmonics, electromagnetic interference (EMI), reflected wave voltages, common mode currents, and potential induced voltages in adjacent cables and equipment.

The interconnecting cable between the motor and drive is an integral part of the entire system. Every VFD system is different and, typically has manufacturer's recommendations for cables and installation. Therefore consultation between the system designer, drive manufacturer, motor manufacturer, and the cable manufacturer is recommended for proper cable selection and installation. In the absence of specific manufacturer's recommendations refer to IEEE Std 1580 for recommended cable construction.

5.6 Fieldbus cables

The Fieldbus cable can be a single shielded pair (SP) or multi shielded twisted pairs (STP), 18 AWG or 16 AWG, with tinned copper conductors and an overall shield (IS – OS). A number of devices share the same Fieldbus wires. The recommended design criteria for these cables are in IEEE Std 1580 with thermoset insulations and jackets. These cables may be armored or unarmored and can be halogenated or low smoke zero halogen (LSZH) cables. The selection will depend on its application.

Fieldbus cables shall comply with one of the following:

- Foundation™ Specification—H1 Cable Test Specification FF-844" rev FS.12-Jan. 6, 2011
- IEC 61158-2 Ed. 6.0 [B7]

In addition, fieldbus cables shall also comply with one of the following:

- Instrument tray cable (ITC) per UL 2250; 300 V
- Power limited tray cable (PLTC) per UL 13; 300 V
- Tray cable (TC) per UL 1277; 600 V
- Metal clad cable (MC or MC-HL) per UL 1569 and UL 2225
- UL 1309 Marine Shipboard Cable per UL1309 or IEEE Std 1580
- Control and Instrumentation Cable (CIC) or Armored Control and Instrumentation Cable (ACIC) per CSA C22.2 No. 239
- CSA C22.2 No 245 Marine Shipboard Cable
- Instrumentation and control per European standard EN 50288-7; 300 V

The following is a partial list of the Fieldbus cable electrical characteristics:

- Characteristics impedance, Z_0 shall be 100 ± 20 Ω at 31.25 kHz
- Maximum conductor resistance for #18 AWG shall be 23.5 Ω/km, #16 AWG shall be 16.4 Ω/km per conductor at 20 ºC
- Attenuation at 39 kHz is less than 3 dB/km
- Max propagation delay change 7.8125 kHz to 39.0625 kHz = 1.7 µs/km
- Wire-to-shield capacitance unbalance:No more than 4 pF/m
- Minimum shield coverage 90%

5.7 Ampacity

The current rating (ampacities) of the various cable types are addressed in Table 1 through Table 9.

Current rating should be adjusted as noted to suit the ambient temperature in which the cable is installed if it differs from 45 ºC. Cable ampacities shown are for single-banked installations. Double-banked cables should be derated in accordance with footnote b of Table 1.

Conductors should be sized to limit conductor operating temperatures at the termination device to those designated for the termination devices involved. In selecting circuit conductors, the designer shall assure that the actual conductor temperature does not exceed the lowest temperature rating of any terminal on any connected device. Other factors, such as ambient temperature, within enclosures and the single conductor configuration of most terminations also should be taken into consideration when determining the actual conductor temperatures attainable.

Other segments of the cable run where different thermal conditions exist from those at the termination point may require separate derating considerations. The lowest ampacity calculated for any 305 cm (10 ft) section in the cable run will determine the cable size.

The ampacities for cable types manufactured and tested in accordance with U.S. Navy military specifications MIL-DTL-24643C, MIL-DTL-24640C, and MIL-DTL-915G are to be in accordance with MIL-HDBK-299. Ampacities at 45 ºC are to be determined by dividing the 40 ºC ampacities in MIL-HDBK-299 by the 40 ºC factors contained in Table 2 for the appropriate insulating material. For double-banked installations, the values for U.S. Navy military specification cables are to be multiplied by 0.8, in accordance with footnote b of Table 1.

Table 1—Distribution, control, and signal cables, 2000 V or less- copper conductors—single-banked, maximum current rating (Types T, T/N, E, X, S, LSE, LSX, and P) based on 45 ºC ambient

AWG/ kcmil	Cross sectional		Single conductor				Two conductor				Three conductor			
	mm²	Circular mils	T[a]	LSE LSX T/N[b] E, X	S, P	P	T[a]	LSE LSX T/N[b] E, X	S, P	P	T[a]	LSE LSX T/N[b] E, X	S, P	P
			75 ºC	90 ºC	100 ºC	110 ºC	75 ºC	90 ºC	100 ºC	110 ºC	75 ºC	90 ºC	100 ºC	110 ºC
22	0.355	700	7	8	9	10	6	7	8	9	5	6	7	8
20	0.517	1020	9	11	12	13	8	9	10	11	6	8	9	10
18	0.821	1620	13	15	16	17	11	13	14	15	9	11	12	13
16	1.31	2580	18	21	23	25	15	18	19	20	13	15	16	17
—	1.5	2960	20	24	26	—	17	20	22	—	14	17	18	—
15	1.65	3157	21	26	28	—	18	22	23	—	15	18	19	—
14	2.08	4110	28	34	37	40	24	27	31	33	20	24	25	27
12	3.31	6530	35	43	45	48	31	36	40	43	24	29	31	33
10	5.26	10 400	45	54	58	62	38	46	49	52	32	38	41	44
8	8.37	16 500	56	68	72	77	49	60	64	69	41	48	52	56
7	10.5	20 800	65	77	84	—	59	72	78	—	48	59	63	—
6	13.3	26 300	73	88	96	103	66	79	85	91	54	65	70	75
5	16.8	33 100	84	100	109	117	78	92	101	108	64	75	82	88
4	21.2	41 700	97	118	128	137	84	101	110	118	70	83	92	99
3	26.7	52 600	112	134	146	156	102	121	132	141	83	99	108	116
2	33.6	66 400	129	156	169	181	115	137	149	160	93	111	122	131
1	42.4	83 700	150	180	194	208	134	161	174	186	110	131	143	153
1/0	53.5	10 600	174	207	227	243	153	183	199	213	126	150	164	176
2/0	67.4	133 000	202	240	262	281	187	233	242	259	145	173	188	201
3/0	85.0	168 000	231	278	300	321	205	245	265	284	168	201	218	234
4/0	107.2	212 000	271	324	351	376	237	284	307	329	194	232	252	270
250	126.7	250 000	300	359	389	—	264	316	344	—	217	259	282	—
262	133.1	262 600	314	378	407	436	278	333	358	383	228	273	294	315
300	152	300 000	345	412	449	—	296	354	385	—	242	290	316	—
313	158.7	313 100	351	423	455	487	303	363	391	419	249	298	321	344
350	177.3	350 000	372	446	485	—	324	387	421	—	265	317	344	—
373	189.4	373 700	393	474	516	553	339	406	442	473	277	332	361	387
400	203	400 000	410	489	533	—	351	419	455	—	286	342	371	—
444	225.2	444 400	453	546	588	630	391	468	504	540	319	382	411	440
500	253.3	500 000	469	560	609	—	401	479	520	—	329	393	428	—

AWG/ kcmil	Cross sectional		Single conductor				Two conductor				Three conductor			
	mm²	Circular mils	T[a]	LSE LSX T/N[b] E, X	S, P	P	T[a]	LSE LSX T/N[b] E, X	S, P	P	T[a]	LSE LSX T/N[b] E, X	S, P	P
			75 ºC	90 ºC	100 ºC	110 ºC	75 ºC	90 ºC	100 ºC	110 ºC	75 ºC	90 ºC	100 ºC	110 ºC
535	271.3	535 000	485	579	630	676	415	496	538	576	340	407	443	475
600	304	600 000	521	623	678	—	450	539	585	—	368	440	478	—
646	327.6	646 000	557	671	731	783	485	581	632	677	396	474	516	553
750	380	750 000	605	723	786	—	503	602	656	—	413	494	537	—
777	394.2	777 000	627	755	822	881	525	629	684	733	431	516	562	602
1 000	506.7	100 0000	723	867	939	—	601	721	834	—	493	592	641	—
1 111	563.1	1 11 1000	767	942	1025	1098	637	784	854	—	523	644	701	—
1 250	635	1 250 000	824	990	1072	—	—	—	—	—	—	—	—	—
1 500	761	1 500 000	917	1100	1195	—	—	—	—	—	—	—	—	—
2 000	1013	2 000 000	1076	1292	1400	—	—	—	—	—	—	—	—	—

NOTE 1—Current ratings are for ac or dc. Exceptions are stated in Table 4.

NOTE 2—Current rating of four-conductor cables, where one conductor does not act as a normal current-carrying conductor (e.g., grounded neutral or grounding conductor), is the same as three-conductor cables.

NOTE 3—Ampacities for distribution, control, and signal cables are based on an ambient temperature of 45 ºC and maximum conductor temperature not exceeding 75 ºC for Type T, 90 ºC for Types T/N, X, E, LSE, and LSX, 100 ºC for Type S, and 110˚C for Type P.

NOTE 4—The current ratings in this table are for marine installations with cables arranged in a single bank per hanger (single banked) with maintained spacing of less than one cable diameter between adjacent cables and are 85 % of the IEEE Std 835™ [B10] calculated free air values. Ampacity values are based on an ambient of 45 ˚C, no solar heat, and no wind. The original IEEE calculated current capacities of these cables were based on cables installed in free air with at least one cable diameter spacing between adjacent cables. For other installed conditions refer to IEEE Std 835 [B10].

NOTE 5—For cables with maintained spacing of at least one cable diameter apart, the values from this table may be divided by 0.85.

NOTE 6—Where cables or insulated conductors are subjected to the effects of solar radiation the current rating may be adjusted by the methods specified in IEC 60287-1-1 Ed. 2.1 [B3] and IEC 60287-2-1 Ed. 2.0 [B4].

NOTE 7—Single conductor cables configured in triplex or triangular configuration may be treated conservatively as three conductor cables when determining ampacity, or the manufacturer may be consulted for more specific values.

[a]For service voltage above 1000 V, Types T and T/N should not be used.

[b]For those instances in which cables are double banked, the current ratings in Table 1 should be multiplied by 0.8.

[c]If ambient temperatures differ from 45 ˚C, cable ampacities should be multiplied by the factors in Table 2.

Adjustments for ambient temperatures other than 45 ˚C are shown in Table 2.

Table 2—Adjustments for ambient temperature

Ambient temperature (°C)	Type T insulated cables	Type T/N, X, E, LSE, LSX insulated cables	Type S and P insulated cables	Type P insulated cables at 110 °C
30	1.22	1.15	1.13	1.11
40	1.08	1.05	1.04	1.04
50	0.91	0.94	0.95	0.96
60	—	0.82	0.85	0.88
70	—	—	0.74	0.78
80	—	—	—	0.74

Ampacity adjustment factors for more than three conductors in a cable with no load diversity: Percent of values in Table 1 for Three Conductor Cable as adjusted are shown in Table 3.

Table 3—Number of conductors for ambient temperature, if necessary

Number of conductors	Ampacity adjustment (%)
4 through 6	80
7 through 9	70
10 through 20	50
21 through 30	45
31 through 40	40
41 through 60	35

Table 4—Single-conductor distribution cables, 2000 V or less, dc only, copper conductors—single-banked (single-layered), maximum current ratings based on 45 ˚C ambient

kcmil	75 °C	90 °C	100 °C	110 °C
750	617	738	802	859
1000	747	896	964	1033
1250	865	1038	1126	1206
1500	980	1177	1276	1367
2000	1195	1435	1557	1668
Refer to Notes in Table 1				

5.7.1 Ampacities for medium voltage cables

Ampacities for medium-voltage power cable, copper conductor—single-banked (single-layered), maximum current rating based on 45 ºC ambient, shields grounded on one end (open-circuited shields) are shown in Table 5 through Table 7. The allowable ampacities are based on the conductor temperature rise in a given ambient. For three phase applications, it is recommended that single conductors be installed in triplex or triangular configuration to reduce electrical losses.

Table 5—Medium voltage power cable, copper conductor—single conductor, single-banked, maximum current ratings based on 45 °C ambient[c]

AWG / kcmil	mm²	Circular mils	Single conductor cable					
			2001−5000 V shielded		5,001−15,000 V shielded		15,001−35,000 V shielded	
			90 °C	105 °C	90 °C	105 °C	90 °C	105 °C
6	13.30	26 240	89	103	—	—	—	—
4	21.15	41 740	120	135	123	—	—	—
2	33.62	66 360	158	178	162	178	—	—
1	42.40	83 690	182	205	187	202	182	204
1/0	53.50	105 600	210	237	210	234	210	237
2/0	67.44	133 100	242	273	241	271	242	270
3/0	85.02	167 800	279	315	278	311	279	311
4/0	107.2	211 600	324	366	321	359	319	364
250	126.7	250 000	359	405	359	400	355	400
263	133.1	262 600	370	418	366	413	358	412
313	158.6	313 100	413	466	409	462	397	459
350	177.3	350 000	444	501	444	493	440	494
373	189.3	373 700	462	522	456	515	442	513
444	225.2	444 400	515	581	508	573	495	540
500	253.3	500 000	561	629	553	618	549	617
535	271.2	535 300	580	655	571	645	557	642
646	327.5	646 400	652	736	641	724	619	720
750	380.0	750 000	727	813	715	799	703	793
777	394.0	777 700	735	830	721	814	692	810
1 000	506.7	1 000 000	856	970	856	957	840	948

NOTE 1—These current ratings are for marine installations with cables arranged in a single bank per hanger with maintained spacing of less than one cable diameter between adjacent cables, and are 85% of the free air values.

NOTE 2—Ampacity values are based on an ambient temperature of 45˚C, with no solar heat, no wind. For other installed conditions refer to IEEE Std 835 [B10].

NOTE 3—Where cables or insulated conductors are subjected to the effects of solar radiation the current carrying capacity may be adjusted by the methods specified IEC 60287-1-1 Ed. 2.1 [B3] and IEC 60287-2-1 Ed. 2.0 [B4].

NOTE 4—For cables with maintained spacing of at least one cable diameter apart, the values from this table may be increased by dividing by 0.85.

[a]The actual conductor operating temperature must be compatible with the connected equipment, especially at the connection points.

[b]Conductor selection should be coordinated with circuit and system overcurrent and short-circuit protection to avoid cable damage during through-fault conditions. See ICEA P-32-382 to determine conductor short-circuit withstand current.

[c]If ambient temperatures differ from 45 ˚C, cable ampacities should be multiplied by the factors in Table 8.

[d]For single conductor cable installations, grounding at only one end may result in a voltage buildup on the shield. The magnitude of the voltage is a function of the geometry of the shielded cable installation, the phase current, and the distance from the point of grounding. Care should be taken to limit this voltage to safe levels of 25 V or less.

Table 6—Medium voltage power cable, copper conductor—triplex or triangular configuration, maximum current rating based on 45 °C ambient[c]

AWG / kcmil	mm²	Circular mils	Single-conductor cable (in triplex or triangular configuration)					
			Up to 8 kV shielded		8,001−15,000 V shielded		15,001−35,000 V shielded	
			90 °C	105 °C	90 °C	105 °C	90 °C	105 °C
6	13.30	26 240	92	106	—	—	—	—
4	21.15	41 740	121	135	—	—	—	—
2	33.62	66 360	159	187	164	187	—	—
1	42.40	83 690	184	216	189	216	192	216
1/0	53.50	105 600	212	245	217	242	220	245
2/0	67.44	133 100	244	284	250	284	250	284
3/0	85.02	167 800	281	327	288	327	288	327
4/0	107.2	211 600	325	375	332	375	332	375
250	126.7	250 000	360	413	366	413	366	413
263	133.1	262 600	371	425	377	425	376	425
313	158.6	313 100	413	473	418	471	416	471
350	177.3	350 000	444	508	448	505	446	505
373	189.3	373 700	460	526	464	523	462	523
444	225.2	444 400	510	581	514	580	512	580
500	253.3	500 000	549	625	554	625	551	625
535	271.2	535 300	570	648	574	648	570	648
646	327.5	646 400	635	720	638	720	632	720
750	380.0	750 000	697	788	697	788	689	788
777	394.0	777 700	709	802	709	802	701	802
1 000	506.7	1 000 000	805	913	808	913	798	913

NOTE 1—These current ratings are for marine installations with cables installed in triplex or triangular configuration and with a minimum maintained spacing of 2.15 times one single conductor cable diameter between adjacent bundles.

NOTE 2—Ampacity values are based on an ambient temperature of 45˚C, with no solar heat, no wind. For other installed conditions refer to IEEE Std 835 [B10].

NOTE 3—Where cables or insulated conductors are subjected to the effects of solar radiation the current carrying capacity may be adjusted by the methods specified in IEC 60287-1-1 Ed. 2.1 [B3] and IEC 60287-2-1 Ed. 2.0 [B4].

[a]The actual conductor operating temperature must be compatible with the connected equipment, especially at the connection points.

[b]Conductor selection should be coordinated with circuit and system overcurrent and short-circuit protection to avoid cable damage during through-fault conditions. See ICEA P-32-382 to determine conductor short-circuit withstand current.

[c]If ambient temperatures differ from 45 ˚C, cable ampacities should be multiplied by the factors in Table 8.

[d]For single conductor cable installations, grounding at only one end may result in a voltage buildup on the shield. The magnitude of the voltage is a function of the geometry of the shielded cable installation, the phase current, and the distance from the point of grounding. Care should be taken to limit this voltage to safe levels of 25 V or less.

[e]For single conductor cable installations in triangular or triplex configuration, and if more than one parallel run is installed, there should be a maintained spacing of 2.15 times one conductor diameter between each triangular configuration group. Otherwise cables are considered double-banked, and ampacities should be derated by a factor of 0.8.

Table 7—Medium voltage power cable, copper conductor—three conductor, single-banked configuration, maximum current rating based on 45 °C ambient[c]

AWG / kcmil	mm²	Circular mils	Three-conductor cable					
			Up to 8 kV shielded		8,001−15,000 V shielded		15,001−35,000 V shielded	
			90 °C	105 °C	90 °C	105 °C	90 °C	105 °C
8	8.37	16 510	—	—	—	—	—	—
6	13.30	26 240	75	85	—	—	—	—
4	21.15	41 740	99	112	—	—	—	—
2	33.62	66 360	129	146	133	150	—	—

AWG / kcmil	mm²	Circular mils	Three-conductor cable					
			Up to 8 kV shielded		8,001−15,000 V shielded		15,001−35,000 V shielded	
			90 °C	105 °C	90 °C	105 °C	90 °C	105 °C
1	42.40	83 690	149	168	151	170	149	172
1/0	53.50	105 600	171	193	174	196	174	196
2/0	67.44	133 100	197	222	199	225	198	225
3/0	85.02	167 800	226	255	229	259	230	257
4/0	107.20	211 600	260	294	263	297	262	294
250	126.70	250 000	287	324	291	329	291	327
263	133.10	262 600	296	334	299	338	299	336
313	158.60	313 100	328	370	331	374	329	373
350	177.30	350 000	352	397	355	401	351	400
373	189.30	373 700	365	412	367	414	363	414
444	225.20	444 400	387	437	388	438	402	470
500	253.30	500 000	434	490	434	490	432	490
535	271.20	535 300	449	507	449	507	447	507
646	327.50	646 400	496	560	497	561	496	559
750	380.00	750 000	541	611	542	612	541	609
777	394.00	777 700	550	621	550	621	550	619
1 000	506.70	1 000 000	622	702	623	703	622	703

NOTE 1—These current ratings are for marine installations with cables arranged in a single bank per hanger with maintained spacing of less than one cable diameter between adjacent cables, and are 85 % of the free air values

NOTE 2—Ampacity values are based on an ambient temperature of 45˚C, with no solar heat, no wind. For other installed conditions refer to IEEE Std 835 [B10].

NOTE 3—Where cables or insulated conductors are subjected to the effects of solar radiation the current carrying capacity may be adjusted by the methods specified in IEC 60287-1-1 Ed. 2.1 [B3] and IEC 60287-2-1 Ed. 2.0 [B4].

NOTE 4—For cables with maintained spacing of at least one cable diameter apart, the values from this table may be increased by dividing by 0.85.

[a]The actual conductor operating temperature must be compatible with the connected equipment, especially at the connection points.

[b]Conductor selection should be coordinated with circuit and system overcurrent and short-circuit protection to avoid cable damage during through-fault conditions. See ICEA P-32-382 to determine conductor short-circuit withstand current.

[c]If ambient temperatures differ from 45 ˚C, cable ampacities should be multiplied by the factors in Table 8.

[d]For single conductor cable installations, grounding at only one end may result in a voltage buildup on the shield. The magnitude of the voltage is a function of the geometry of the shielded cable installation, the phase current, and the distance from the point of grounding. Care should be taken to limit this voltage to safe levels of 25 V or less.

Adjustments to the values shown in Table 5 through Table 7 for different ambient temperatures are shown in Table 8.

Table 8—Adjustments for ambient temperature

Conductor temperature °C	30 °C	40 °C	45 °C	50 °C	55 °C	60 °C	70 °C
90 °C	1.10	1.05	1.00	0.94	0.88	0.82	—
105 °C	1.08	1.04	1.00	0.96	0.92	0.86	0.76

5.7.2 Ampacities for nickel-coated copper conductor, 27% nickel

For critical circuit cables described in 4.4.1.4 using 27% nickel-coated copper conductors, ampacities for low-voltage applications are given in Table 9. Alternate conductor compositions with similar performance may be used with the manufacturer's ampacity limits. Nickel-coated copper conductors shall conform to ASTM B355-11 and UL 44 requirements where applicable.

Table 9—Insulated nickel-coated copper conductors (27% nickel), 2000 V or less, 75 °C rated, (not more than three current-carrying conductors in raceway), maximum current rating based on 45 °C ambient

AWG / kcmil	mm2	Circular Mils	Nickel-coated copper conductor (27% nickel) ampacity
18	0.82	1 620	7
16	1.31	2 580	8
14	2.08	4 110	15
12	3.31	6 530	18
10	5.26	10 380	25
8	8.37	16 510	32
6	13.3	26 240	41
4	21.15	41 740	53
2	33.62	66 360	73
1/0	53.5	105 600	98
2/0	67.44	133 100	110
4/0	107.2	211 600	147
250	126.7	250 000	168
350	177.3	350 000	205
500	253.3	500 000	254
750	380	750 000	315
1 000	507	1 000 000	364
1 250	633.3	1 250 000	397
1 500	760	1 500 000	426
2 000	1013.3	2 000 000	459

5.7.3 Ambient temperatures

The use of the various conductor insulation types should be restricted to the maximum ambient temperatures shown in Table 10 in shipboard spaces.

Table 10—Maximum ambient temperatures

Cable type	Insulation	Maximum ambient temperature
T	PVC	50 °C
T/N	PVC/Polyamide	60 °C
E	EPR	60 °C
X	XLPE	60 °C
LSE	LSEPR	60 °C
LSX	LSXLPE	60 °C
S	Silicone	70 °C
P	XLPO	80 °C

5.8 Armored cables

In classified locations, refer to 6.4.4. In unclassified locations where the cable may be exposed to mechanical damage, protective measures such as the use of armored cables should be taken. An overall sheath is required on cables with an aluminum or tinned copper armor.

5.9 Corrosion protection

Corrosion of the metal components within a cable 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. The metallic components of a cable can also be protected by the use of jackets, especially in hazardous environments. Corrosion of conductors is accelerated at higher temperatures, the biggest problem being oxidation.

5.10 Skin effect ratio

See Table 11 for skin effect ratios.

Table 11—Skin effects ratio, 65 °C at 60 Hz

Area in circular mil	Column 1	Column 2
Up to 3 AWG	1.000	1.00
2 and 1 AWG	1.000	1.01
1/0	1.001	1.02
2/0	1.001	1.03
3/0	1.002	1.04
4/0	1.004	1.05
250 000 kcmil	1.005	1.06
300 000	1.006	1.07
350 000	1.009	1.08
400 000	1.011	1.10
500 000	1.018	1.13
600 000	1.025	1.16
750 000	1.039	1.21
800 000	1.044	1.23
1 000 000	1.067	1.28
1 250 000	1.102	1.39
1 500 000	1.142	—
1 750 000	1.185	—
2 000 000	1.233	—
2 500 000	1.326	—

Column 1—Use for the following:

a) Single-conductor nonmetallic-sheathed cable in air or nonmetallic conduit.
b) Single-conductor metallic-sheathed cable with sheath insulated in air or separate nonmetallic conduit.
c) Multiple-conductor nonmetallic-sheathed cable in air or nonmetallic conduit.

Column 2—Use for the following:

a) Multiple-conductor metallic-sheathed cable.
b) Multiple-conductor nonmetallic-sheathed cable in metallic conduit.
c) Two or more single-conductor nonmetallic-sheathed cables in the same metallic conduit.

NOTE—For intermediate conductor sizes, interpolation is recommended.

For close spacing such as multiconductor cables or several cables in the same conduit, there is additional apparent resistance due to proximity loss and sheath eddy-current effects. This apparent resistance varies with spacing (insulation thickness) but for most purposes can be neglected without significant error.

5.11 Short-circuit considerations

The cross-sectional area of the conductors should be sufficient to ensure that under short-circuit conditions, the maximum rated conductor temperature for short-circuit operation is not exceeded, taking into consideration the time-current characteristics of the circuit protective device and the peak value of the prospective short-circuit current. For cable short-circuit current curves, refer to ICEA P-32-382.

5.12 Fire safety considerations

A vast majority of materials used in the insulation and sheathing (or 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. This can be accompanied by the generation of smoke and acid gas during a fire.

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, limiting the effects of the byproducts of combustion, including acid gasses, on people and equipment are an equally important consideration. This has led to the formulation of materials with low or zero levels of halogens.

5.13 Spare conductors

Each control, communication, or signal system cables with more than four conductors or three pairs should be selected to provide 10% spare circuit conductors or pairs, but not less than required for a single additional circuit. Where multiplexed systems are employed, conductor bandwidth should be sufficient to provide for a 10% growth.

6. Cable installation

6.1 Single-conductor ac cables—special considerations

To avoid an undesirable inductive effect in ac installations, the following precautions should be observed:

a) Closed magnetic circuits around single-conductor ac cable should be avoided.

b) No magnetic material should be permitted between cables of different phases of a circuit.

c) Single-conductor ac cables should not be located closer than 76 mm (3 in) from parallel magnetic material.

d) Unless the cables are bundled in triplex circuit groups single-conductor ac cable (including cables in flat configuration) should be supported on insulators, or nonferrous metal hangers or trays. Single conductor cables installed in triangular or triplex circuit groups may utilize ferrous metallic support systems.

e) Where single-conductor ac cables penetrate a bulkhead or other ferrous plate or enclosure, conductors of each phase of the same circuit should pass through a common nonferrous plate to prevent heating of the surrounding ferrous material.

f) Cables in circuit groups in flat configuration should be transposed to avoid impedance imbalance between phases. This transposition should be made at intervals of not over 15 m (50 ft) and need not be made in cable runs of less than 30 m (100 ft). At each interval, an outer cable in the circuit group should be relocated to the opposite side of the circuit group, without altering the orientation of the remaining cables. At each successive interval, the cable formerly adjacent to the outer cable will be the next cable to be relocated to the opposite side of the circuit group, and so on. For example, a single circuit comprised of phases A, B, and C in a flat circuit configuration would require three transpositions before the cables return to the original orientation (i.e., A-B-C → C-A-B → B-C-A → A-B-C). Cables in dual, triplex, triangular, or quad configuration circuit groups need not be transposed. For further information on single-point bonding, standing voltages and cable transposition refer to IEEE Std 575™ [B9].

g) Single-conductor cables should be adequately secured to prevent displacement by short-circuit conditions as specified in 6.8.

6.2 Optical fiber cables—special considerations

6.2.1 Pulling optical fiber cable

Optical fiber is a type of cable suitable for communication and control backbone systems. However, just as with copper cable, care must be taken when pulling optical fiber so as not to exceed the minimum cable bend radius or the manufacturer's recommended pulling tension, based on cable construction. A minimum bend radius of 20 times the outer diameter of the cable during installation and a minimum of 10 times the outer diameter during operation should be observed. The specification for the cable should be consulted and will generally list the minimum bending radii and the maximum installation and operational tensions. When using a pull rope, it is recommended to use a multi-weave pull sock over the end of the cable not to overstress the internal fiber strands or cable terminations (if any). A service loop should be formed at the terminated end to relieve tension and allow for future moves or changes.

When pulling the cable it is best to eliminate any twisting of the cable. Some cables may have a memory effect and exhibit an inclination to twist when pulling off of a reel or round coil. It may be beneficial to unspool the cable and lay on the ground in a figure 8 pattern. This puts a half twist in one direction on one side of the figure eight and then reverses it on the other, thereby balancing the natural twist of the cable. Use of a pulling eye with a swivel is also helpful to control twisting.

Use of a cable lubricant during pulling is recommended to reduce overall tension and impulse loading during the pull. Ensure that lubricant used is compatible with cable jacketing material. Use of a pull rope with minimal stretch also helps to even out the pulling tension. For a long run where maximum tension may be a concern, use of a tension monitor or a pulling eye with a designed breakaway force may be beneficial.

6.2.2 Run length

Care should be taken not to exceed a vertical run maximum specified for the type of optical cable. Certain types, particularly loose tube constructions, may have a limited unsupported vertical run distance. Consult cable manufacturer for any limitations that may apply.

Care should be taken to ensure there is enough optical power budget (signal strength) in your system to cover optical losses due to cable length, interconnects, and splices.

6.2.3 Cable ties

Optical cables can be susceptible to damage or performance degradation due to excessively tight cable ties. This is particularly true for the small diameter unarmored single fibers that are typically used as "jumper cables" or "patch cables" inside cabinets. The resulting effect is termed "microbending," a condition caused by local stress concentration on the fiber. Armored and multifiber rugged jacketed cables are less susceptible to microbending. To mitigate microbending, use cable supports with a large surface area contacting the cable and protect the cable from sharp edges on supports or any point along the cable run.

6.2.4 Temperature considerations

Care should be taken not to place fiber optic cables near high temperature equipment or copper conductors that can exceed 85 ºC when in use. Many fiber optic cables use a soft acrylate buffer material that is typically rated at 85 ºC maximum directly surrounding the individual fibers. Check the specification of your particular cable if this may be a concern. Specialty higher temperature cables are available.

6.2.5 Barrier gland terminations of optical fiber cable

Properly size the gland to the cable manufacturer's outside diameter specification listing. Terminate cables with continuous corrugated metal or marine braided armor per the recommendations of the gland manufacturer.

Cables with 2.0 mm diameter tight buffered subunits containing fibers may be considered to be substantially filled to protect the fiber stand(s). The compound mixture should be applied with each tube segregated so that the compound fills the voids of the potting cup, per gland manufacturer's recommendations.

Patch cord style cables with 3.0 mm diameter tight buffered subunits containing fibers that are substantially filled to protect the fiber strand(s) should be treated as previously mentioned. If the cable is not substantially filled, representing a potential path for gas migration, the following procedures should be followed: Strip the 3.0 mm subunit tube and remove aramid yarn to expose 900 µ fiber midway into the potting cup. The compound mixture or other suitable sealing system should be applied with each fiber segregated so that the compound fills the voids of the potting cup, per gland manufacturer's recommendations.

Loose tube constructed cables containing subunit tube(s) populated with multiple fibers filled with water blocking material is another cable type. This water blocking material may not be gas tight, and proper fiber breakout should be implemented. One recommended technique is to transition the 250 µ coated fiber(s) from each subunit tube(s), cleaning the water blocking material from each fiber. Apply an adhesive blocking mechanism or other suitable sealing system in the tubes at the fiber egression point and then install the fiber(s) into a 900 µ or 900 µ/2.0 mm furcation tube supplied with the breakout kit. Each tube should be stripped midway into the potting cup. The compound mixture should be applied with each fiber segment segregated so that the compound fills the voids of the potting cup, per gland manufacturer's recommendations.

Installation of fiber optic cables for commercial marine vessels is, in many circumstances, similar to installation of fiber optic cables on Naval vessels. Refer to MIL-STD-2042 Parts 1 through 7 [B12] through [B18] for additional information.

6.3 Cable continuity and grounding

All cable should be continuous between terminations. However, splicing is permitted under certain conditions (see 6.11). For cable provided with armor (multiple conductor cables only), the armor should be electrically continuous between terminations and should be grounded at each end (multiconductor cables only), except that for final subcircuits, the armor may be grounded at the supply end only.

6.4 Cable locations

6.4.1 General locations

General locations are as follows:

a) Cables should not be installed in spaces where excessive heat and gases may be encountered such as galleys, boiler rooms and pump rooms, or spaces where cables may be exposed to damage such as cargo spaces or exposed sides of deck houses. Cables should not be located in cargo tanks, ballast tanks, fuel tanks, or water tanks except to supply equipment and instrumentation specifically designed for such locations and whose functions require it to be installed in the tank. Such equipment may include submerged cargo pumps and associated control devices, cargo monitoring, and underwater navigation systems.

b) Unless unavoidable, cables should not be located behind or embedded in structural thermal, fire, or acoustic insulation. Where cables are installed behind paneling, all connections should be readily accessible and the location of concealed connection boxes should be indicated. Cables should preferably not be run through refrigerated cargo spaces.

c) If a cable enters a battery room, the penetration through the bulkhead, deck, or overhead should be made gastight. The cables should be sealed to prevent the entrance of electrolyte by spray or creepage. All connections within the battery room should be resistant to the electrolyte. The current rating of a connecting cable should be at least equal to the maximum charging current or maximum discharge current, whichever is greater. The current rating of the cables shall be in accordance with Table 1 and Table 4 corrected to the appropriate ambient temperature.

d) Cables should not be located below the faceplate of the vessel's main bottom structural members or within 610 mm (24 in) above any double bottom tank top.

e) Cables should, as far as is practicable, be fixed in accessible positions, so chosen that the cables are not exposed to drip or accumulation of water or oil, steam or oily vapor, high temperature from boilers, steam pipes, exhaust pipes, radiators, resistors, or other hot objects or mechanical damage.

f) Cables, unless adequately protected, should not be laid under machines or floor plates.

g) Cables should not be led across expansion joints in the superstructure unless this is unavoidable; where cables must cross an expansion joint they should be arranged with a loop suitably supported and having an internal radius not less than twelve times the overall diameter of the largest cable, to help ensure the necessary flexibility.

h) All cables within 9 m (28 ft) of any receiving antenna system, radio room or radio navigation apparatus, unless a metallic deck or bulkhead intervenes, should be metal-sheathed, metal-braided or otherwise adequately screened, or arranged so as to prevent the radiation or reception of interfering spurious signals.

i) Cables, other than those feeding services in a radio room should not be installed therein, but cables that must pass through a screened radio room should be run throughout their length within the room, in continuous metallic conduit or trunking, which shall be bonded to the screening of the room at the points of entry and exit.

j) All cables that must enter the radio room should be grouped together, so far as is practicable, so that they enter at one point only and, when the radio room is screened, the screening of the cables entering the room shall be bonded to the room screening at the point of entry.

k) Cables carrying pulses of high amplitude, and power cables supplying units in which such pulses are present, should be segregated from cables for other services by a minimum of 610 mm (24 in).

l) Cables terminating in equipment capable of generating high temperatures, such as lighting fixtures, electric heaters, etc. should be suitable for operation at the temperature of the fixture without sustaining damage to the insulation.

m) Exposed cable should not cross through walkway areas. When it is not practical to route cables around walkways, the cables may pass below walkways, provided the walkway surface (e.g., grating) is raised above the cable area to eliminate any trip hazard and the cables are suitably protected as provided in 6.6.

n) Any unused (i.e., abandoned) cables should be removed.

o) Cables used in refrigerated spaces should be suitable for applications at −40 ºC, or should be protected by other means (refer to 6.6).

6.4.2 Portable cords and cables

Neither portable cords, nor portable cables shall be used for fixed wiring.

6.4.3 Propulsion cables

The effects of electromagnetic interference, impedance, system harmonics, short-circuit bracing, and, for voltages above 2001 V, corona should be taken into consideration when selecting cable constructions (single or multiple conductor) for electric propulsion systems.

Propulsion system cables should be run as directly as possible and in accessible locations where they can be readily inspected. Propulsion cables rated 2001 V or greater shall be shielded and shall be terminated with a stress cone or other stress-terminating device. Propulsion cables should not be spliced. Single-conductor propulsion cables should be adequately secured to prevent displacement by short-circuit conditions.as specified in 6.8.

Propulsion system power cables interconnecting generators, main switchboards, main transformers, static power converters, and motors should be separated from ship service, control, and signal cables by at least 610 mm (24 in) to reduce radiated electromagnetic interference.

If required for harmonic attenuation, propulsion cables should be armored or shielded and of the types identified in 4.1.1.3. Cables should be sized to provide 125% of motor- and drive-rated current continuously. Voltage drop should not exceed 5%. This recommendation may not apply to VFD cables used in other applications.

6.4.4 Hazardous locations

Wiring methods for hazardous locations shall follow the practices recommended for Divisions and Zones in API RP 14F and API RP 14FZ, respectively. Optical fiber cables installed in Class I Division 1 and Zone 1 classified locations shall have an external armor and sheath. Optical fiber cables utilized in systems compliant with IEC 60079-28 protection method “op is” are exempted from the armor and sheath requirement.

6.4.5 Circuits in the vicinity of magnetic compass

To avoid influences on the magnetic compass, no wiring or equipment that may produce stray magnetic fields and no magnetic structural material for which complete compensation cannot be made should be installed close to this compass.

Wiring in the binnacle should be limited to a single twisted pair of conductors used for the binnacle light.

The minimum distance for other wiring and equipment from the magnetic compass should be approximately as follows:

a) Single-conductor wiring should not be installed on the bridge.
b) Direct-current wiring
    1) Parallel laid twin conductors
        i) 0 to 1 A: 0.6 m
        ii) 1 to 10 A: 1.5 m
        iii) Over 10 A: 2.5 m
    2) Twisted conductors
        i) 1 to 10 A: 1.0 m
        ii) Over 10 A: 1.5 m
    3) Motors (except windshield wipers): 3.7 m
    4) Telephone transmitters and receivers
        i) Battery powered: 1.5 m
        ii) Sound powered: 2.1 m
    5) Loudspeakers: 3.7 m
    6) Searchlight projectors, except when made of nonmagnetic material: 3.7 m
    7) Magnetically operated relays, indicators, and so on: 2.5 m
    8) Telegraphs, electric: 1.2 m
    9) Windshield wipers: 1.2 m
c) Multiple-conductor cables carrying alternating current should have no appreciable effect on the indication of the compass.

A continuous steel deck or bulkhead between the compass and any motor or other equipment will act as a magnetic shield and the above recommendations for minimum distances do not apply.

All magnetic compasses should be adjusted to meet the average operating conditions, and the effect of electric circuits in close proximity should be checked by turning them on and off during adjustment.

6.5 Cable penetrations

6.5.1 General

Cables that pass through bulkheads or structural members (beams) shall be fitted with a protective collar of like material of the material penetrated. The method used shall meet the requirements of the penetrated compartment.

The size of holes required for the installation of the cables for various systems should be such that they will not affect the structural strength of the various members through which they pass. However, if the size or position of the hole is such that the strength of the structural member is affected, suitable reinforcing of the structural member should be provided.

Watertight penetrations should be employed where cables pass through watertight decks or bulkheads.

Multi-cable penetrators (e.g., multi-cable transits) may be used for the passage of cables through watertight and/or fire boundary bulkheads and decks. Multi-cable transits are for use in penetrations where cables penetrate a rated structure, bulkhead, wall, deck, floor, panel, or enclosure. In all cases, the penetration seal should re-instate the function and rating of the penetrated structure, bulkhead, wall, deck, floor, panel, or enclosure. Multi-cable transits should not be used in tanks, or in areas which are exposed to a constant pressure differential. Multi-cable transits should be suitable for shipboard environmental conditions and other applicable conditions that may occur (e.g., vibration, blast wall applications, shock loading, salt spray, ultraviolet resistance, and chemical resistance).

Where cables pass through non-watertight or non-fire rated bulkheads, beams, etc., a suitable bushing should be used to prevent cable damage during installation. When the thickness of the bulkhead or web is 6 mm (0.24 in) or more, the bushing may be omitted but the edges of the holes should be rounded.

Where cables pass through fire boundaries, arrangements should be made to ensure the integrity of the fire boundary is not impaired. Nonmetallic stuffing tubes should not be used in fire boundaries.

6.5.2 Connection of cables to enclosures/equipment—Ordinary (non-hazardous) locations, single, and multiple cable entry devices

Cables should be secured at the point of entry into enclosures or equipment by entry devices tested and certified for the cable type and ingress rating of the enclosure or equipment. Cable fittings may require the use of thread sealing washers, hubs or a suitable grease to maintain the appropriate ingress protection rating of the enclosure or equipment.

NOTE—National Pipe Thread (NPT) threaded entries may not maintain the ingress level of the equipment and will require the use of suitable grease. Suitable grease should be of the type that does not harden over time, does not contain evaporating solvents, does not promote corrosion and maintains grounding continuity.[13]

For non-threaded or straight threaded entries, cable fittings should be secured with an anti-vibration washer/locknut.

To prevent twisting and/or pulling, cables should be fixed by a clamp or other means, as close as practical to the cable entry device, preferably within 300 mm (12 in).

Where armored cables are used, the armor should be grounded by suitable entry devices. Such entry devices should be tested and certified for the cable type and available short-circuit values (refer to 5.3.2).

For installations exposed to sea water spray or periodic water deluge from fire protection deluge systems, the use of deluge protected cable entry devices and equipment should be considered.

[13]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

6.5.3 Connection of cables to enclosures/equipment—Hazardous locations, single and multiple cable entry devices

6.5.3.1 Class I Division 1

Suitable cables should be installed in accordance with 6.4.4 and be sealed at the point of entry to the equipment with a fitting that is tested and certified for use in the location and cable type. The cable sheath and any other covering should be removed so that the sealing compound/resin material surrounds each insulated conductor to minimize the passage of gasses or vapors. If present, uninsulated ground conductors should be sealed per the fitting manufacturer's installation instructions. Instrumentation cables containing shielded and twisted cable pairs do not require the removal of the shielding material or separation of the twisted pairs, provided the fitting is sealed with an approved means to minimize the entrance of gasses or vapors into the cable core.

6.5.3.2 Class I Division 2

Suitable cables should be installed in accordance with 6.4.4. If the enclosure or equipment contains any ignition capable components and is required to be explosion-proof, the cable should be sealed at the point of entry to the equipment with a fitting that is tested and certified for use in the location and for the specific cable type. The cable sheath and any other covering should be removed so that the sealing compound/resin material surrounds each insulated conductor to minimize the passage of gasses or vapors. If present, uninsulated ground conductors should be sealed per the fitting manufacturer's installation instructions. Instrumentation cables containing shielded and twisted cable pairs do not require the removal of the shielding material or separation of the twisted pairs, provided the fitting is sealed with an approved means to minimize the entrance of gasses or vapors into the cable core. If the enclosure or equipment does not contain any ignition capable components and is not required to be explosion-proof, the cable should be terminated per 6.5.2 (non-hazardous locations).

6.5.3.3 Class I Zone 0

Except for specific applications no electrical equipment or wiring of any kind is permitted unless part of an intrinsically safe circuit or system (protection technique 'ia', see IEC 60079-11 or UL 60079-11).

6.5.3.4 Class I Zone 1

Suitable cable types should be installed in accordance with 6.4.4. For flame-proof type 'd' enclosures or equipment, employing the protection technique AEx d IIA, IIB or IIC, or Ex d IIC, the cable should be sealed at the point of entry to the equipment with a fitting that is tested and certified for use in the location, and for the specific cable type and protection technique. The cable sheath and any other covering should be removed so that the sealing compound/resin material will surround each insulated conductor to minimize the passage of gasses or vapors. Any uninsulated ground conductors should be unwound/splayed open so that the sealing compound/resin surrounds each individual uninsulated strand. For installations conforming to IEC 60079-14, cable entry devices that utilize a sealing ring to perform the flame-proof seal are permitted in Ex d equipment provided they are selected in accordance with IEC 60079-14 Ed. 5.0 subclauses 9.3.2 and 10.6.2.

For increased safety type 'e' enclosures or equipment, employing the protection technique AEx e or Ex e, the cable should be terminated at the point of entry to the equipment with a fitting that is tested and certified for use in the location, and for the specific cable type and protection technique AEx e or Ex e.

Where armored cables are used, in addition to the requirements of 6.4.4, the armor should be effectively grounded by an entry device that is tested and certified for the cable type and applicable short-circuit values.

6.5.3.5 Class I Zone 2

Suitable cable types should be installed in accordance with 6.4.4 and be terminated in accordance with 6.5.3.4 (Class I Zone 1).

6.5.3.6 Grounding

All armor and/or metallic coverings on cables should be electrically continuous throughout their entire length and should be effectively grounded by a grounding type cable entry device that is tested and certified for the cable type and applicable short-circuit values.

6.6 Cable protection

Cables should be adequately protected where exposed to damage. Armored cables should be considered or may be required depending on application or location. Cables passing through tanks and where exposed on weather decks where they are particularly liable to damage, such as locations in way of cargo ports, hatches, tank entry trunks, and where crossing below walkways should be protected by installation in conduit, under angle iron supports, covered raceways, or equivalent means.

Where cables pass through insulation, a continuous conduit should protect them. For wiring entering refrigerated compartments, the conduit should be of thermal-insulating material (fiber or phenolic tubing) joined to the bulkhead stuffing tube, or a section of such material should be inserted between the bulkhead stuffing tube and the metallic conduit.

Where cables are installed in conduit, the space factor (ratio of the sum of the cross-sectional areas corresponding to the external diameter of the cables to the internal cross sectional areas of the conduit) shall not be greater than 0.40 except for two cables, where the space factor shall not exceed 0.31 and single cables, where the space factor shall not exceed 0.53. Conduits shall be so arranged or designed to prevent the accumulation of internal condensation.

6.7 Cable rodent protection

Cable penetration materials, such as plastic sealant and foams, should be resistant to vermin.

6.8 Cable support and retention

Cables should be adequately secured against displacement due to vibration, axial, lateral and torsional forces and to prevent excessive movement due to fault current magnetic forces. Multiple cables should be supported in metal hangers or trays, arranged as far as practicable to permit painting of the adjacent structure without undue disturbance of the installation. For cables subject to fault current magnetic forces, the cables should be securely bound in circuit groups (e.g., bundled in a triangular or triplex formation or single banked in flat formation), unless the cable retaining devices have been tested to provide secure binding in a double banked installation without compromising adjacent cables. Adequate space should be provided between those cables subject to fault current magnetic forces and any adjacent cables.

NOTE—Cables subject to fault current magnetic forces deflect violently during fault conditions due to the alternating attractive and repulsive magnetic fields. One method to mitigate cable damage is to provide at least 2.15 cable diameters of clear space adjacent to securely bound triangular and triplex circuit groups and at least one cable diameter of clear space adjacent to each securely bound single banked cable to accommodate cable deflection.

Installation of cables beyond double banking is not recommended for any cables. Control and signal cables should preferably be single banked, but may be double banked with other signal and control cables.

Clips or straps used for cable support should each be secured by two screws, except that clips for supporting one-cable, two-conductor 10 AWG or smaller may be of the one screw type. Metal buckles or other suitable methods should secure metallic band strapping used for cable support. Metallic band strapping used for cable support should be steel and corrosion treated if not a corrosion-resistant material. For single conductor cables, metallic band strapping should be non-ferrous. The support for all cables should prevent undue sag, but in no case should exceed the distance between frames or 610 mm (24 in), whichever is less. Metallic band strapping should be applied so the cables remain tight without damage to the cable insulation, armor or outer sheath. For single banked cable layers, the metallic band strapping may enclose the entire layer and need not be strapped around individual cables, except as required for cables that may be subject to fault current magnetic forces. Cable supports and retaining devices should accommodate any potential differential expansion between the cables and the retaining devices without cable damage. Cable retaining devices should accommodate any cable expansion that is likely to occur. Metallic staples shall not be used for fixing cables.

When metallic band strapping is used to secure cables, the installer should consider the use of cable support systems employing rungs that are slotted to facilitate the installation of the strapping. All cable restraint methods should be axially aligned with the cables such that the restraint devices are secured at right angles to the cable.

Metal supports should be designed to secure cables without damage to the insulation, armor, or outer sheath. The supports should be arranged such that the cable is supported for a length of at least 13 mm (0.51 in). Cables in vertical runs or installed such that the retaining devices carry some portion of the cable weight should be restrained by retaining devices of at least 13 mm (0.51 in) wide. Cable retention devices should be installed not less than every 610 mm (24 in) on vertical and horizontal runs, including turns. Non-metallic or composite retaining devices may be used in horizontal runs where cables will not fall if the retention devices fail. When non-metallic or composite cable retaining devices are used on exterior cable runs, they should be of a type resistant to ultraviolet light (sunlight). When non-metallic or composite cable retaining devices are used in exterior cable runs or interior vertical cable runs, they should have additional provisions for metallic band strapping to prevent cables from falling if the retention devices fail. When metallic band strapping is used in conjunction with non-metallic or composite cable retaining devices, the metallic band strapping may be less than 13 mm (0.51 in) wide, but should be designed to carry the weight of the applied cable load.

To prevent excessive movement due to fault current magnetic forces, cables should be securely bound in circuit groups. The cable retaining devices employed for the purpose of secure binding should comply with all of the following:

a) Capable of withstanding the maximum mechanical forces delivered during a fault.
b) Suitable for the specific cable size and available fault current.
c) After exposure to fault current, there should be no failure to the cable retaining devices that affects the intended function of holding the cables in place.
d) After exposure to a fault current, the cable retaining devices shall be intact with no missing parts.
e) There shall be no cuts or damage visible to normal or corrected vision to the outer sheath of the cable caused by the cable retaining devices.

NOTE 1—One technique to validate cable integrity after exposure to fault current magnetic forces is to measure the voltage withstand of the cable. IEC 61914 includes test procedures for cable retention devices.

NOTE 2—Since fault current magnetic forces imposed on cables and their retaining devices are dynamic in nature, the *mechanical* force withstand criteria should be demonstrated by short-circuit testing. Static tests are not representative of fault current magnetic forces. IEC 61914 includes test procedures for cable retention devices. Care should be taken during testing to ensure the test is representative of the installation, or is more severe than the installation.

NOTE 3—The mechanical force between conductors during a short circuit is a function of the current magnitude in each conductor, as well as the conductor spacing. The maximum mechanical force between two conductors can be calculated by the following formula (IEC 61914):

$$F = \frac{\mu_0 i_1 i_2}{2\pi S}$$

where

F = force (Newtons/meter)
μ_0 = magnetic permeability of air = $4\pi \times 10^{-7}$ N/A^2 (Newtons per ampere squared)
i_1 = instantaneous current magnitude in first conductor (amperes)
i_2 = instantaneous current magnitude in second conductor (amperes)
S = spacing between conductor centers (meters)

To calculate the maximum force between conductors, first compute the time dependent force vectors at each conductor due to each of the other conductors; then sum the vector components to determine the resultant force acting on each conductor. The calculations should take into account the symmetrical, asymmetrical and the unidirectional aperiodic current (i.e., dc offset) components of the short-circuit waveform. The calculations should evaluate the forces through at least two electrical cycles, beginning with the initiation of the fault and considering an adequate sampling of data points. The point of maximum force may not correspond to the peak amplitude of a waveform.

NOTE 4—During short-circuit conditions the current magnitude in one or more of the phases may exceed √2 times the RMS current value, and can theoretically be as great as 2*√2 times the RMS current value.

NOTE 5—One technique to restrain cables subject to fault current magnetic forces is through the use of cable cleats.

6.9 Radii of bends

Radii of bends during cable installation shall not be less than those listed Table 12. For specific cable types refer to cable manufacturer’s recommendations.

Table 12—Bending radii for cables rated up to 2 kV

Cable construction	Overall diameter of cable (D)	Minimum internal radius of bend
Unarmored	≤ 25mm	4 D
	> 25mm	6 D
Armored (braid armor)	Any	6 D
Armored (other armor types)	Any	7 D

Table 13—Bending radii for cables rated 2001–35,000 V

Cable construction	Overall diameter of cable (D)	Minimum internal radius of bend
Single conductor (tape shield)	Any	12 D
Multiconductor (tape shield)	Any	7 D
Unarmored (braid shield)	Any	6 D
Armored (braid shield)	Any	7 D

6.10 Cable pulling tension

Care should be taken to prevent damage to insulation or distortion of cable during installation. The conductors used in marine shipboard cables are made of fully annealed copper. As such the copper conductors do not have a truly defined tensile strength. The value of the tensile strength depends on the diameter of each strand in the conductor. The values cited in technical journals range from 165 500–241 300 kPa (24 000 psi to 35 000 psi).

The cable constructional details are shown in IEEE Std 1580. In view of the range of individual strand diameters allowed for in IEEE Std 1580, the value of 165 500 kPa (24 000 psi) has been used as the tensile strength of the fully annealed copper conductors in calculating the safe pulling tensions. This results in a value of 0.0036 kg (0.008 lb) per circular mil for fully annealed copper conductors. The pulling force in Newtons should not exceed 0.036 times the circular mil area of the copper cross-sectional area (see Table 10 and Table 11 in IEEE Std 1580-2010) times the number of conductors in the cable when pulling on the conductors utilizing pulling eyes and bolts.

When pulling single conductors in parallel, it is difficult to ensure equal tensions on each member. As such, it is recommended that the total maximum pulling tension be reduced by 20%.

For recommended maximum pulling tensions for specific conductor sizes and number of conductors when pulling by attachment to the conductors, refer to the tables in B.3.

In order to prevent the pulling tensions from adversely affecting the dc resistance of the installed cable, a safety factor of approximately 2.4 has been used in the calculations.

The following guidelines should be followed in pulling cables into raceways:

a) For multi-conductor cables with mixed conductor sizes, use only the larger conductors for pulling and for calculating the safe pulling tensions.

b) For composite cables consult the cable manufacturer for the safe pulling tensions.

c) Do not pull on drain wires or braids nor use them in calculating pulling tensions.

d) The recommended working load of the pulling rope should range from 10% to 25% of the breaking strength of the pulling rope. A rope with minimal stretch characteristics reduces surging during the pull.

e) Proper attention has to be given to the actual physical constraints involved in the pull. This includes attention to the direction of pull, number of bends, angle of bends, changes in elevation, weight of cable, jamming ratio, sidewall pressure on sheaves, method of attachment, clearance, etc. In case of doubt, consult the cable manufacturer for recommendations.

f) Do not exceed the working load recommended by the pulling device manufacturer.

g) For long cable pulls, a swivel is recommended to be installed between the pulling head and rope.

h) If pulling lubricants are required, use lubricants that are compatible with the insulation and/or jacket. Consult the cable manufacturer for more details.

i) Pull cables slowly and steadily and do not stop once the pull has started.

j) If basket grips are used, the back end of the grip should be securely fastened to the cable. If basket grips are used, the maximum pulling tension should be limited to the lesser of 4.5 kN (1000 lbf) or the calculated value for the cable being pulled.

k) The cable must be trained into the raceway to prevent it from dragging on the edge of the raceway entry edge.

l) For installations in cable tray, rollers should be employed and adequately spaced to prevent cables from dragging on the tray.

m) The ends of cables should be sealed with putty; silicone caulking or heat shrinkable end caps and overwrapped with tape to keep out moisture.

n) The pulling force must not exceed the smaller value of

    1) Allowable conductor tension,

    2) Rated pulling device tension, or

    3) Allowable sidewall load

o) The sidewall pressure should not exceed a maximum of 7.3 kN/m (500 lbf/ft) of the inside radius of the bend.

p) When installing low smoke cables, additional consideration should be given to handling and lubrication due to their possible lower tear strength and higher coefficient of friction compared to other marine cable.

For more information, refer to IEEE Std 1185™ [B11].

6.11 Cable splicing

6.11.1 Conditions

A cable may be spliced under the following conditions:

a) A cable installed in a structural subassembly may be spliced to a cable installed in another structural subassembly to facilitate modular construction techniques.

b) For a vessel receiving alterations, a cable may be spliced to extend a circuit.

c) A cable of exceptional length may be spliced to facilitate its installation.

d) A cable may be spliced to replace a damaged section when the remainder of the cable is determined to be in good mechanical and electrical condition.

Propulsion cable, cables for repeated flexing service, medium voltage cables, and cables in hazardous locations should not be spliced.

A cable terminated in a junction box is not considered a splice.

6.11.2 Procedure

Splices should be accessible. Cable splicing should consist of a conductor connector, replacement insulation, replacement cable jacket, and, where applicable, replacement armor and shielding. Cable splices should establish electrical continuity in conductors, armor, or shields. Manufacturer's installation instructions should be respected without modification. Unless conflicting with manufacturers' instructions, the following general procedures should be adhered to:

a) Conductors should be joined using a butt connector that meets UL 486A-486B. A long barrel butt connector with wire stops should be used for wire sizes 10 AWG or larger.

b) Splices in multiconductor cables should be staggered in such a way that the connector for each conductor is not contiguous to the connector of an adjacent conductor. The conductor insulation should be removed no more than necessary to accept the connector.

c) Conductor replacement insulation that has the same or a greater thickness than that of the cable insulation, and the same or better thermal and electrical properties of the cable, should be applied.

d) For shielded cables, replacement shielding should be provided and have the same or greater electrical properties. Replacement elements should be secured by a method that does not exert more pressure than necessary to establish adequate electrical contact. Shielded cables should have at least a 13 mm (0.51 in) overlap between replacement shielding material and the permanent shielding.

e) The replacement cable jacket material should have physical properties that are the same as, or equivalent to, the cable jacket. The replacement cable jacket should be centered over the splice and should overlap the existing cable jacket by at least 51 mm (2 in). The replacement cable jacket should be installed to make a watertight seal with the existing cable jacket.

Electrical continuity of any cable armor should be reestablished. A jumper of wire or braid, or replacement armor of the same metal, should be installed. For cable with a sheath over the armor, a replacement covering should be applied.

6.12 Medium voltage cable termination

Medium voltage shielded cable termination kits shall contain materials, which are compatible with the cables insulation, shields, and jacket. MV shielded cable terminations should be heat shrinkable or cold shrink designs compliant to class 1A of IEEE Std 48. Hand-taped terminations may also be acceptable. Termination shall provide a moisture barrier from the lug to the cable jacket. Medium voltage cable terminations should be qualified to class 1A of IEEE Std 48.

Terminations should be performed as follows:

a) Conductors should be connected using a compression type terminal connector that meets UL 486E.

b) The replacement cable jacket material should have physical properties that are the same as, or equivalent to, the cable jacket. The replacement cable jacket should be installed to make a watertight seal with the existing cable jacket.

c) Craftsmen competency: It is recommended that personnel performing terminations submit MV shielded cable certification of competency prior to terminations of shielded cables.

d) Manufacturers' installation instructions should be respected without modification.

e) Shields of medium voltage cable should be grounded at a minimum of one point for safety and reliable operation by means of a solder blocked tinned copper braid firmly affixed by a constant force spring, or by soldering. Refer to API RP14F for ramifications of single point versus multipoint grounding of shields.

f) In the case of armored cables, the armor should be grounded at a minimum of one point.

6.13 Cold temperature installation

Since most cable products are based on polymeric materials, the most significant influence of ambient 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/rubber type 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. Care should be taken when selecting cables for installation in cold temperatures. Consult the cable manufacturer for cold temperature installation recommendations.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] ASTM E119-14, Standard Test Methods for Fire Tests of Building Construction and Materials.

[B2] DIN 57472-501 VDE 0472-501:1983-04, Testing of Cables, Wires and Flexible Cords, Non-Halogen Verification.

[B3] IEC 60287-1-1 Ed. 2.1 Electric cables—Calculation of the current rating—Part 1-1: Current rating equations (100 % load factor) and calculation of losses—General.

[B4] IEC 60287-2-1 Ed. 2.0 Electric cables—Calculation of the current rating—Part 2: Thermal resistance—Section 1: Calculation of thermal resistance.

[B5] IEC 60754-2 Ed. 2.0, Test on gases evolved during combustion of materials from cables—Part 2: Determination of acidity (by pH measurement) and conductivity.

[B6] IEC 60949 Ed. 1.0, Calculation of Thermally Permissible Short-Circuit Currents, Taking Into Account Non-Adiabatic Heating Effects.

[B7] IEC 61158-2 Ed. 6.0, Industrial Communication Networks—Fieldbus Specifications—Part 2: Physical Layer Specification and Service Definition.

[B8] IEEE Std 141™-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants.

[B9] IEEE Std 575™, IEEE Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV.

[B10] IEEE Std 835™-1994, IEEE Standard Power Cable Ampacity Tables.

[B11] IEEE Std 1185™-2010, IEEE Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities.

[B12] MIL-STD-2042/1, Military Standard: Fiber Optic Cable Topology Installation Standard Methods for Naval Ships (Cables) (Part 1 of 7 Parts).

[B13] MIL-STD-2042/2, Military Standard: Fiber Optic Cable Topology Installation Standard Methods for Naval Ships (Equipment) (Part 2 of 7 Parts).

[B14] MIL-STD-2042/3, Military Standard: Fiber Optic Cable Topology Installation Standard Methods for Naval Ships (Cable Penetrations) (Part 3 of 7 Parts).

[B15] MIL-STD-2042/4, Military Standard: Fiber Optic Cable Topology Installation Standard Methods for Naval Ships (Cableways) (Part 4 of 7 Parts).

[B16] MIL-STD-2042/5, Military Standard: Fiber Optic Cable Topology Installation Standard Methods for Naval Ships (Connectors and Interconnections) (Part 5 of 7 Parts).

[B17] MIL-STD-2042/6, Military Standard: Fiber Optic Cable Topology Installation Standard Methods Ffor Naval Ships (Tests) (Part 6 of 7 Parts).

[B18] MIL-STD-2042/7, Military Standard: Fiber Optic Cable Topology Installation Standard Methods for Naval Ships (Pierside Connectivity Cable Assemblies and Interconnection Hardware) (Part 7 of 7 Parts).

[B19] MODUK DEF STAN 02-713, Determination of the Toxicity Index of Products of Combustion from Small Specimens of Materials—Issue 3 dated 2/2012.

Annex B

(informative)

Ancillary topics

B.1 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. Non-halogenated 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-DTL-24643C, CSA acid gas test, IEC 60754-2 Ed 2.0 [B5] and DIN 57472-501 VDE 0472-501:1983-04 [B2] acid gas tests. Actual corrosion measurements can also be made. Methods employed are the cone corrosimeter (ASTM committee D09.21) or the NBS radiant heat chamber (ASTM committee E5.21) which uses metal loss of a circuit board coupon to assess corrosivity.

B.2 Toxicity

The chemical analysis techniques used are spectroscopy, colorimetry, and chromatography. The MODUK DEF STAN 02-713 [B19] test standard is one such method.

B.3 Cable pulling tension

The following tables provide calculated maximum pulling tensions for cables with flexible conductors per IEEE Std 1580 when pulling by direct attachment to the conductors.

Table B.1—Maximum allowable conductor tension (lbs) for flexible conductors per IEEE Std 1580

Conductor size (AWG)	Number of conductors				
	1	2	3	4	5
22	6	12	18	24	30
20	10	19	29	39	49
18	15	30	46	61	76
16	19	39	58	78	97
14	31	61	92	123	153
12	49	97	146	195	244
10	83	165	248	330	413
8	120	239	359	478	598
6	197	394	591	789	986
5	294	588	882	1176	1471
4	333	667	1000	1333	1667
3	404	808	1212	1616	2020
2	485	970	1454	1939	2424

Conductor size (AWG)	Number of conductors				
	1	2	3	4	5
1	676	1351	2027	2702	3378
1/0	860	1719	2579	3439	4299
2/0	1050	2101	3151	4202	5252
3/0	1351	2702	4053	5404	6755
4/0	1719	3439	5158	6878	8597
262	2101	4202	6303	8403	10504
313	2505	5010	7515	10019	12524
373	2990	5979	8969	11959	14948
444	3555	7111	10666	14221	17776
535	4283	8565	12848	17130	21413
597	4783	9567	14350	19134	23917
646	5171	10343	15514	20685	25857
777	6222	12444	18665	24887	31109
1111	8888	17776	26665	35553	44441

NOTE—When pulling single conductors in parallel, it is difficult to ensure equal tension on each member. As such, it is recommended that the total maximum pulling tension be reduced by 20 %.

Table B.2—Maximum allowable conductor tension (lbs) for multi-conductor cables that have equal sized conductors and flexible conductors per IEEE Std 1580

Number of conductors	Conductor size (AWG)						
	22	20	18	16	14	12	10
2	12	19	30	39	61	97	165
3	18	29	46	58	92	146	248
4	24	39	61	78	123	195	330
5	30	49	76	97	153	244	413
6	36	58	91	116	184	292	495
7	42	68	106	136	215	341	578
8	48	78	122	155	245	390	660
9	54	88	137	175	276	438	743
10	60	97	152	194	306	487	826
11	66	107	167	213	337	536	908
12	72	117	182	233	368	584	991
13	78	126	198	252	398	633	1073
14	84	136	213	272	429	682	1156
15	90	146	228	291	460	731	1238
16	97	156	243	311	490	779	1321
17	103	165	258	330	521	828	1403
18	109	175	274	349	552	877	1486
19	115	185	289	369	582	925	1568
20	121	195	304	388	613	974	1651
21	127	204	319	408	644	1023	1734
22	133	214	334	427	674	1071	1816
23	139	224	350	446	705	1120	1899
24	145	233	365	466	736	1169	1981
25	151	243	380	485	766	1218	2064
26	157	253	395	505	797	1266	2146
27	163	263	410	524	827	1315	2229
28	169	272	426	543	858	1364	2311
29	175	282	441	563	889	1412	2394
30	181	292	456	582	919	1461	2477
31	187	302	471	602	950	1510	2559

Number of conductors	Conductor size (AWG)						
	22	20	18	16	14	12	10
32	193	311	486	621	981	1559	2642
33	199	321	502	640	1011	1607	2724
34	205	331	517	660	1042	1656	2807
35	211	340	532	679	1073	1705	2889
36	217	350	547	699	1103	1753	2972
37	223	360	562	718	1134	1802	3054
38	229	370	578	738	1165	1851	3137
39	235	379	593	757	1195	1899	3220
40	241	389	608	776	1226	1948	3302
41	247	399	623	796	1257	1997	3385
42	253	409	638	815	1287	2046	3467
43	259	418	654	835	1318	2094	3550
44	265	428	669	854	1349	2143	3632
45	271	438	684	873	1379	2192	3715
46	277	447	699	893	1410	2240	3797
47	284	457	714	912	1440	2289	3880
48	290	467	730	932	1471	2338	3962
49	296	477	745	951	1502	2386	4045
50	302	486	760	970	1532	2435	4128
51	308	496	775	990	1563	2484	4210
52	314	506	790	1009	1594	2533	4293
53	320	516	806	1029	1624	2581	4375
54	326	525	821	1048	1655	2630	4458
55	332	535	836	1067	1686	2679	4540
56	338	545	851	1087	1716	2727	4623
57	344	554	866	1106	1747	2776	4705
58	350	564	882	1126	1778	2825	4788
59	356	574	897	1145	1808	2874	4871
60	362	584	912	1164	1839	2922	4953
61	368	593	927	1184	1870	2971	5036

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