IEEE Std 45-1998
(Revision of IEEE Std 45-1983)

IEEE Recommended Practice for Electric Installations on Shipboard

Sponsor

Marine Transportation Committee
of the
IEEE Industry Applications Society

Approved 16 September 1998

IEEE-SA Standards Board

Abstract: Recommendations for the selection and installation of equipment on merchant vessels with electric apparatus for lighting, signaling, communication, power, and propulsion are provided.
Keywords: marine electrical engineering, marine vessels, shipboard systems, ships

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

ISBN 0-7381-0436-1

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Introduction

(This introduction is not part of IEEE Std 45-1998, IEEE Recommended Practice for Installations on Shipboard.)

IEEE Std 45-1998, IEEE Recommended Practice for Electric Installations on Shipboard, constitutes the chief undertaking of the Marine Transportation Committee of the IEEE Industry Applications Society.

Due to the differences among the requirements of the various classification societies and the insurance companies regarding electric installations on shipboard, and the lack of any accepted standard engineering practice for marine installations, the AIEE[1] in 1913 appointed the Marine Committee (now called Marine Transportation Committee) to take up the preparation of standard marine rules. The first edition was prepared covering two important divisions; namely, fire protection requirements and marine construction requirements. They were adopted by the American Bureau of Shipping and published as Section 37 of their Rules for the building and classing of vessels. As the first edition of the rules did not cover the entire field of use of electricity on shipboard, the Marine Committee of the Institute was continued. The recommendations were considerably amplified in the editions issued in 1920, 1927, 1930, 1938, 1940, 1945, 1948, 1951, 1955, 1958, 1962, 1967, 1971, 1977, and 1983.

This edition has been completely rewritten. It includes many significant additions, changes, and deletions to reflect North American and International marine electrical engineering technology and the latest system design, installation, and test practices necessary to ensure safe and reliable operation.

The following persons were on the Marine Transportation Committee and balloted to approve this document for submission to the IEEE Standards Board:

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[1]In 1963 the American Institute of Electrical Engineers (AIEE) merged with the Institute of Radio Engineers (IRE) to become the Institute of Electrical and Electronics Engineers, Inc. (IEEE).

Contents

IEEE Recommended Practice for Electric Installations on Shipboard

1. Overview and general recommendations

1.1 Scope

These marine recommendations are intended to serve as a guide for the selection and installation of equipment on merchant vessels with electric apparatus for lighting, signaling, communication, power, and propulsion. The recommendations define what are considered good present-day engineering practices with reference to the safety of the personnel and of the ship itself as well as reliability and durability of the apparatus. It is recognized that changes and improvements in shipboard requirements may develop which are not specifically covered herein; such changes, if incorporated in the design, should be equal to the safety and reliability levels defined herein and generally in accord with the text of these standards.

Specific nationally recognized standards are referenced in the text. Other standards should be followed to the extent possible.

Attention is directed to the fact that the rules for electrical installations on shipboard are promulgated by the regulatory agencies and the classing societies. Such rules have been given due consideration in these recommendations, but there may be differences among these provisions. Deference should always be made to the regulatory requirements where this standard offers contrary requirements, or where this standard may be silent.

1.2 Purpose

The main purpose of this standard is to provide a consensus of recommended practices in the unique field of marine electrical engineering as applied specifically to ships, shipboard systems, and equipment.

1.3 Vessel classification

Marine vessels and platforms are grouped as following:

— *Group No 1:* Ocean-going vessels that navigate on any ocean or the Gulf of Mexico 20 mi or more off shore.
— *Group No 2:* Ocean-going vessels that navigate on any ocean or the Gulf of Mexico but less than 20 mi off shore.
— *Group No 3:* Vessels navigating on the Great Lakes only.
— *Group No 4:* Vessels navigating bays, sounds, and lakes other than the Great Lakes.
— *Group No 5:* Vessels navigating rivers only.
— *Group No 6:* Fixed and floating offshore petroleum facilities.
— *Group No 7:* Recreational vehicles.

1.4 Applicability

These recommendations have been prepared for application to all vessels in Group 1 through 5. Group Nos 6 and 7 are governed by other standards.

1.5 Documentation

Every vessel should be provided with comprehensive sets of drawings and instruction books that provide complete and detailed information regarding the operation and maintenance of the systems and equipment installed. Drawings for each system should provide cable routing information, cable identification, cable sizes, loads, protective device settings, circuit data, conductor termination details, and material lists. Calculation of fault currents with associated breaker coordination curves should also be provided. Instruction books should include descriptions and illustrations that provide equipment operating instructions, maintenance procedures, test requirements, and spare parts recommendations. A booklet containing the manufacturer's name, size, type, rating, catalog number, or similar identification for all electrical and electronic equipment on the vessel should also be provided for use by shipboard personnel. An as-built one line diagram of the ship's power generation and distribution system should be permanently installed in a location accessible at all times to the engineering personnel.

1.6 Environmental conditions

1.6.1 Normal design and operating conditions

Systems and equipment should be suitable for continuous operation in the following normal conditions of shipboard service:

a) Continuous exposure to severe moisture- and salt-laden atmosphere, high wind velocity, and ice formation encountered at sea.
b) Average ambient temperature values of 40 °C (104 °F) in accommodation areas, and similar spaces; 45 °C (113 °F) in main and auxiliary machinery spaces; 50 °C (122 °F) for rotating machinery and propulsion equipment in main and auxiliary machinery spaces containing significant heat sources such as prime movers and boilers; 65 °C (149 °F) in the uptakes of machinery spaces containing prime movers and boilers; all at relative humidities up to 95%. The design value for sea water cooling temperature should be 32 °C (89.6 °F).
c) Roll and pitch of a vessel underway, as follows:

	Roll		Pitch	
	Static	Dynamic	Static	Dynamic
Ship service equipment	15°	22.5°	5°	7.5°
Emergency equipment	22.5°	22.5°	10°	10°
Switchgear	45°	45°	45°	45°

d) Vibration of a vessel underway: Electrical equipment should be constructed to withstand at least the following:
   1) Vibration frequency range of 5–50 Hz with a velocity amplitude of 20 mm/s.
   2) Peak accelerations due to ship motion in a seaway of ±0.6 g for ships exceeding 90 m in length, and ±1.0 g for smaller ships, with a duration of 5–10 s.

1.6.2 Abnormal design and operating conditions

Special conditions associated with a specific ship design or operating area may exist that require consideration by those responsible for the design and application of electrical systems and equipment. Examples of such conditions are as follows:

— Exposure to damaging fumes or vapors, excessive or abrasive dust, steam, salt spray, etc.
— Exposure to high levels of shock and vibration
— Exposure to excessively high or low temperatures
— Exposure to unusual to flammable atmospheres (See Clause 33)
— Exposure to unusual loading or unloading conditions affecting list and trim
— Unusual operating cycles, frequency of operation, poor power quality, special insulation requirements, stringent or difficult maintenance requirements, etc.

1.7 Equipment construction, testing, and certification

Electrical apparatus and equipment should be constructed and tested in accordance with the requirements of appropriate national and/or international equipment standards. Standards specifically addressing marine requirements should be used whenever applicable. Many appropriate standards are referenced in this document. The apparatus and equipment should be tested and certified by an independent product testing and certification organization that is routinely involved in testing such apparatus or equipment.

1.8 Materials

1.8.1 Corrosion-resistant parts

Where essential to minimize deterioration due to marine atmospheric corrosion, corrosion-resisting materials, or other materials treated in a satisfactory manner to render them adequately resistant to corrosion, should be used. Silver, corrosion-resisting steel, copper, brass, bronze, copper-nickel, certain nickel-copper alloys, and certain aluminum alloys are considered satisfactory corrosion-resisting materials.

The following treatments, when properly performed and of a sufficiently heavy coating, are considered satisfactory corrosion-resistant treatments:

— Electroplating of cadmium, nickel, chromium, silver, copper, or zinc
— Sherardizing
— Galvanizing

— Dipping and painting (phosphate or suitable cleaning, followed by the application of a coating system meeting the requirements of ASTM B117-95[1]).

These provisions apply to the following components:

— *Parts.* Interior small parts that are normally expected to be removed in service, such as bolts, nuts, pins, screws, cap screws, terminals, brushholder studs, springs, etc.
— Assemblies, subassemblies, and other units where necessary due to the unit function, or for interior protection, such as shafts within a motor or generator enclosure, and surface of stator and rotor.
— *Enclosures and their fastenings and fittings.* Enclosing cases for control apparatus, outer cases for signal and communication systems (both outside and inside), and similar items together with all their fastenings and fittings that would be seriously damaged or rendered ineffective by corrosion.

1.8.2 Flame-retardant materials

Flame-retardant materials and structures should be used to the maximum extent practicable throughout the vessel. These materials should have such fire-resisting properties that they will not convey flame nor continue to burn for longer times than specified in the appropriate flame test.

Compliance with the requirements of the preceding paragraph should be determined with the apparatus and according to the methods described in appropriate nationally recognized test laboratory standards for the materials and structures being considered, unless specific applicable tests are invoked in these recommendations.

1.9 Insulation

1.9.1 Preferred insulation system classifications

The preferred insulation system classifications are classes 105, 130, 155, 180, 200, 220, and 240 or greater (based upon maximum temperature limits in degrees Celsius), or A, B, F, H, N, R, and C and as designated by the equipment standard. Refer to Tables 5-1, 5-2, 14-1, 17-1, and 34-1 for dc and ac machine and equipment temperature limits applicable to the different insulation classes.

1.9.2 Brittle material

Porcelain or other brittle insulating materials should not be used for lamp sockets, receptacles, fuse blocks, etc., where the material is rigidly fastened by machine screws or equivalent.

1.10 Equipment enclosures

Equipment enclosures of the types defined in 3.7 (except for explosionproof enclosures), should be manufactured and tested in accordance with the requirements of ANSI/NEMA 250-1991 or IEC 60529: 1989.

2. References

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

ANSI C39.1-1981 (R 1992), Requirements for Electrical Analog Indicating Instruments.[2]

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

ANSI/ASTM D470-93, Standard Methods of Testing Crosslinked Insulations and Jackets for Wire and Cable.

ANSI/ASTM D2671-95, Standard Test Methods for Heat-Shrinkable Tubing for Electrical Use.

ANSI/ASTM D4066-94B Type VIII, Standard Test Methods for Determination of Relative Viscosity, Melting Point, and Moisture Content of Polyamide (PA).

ANSI/ISA-RP 12.6-1995, Wiring Practices for Hazardous (Classified) Locations—Instrumentation, Part I: Intrinsic Safety.

ANSI/NEMA FU1-1986, Low-Voltage Cartridge Fuses.

ANSI/NEMA ICS 1-1993, Industrial Control and Systems General Requirements.

ANSI/NEMA MG 1-1993, Motors and Generators.

ANSI/NEMA 250-1991, Enclosures for Electrical Equipment (1000 Volts Maximum).

ANSI/NFPA 70-1996, National Electrical Code.[3]

ANSI/NFPA 77-1993, Recommended Practice on Static Electricity.

ANSI/NFPA 99-1996, Standard for Health Care Facilities.

ANSI/NFPA 496-1993, Standard for Purged and Pressurized Enclosures for Electrical Equipment.

ANSI/UL 73-1993, Standard for Safety for Motor-Operated Appliances.

ANSI/UL 197-1993, Standard for Safety for Commercial Electric Cooking Appliances.

ANSI/UL 399-1993, Standard for Safety for Drinking-Water Coolers.

ANSI/UL 471-1995, Standard for Safety for Commercial Refrigerators and Freezers.

ANSI/UL 486A-1991, Standard of Safety for Wire Connectors and Soldering Lugs for Use With Copper Conductors.

ANSI/UL 913-1988, Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class II, and III, Division I, Hazardous Locations.

ANSI/UL 921-1992, Standard of Safety for Commercial Electric Dishwashers.

ANSI/UL 1309-1995, Standard for Safety Marine Shipboard Cable.

ANSI/UL 1581-1991, Reference Standard for Electrical Wires, Cables, and Flexible Cords.

ASTM B3-95, Standard Specification for Soft or Annealed Copper Wire.[4]

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[2] ANSI publications are available from the Sales Department of the American National Standards Institute, 11 West 42nd St., New York, NY 10018 USA.

[3] The National Electrical Code is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. Copies are available from the Sales Department of the American National Standards Institute.

[4] ASTM publications are available from the American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohochen, PA 19428 USA.

ASTM B8-95, Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft.

ASTM B33-94, Standard Specification for Tinned Soft or Annealed Copper Wire for Electrical Purposes.

ASTM B117-95, Standard Practice for Operating Salt Spray (Fog) Apparatus.

ASTM B172-95, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors.

ASTM B173-95, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors.

ASTM B174-95, Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors.

ASTM B189-95, Standard Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes.

ASTM D229-96, Standard Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation.

ASTM E662-97, Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials.

ASTM F1003-86 (R1992), Standard Specification for Searchlights on Motor Lifeboats.

ASTM F1166-95a, Standard Practice for Human Engineering Design for Marine Systems, Equipment and Facilities.

ASTM G23-96, Standard Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials.

CSA C22.1-1994, Canadian Electrical Code Part 1/Seventeenth Edition Safety Standard for Electrical Installations. [5]

CSA C22.2 No. 38-1995, Thermoplastic Insulated Wires and Cables; (Gen. Instr. 1).

Distribution, Power, and Regulating Transformers Standards Collection, 1995 Edition.[6]

ICEA T-28-562-1995, Test Method for Measurement of Hot Creep of Polymeric Insulations.[7]

IEC 60529: 1989, Degrees of protection povided by eclosures (IP Code).[8]

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.[9]

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[5] CSA Standards are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, M9W 193, Canada.
[6] This IEEE standards collection is available from IEEE, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331 USA.
[7] ICEA documents are available from the Insulated Cable Engineers Association, Inc., P.O. Box 440, South Yarmouth, MA 02663 USA and NEMA Customer Service 1300 North 17th Street, Suite 1847, Rosslyn, VA 22209 USA.
[8] IEC documents are available from the International Electrotechnical Commission, Case Postale 131, 3, Rue de Varembé, CH-1211, 1211 Genève 20, Switzerland/Suisse.
[9] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855 USA.

IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

IEEE Std 74-1958 (Reaff 1974), IEEE Standard for Test Code for Industrial Control (600 Volts or Less).[10]

IEEE Std 112-1996, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

IEEE Std 113-1973, IEEE Guide Test Code for Direct-Current Machines.[11]

IEEE Std 114-1982, IEEE Standard Test Procedure for Single-Phase Induction Motors.[12]

IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

IEEE Std 432-1992, IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp).

IEEE Std 444-1973 (Reaff 1992), Standard Practices and Requirements for Thyristor Converters for Motor Drives, Part 1—Converters for DC Motor Armature Supplies.

IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

IEEE Std 576-1989, IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry.

IEEE Std 835-1994, IEEE Standard Power Cable Ampacity Tables.

IEEE Std 1202-1991 (Reaff 1996), IEEE Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies.

IEEE Std C37.20.2-1993, IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear.

IEEE/ICEA S-135-1962, IEEE/ICEA Power Cable Ampacities—Copper Conductors (ICEA P-46-246).

IES RP-12-1998, Recommended Practice for Marine Lighting.[13]

IMO Resolution A.686 (20 January 1992), Code on Alarms and Indicators.[14]

MIL-C-17G, Cables, Radio Frequency, Flexible and Semirigid, General Specification for.[15]

MIL-C-24640A, Cable, Electrical, Lightweight for Shipboard Use, General Specification for.

MIL-C-24643A, Cable and Cords, Electrical, Low Smoke, for Shipboard Use, General Specification for.

MIL-HDBK-299-October 1994, Cable Comparison Handbook—Data Pertaining to Electric Shipboard Cable.

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[10] IEEE Std 74-1958 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704 USA, tel. (303) 792-2181.
[11] IEEE Std 113-1973 has been withdrawn. Copies can be obtained from Global Engineering.
[12] IEEE Std 114-1982 has been withdrawn. Copies can be obtained from Global Engineering.
[13] IES publications are available from CSSinfo, 310 Miller Avenue, Ann Arbor, MI 48103 USA.
[14] IMO publications are available from the International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England.
[15] MIL Specifications are available from Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Ave. Philadelphia, PA 19111-5094 USA.

MIL-W-16878F, Wire, Electrical, Insulated, General Specification for.

MIL-W-22759E, Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy.

NEMA AB1-1975, Molded Case Circuit Breakers.

NEMA SG3-1975, Low-Voltage Power Circuit Breakers.

NEMA ST1-1978, Specialty Transformers (Except General Purpose Type).

NEMA WC 3-1992, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-19-81).

NEMA WC 5-1992, Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-61-402).

NEMA WC 7-1988, Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-66-524).

NEMA WC 8-1988 (R1992), Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (ICEA S-68-516).

NES-711 Issue 2, January 1981, Determination of the Smoke Index of the Products of Combustion from Small Specimens of Materials, as modified in MIL-C-24643, paragraph 4.7.27.[16]

SOLAS Consolidated Edition, 1997, Consolidated text of the International Convention for the Safety of Life at Sea, 1974, and its Protocal of 1978: articles, annexes and certificates. Incorporating all amendments in effect from 1 July 1997.[17]

UL 44-1991, Standard for Safety for Rubber-Insulated Wires and Cables.[18]

UL 62-1991, Standard for Safety for Flexible Cord and Fixture Wire.

3. Definitions

3.1 General

3.1.1 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.

3.1.2 Alternating current (ac)

A periodic current with an average value over a period of time of zero. (Unless distinctly specified otherwise, the term refers to a current that reverses at regularly recurring intervals of time and that has alternately positive and negative values.)

[16] NES Standards are available from Procurement Executive, Ministry of Defense, Ship Department, Section TE112, Block G, Foxhill, Bath, England.
[17] SOLAS Publications are available from the International Maritime Organization.
[18] UL standards are available from Global Engineering.

3.1.3 Asynchronous machine

A machine in which the speed of operation is not proportional to the frequency of the system to which it is connected.

3.1.4 Capacitance (capacity)

That property of a system of conductors and dielectrics that permits the storage of electricity when potential differences exist between the conductors. Its value is expressed as the ratio of a quantity of electricity to a potential difference. A capacitance value is always positive.

3.1.5 Capacitor

A device with the primary purpose of introducing capacitance into an electric circuit. Capacitors are usually classified, according to their dielectrics, as air capacitors, mica capacitors, paper capacitors, etc.

3.1.6 Cargo vessel

A vessel that carries bulk, containerized, or roll-on/roll-off dry cargo, and no more than 12 passengers. Research vessels, search and rescue vessels, and tugs are also considered to be cargo vessels in these recommendations.

3.1.7 Cycle

The complete series of values of a periodic quantity that occurs during a period. (It is one complete set of positive and negative values of an alternating current.)

3.1.8 Direct current (dc)

A unidirectional current in which the changes in value (polarity) are either zero or so small that they may be neglected. (As ordinarily used, the term designates a practically nonpulsating current.)

3.1.9 Direct-current (dc) commutating machine

A machine that comprises a magnetic field excited from a dc source or formed of permanent magnets, an armature and a commutator connected therewith. Specific types of dc commutating machines are dc generators, motors, synchronous converters, boosters, balancers, and dynamotors.

3.1.10 Electric coupling

A device for transmitting torque by means of electromagnetic force in which there is no mechanical torque contact between the driving and driven members. The slip type electric coupling has poles excited by direct current on one rotating member, and an armature winding, usually of the double squirrel cage type, on the other rotating member.

3.1.11 Electronics

That branch of science and technology that relates to devices in which conduction is principally by electrons moving through a vacuum, gas, or semiconductor.

3.1.12 Embedded temperature detector

A resistance thermometer or thermocouple built into a machine for the purpose of measuring the temperature.

3.1.13 Frequency

The number of periods occurring in unit time of a periodic quantity, in which time is the independent variable.

3.1.14 Hertz (Hz)

The unit of frequency, one cycle per second.

3.1.15 Induction machine

An asynchronous ac machine that comprises a magnetic circuit interlinked with two electric circuits, or sets of circuits, rotating with respect to each other and in which power is transferred from one circuit to another by electromagnetic induction. Examples of induction machines are induction generators, induction motors, and certain types of frequency converters and phase converters.

3.1.16 Loran

A long-range radio navigational aid of the hyperbolic type whose position lines are determined by the measurement of the difference in the time of arrival of synchronized pulses. (These devices are rapidly being replaced by satellite-based global positioning systems.)

3.1.17 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.

3.1.18 Passenger vessel

A vessel that carries more than 12 persons in addition to the crew.

3.1.19 Radar

A device that radiates electromagnetic waves and utilizes the reflection of such waves from distant objects to determine their existence or position.

3.1.20 Reactance

The imaginary component (± j, or ± 90° phase angle) of impedence, where resistance is the real component with a zero phase angle. Reactance appears in two forms, one as a capacitive reactance (Xc) for a capacitor (C), and the other as inductive reactance (X_l) for an inductor (L). The former has the negative 90° phase angle, and the latter a positive 90° angle. Their values can be expressed in the following relationships:

$$Xc = -j\frac{1}{2\pi\ fC}\text{, and } X_l = j2\pi\, fL,$$

where f is the excitation frequency.

3.1.21 Reactor

A device with the primary purpose of introducing reactance into an electric circuit for purposes such as motor starting, paralleling transformers, and control of current.

3.1.22 Semiconductor rectifier

A device consisting of a conductor and semiconductor forming a junction. The junction exhibits a difference in resistance to current flow in the two directions through the junction. This results in effective current flow in one direction only. The semiconductor rectifier stack is a single columnar structure of one or more semiconductor rectifier cells.

3.1.23 Single-phase circuit

A circuit energized by a single alternating electromotive force.

NOTE—A single-phase circuit is usually supplied through two conductors. The currents in these two conductors, counted outward from the source, differ in phase by 180° or a half cycle.

3.1.24 Slip

In an induction machine, the difference between its synchronous speed and its operating speed. It may be expressed in the following ways:

a) As a percent of synchronous speed
b) As a decimal fraction of synchronous speed
c) Directly in revolutions per minute

3.1.25 Synchronous machines

A machine in which the average speed of normal operation is exactly proportional to the frequency of the system to which it is connected.

3.1.26 Tank vessel

A vessel that carries liquid or gaseous cargo in bulk.

3.1.27 Three-phase circuit

A combination of circuits energized by alternating electromotive forces that differ in phase by one-third of a cycle (120°).

NOTE—In practice, the phases may vary several degrees from the specified angle.

3.2 Cable installation

3.2.1 Lug

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

3.2.2 Multicable penetrator

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.

3.3 Generators

3.3.1 Brushless exciter

An ac (rotating armature type) exciter whose output is rectified by semiconductor devices to provide excitation to an electric machine. The semiconductor devices are mounted on, and rotate with, the ac exciter armature.

3.3.2 Brushless synchronous machine

A synchronous machine that has a brushless exciter with its rotating armature and semiconductor devices on a common shaft with the field of the main machine. This type of machine has no collector, commutator, or brushes.

3.3.3 Compound-wound generator

A dc generator that has two separate field windings. One supplies the predominating excitation, and is connected in parallel with the armature circuit. The other supplies only partial excitation and is connected in series with the armature circuit. It is proportioned to require an equalizer connection for satisfactory parallel operation.

3.3.4 Electric generator

A machine that transforms mechanical power into electric power.

3.3.5 Exciter

The source of all or part of the field current for the excitation of an electric machine.

3.3.6 Homopolar generator

A dc generator in which the magnetic field flux passes in the same direction from one member to the other over the whole of a single air gap area. Characteristically the machines are high-current, low-voltage generators.

3.3.7 Induction generator

An induction machine driven above synchronous speed by an external source of mechanical power.

3.3.8 Inductor type synchronous generator

A generator in which the field coils are fixed in magnetic position relative to the armature conductors. The electromotive forces are produced by the movement of masses of magnetic material.

3.3.9 Permanent magnet generator

An electric generator in which the magnetic flux is provided by one or more pairs of permanent magnets.

3.3.10 Pilot exciter

The source of all or part of the field current for the excitation of another exciter.

3.3.11 Polyphase synchronous generator

A generator whose field circuits are arranged so that two or more symmetrical alternating electromotive forces with definite phase relationships are produced at the terminals. Polyphase synchronous generators are usually two-phase, producing two electromotive forces displaced 90 electrical degrees apart, or three-phase, producing three electromotive forces displaced 120 electrical degrees apart. (Polyphase generators used for marine services are generally three phase.)

3.3.12 Shunt-wound generator

A dc generator in which the entire field excitation is ordinarily derived from one winding consisting of many turns with a relatively high resistance. This winding is connected in parallel with the armature circuit in a self-excited generator. In a separately excited generator, the winding is connected to the load side of another generator or another dc source.

3.3.13 Single-phase synchronous generator

A generator that produces a single alternating electromotive force at its terminals. It delivers electric power that pulsates at double frequency.

3.3.14 Stabilized shunt-wound generator

Same as the shunt-wound type, except that a series field winding is added. The series field winding is proportioned such that it does not require equalizers for satisfactory parallel operation. The voltage regulation of this type of generator should be the same as shunt-wound generators.

3.3.15 Synchronous generator

A synchronous ac machine that transforms mechanical power into electric power. (A synchronous machine is one in which the average speed of normal operation is exactly proportional to the frequency of the system to which it is connected.)

3.3.16 Variable speed constant frequency generator (VSCF)

An ac generator designed to have a constant frequency output with a variable speed input. This may be accomplished with an induction generator having an ac/ac converter feedback circuit that excites the wound rotor at a frequency to produce a constant frequency output. This may also be accomplished by a synchronous generator whose variable output frequency is fed into a frequency changer that produces a constant output frequency. Basic frequency changers may be of the cycloconverter or dc link type.

3.4 Motors

3.4.1 Adjustable-speed motor

A motor whose speed can be varied gradually over a range of speeds, but when once adjusted remains practically unaffected by the load, such as a dc shunt-wound motor with field resistance control designed for a range of speed adjustments.

3.4.2 Adjustable-varying-speed motor

A motor whose speed can be adjusted gradually, but when once adjusted for a given load will vary with change in load; such as a dc compound-wound motor adjusted by field control or a wound-rotor induction motor with speed control.

3.4.3 Amortisseur winding

A permanently short-circuited winding used for starting induction motors consisting of conductors embedded in the pole shoes of a synchronous machine and connected together at the ends of the poles, but not necessarily connected between poles.

3.4.4 Base speed of an adjustable-speed motor

The lowest speed obtained at rated load and rated voltage at the specified temperature rise.

3.4.5 Breakdown torque

The maximum torque a motor will develop, with rated voltage applied at rated frequency, without an abrupt drop in speed.

3.4.6 Compound-wound motor

A dc motor that has two separate field windings: one, usually the predominating field, connected in parallel with the armature circuit, and the other connected in series with the armature circuit. Speed and torque characteristics are between those of shunt and series motors.

3.4.7 Continuous duty

A requirement of service that demands operation at a constant load for an indefinite period of time.

3.4.8 Electric motor

A machine that transforms electric power into mechanical power.

3.4.9 Induction motor

A polyphase ac motor in which the secondary field current is created solely by induction. The motor operates at less than synchronous speed and less than unity power factor. The operating speed is dependent on the frequency of the power source. It is generally the motor of choice for auxiliary drives.

3.4.10 Intermittent duty

A requirement of service that demands operation for alternate periods (1) load and no load; or (2) load and rest; or (3) load, no load and rest, as specified.

3.4.11 Locked-rotor torque

The minimum torque of a motor developed for all angular positions of the rotor, when at rest, and with rated voltage and frequency applied.

3.4.12 Motor reduction unit

A motor with an integral mechanical means of obtaining a speed different from the speed of the motor.

NOTE—Motor reduction units are usually designed to obtain a speed lower than that of the motor, but may also be built to obtain a speed higher than that of the motor.

3.4.13 Multispeed motor

A motor that can be operated at any one of two or more definite speeds, each being practically independent of the load. For example, a dc motor with two armature windings, or an induction motor with windings capable of various pole groupings.

3.4.14 Pull-out torque

The maximum sustained torque that a synchronous motor will develop at synchronous speed with rated voltage applied at rated frequency and with normal excitation.

3.4.15 Series-wound motor

A dc motor in which the field circuit and armature circuit are connected in series. Speed is inversely proportional to the square root of load torque. Motor operates at a much higher speed at light load than at full load.

3.4.16 Shunt-wound motor

A dc motor in which the field circuit is connected either in parallel with the armature circuit or to a separate source of excitation voltage.

3.4.17 Squirrel-cage induction motor

A motor in which the secondary circuit consists of a squirrel-cage winding suitably disposed in slots in the secondary core.

3.4.18 Squirrel-cage winding

A permanently short-circuited winding, usually uninsulated (primarily used in induction machines) having its conductors uniformly distributed around the periphery of the machine and joined by continuous end rings.

3.4.19 Stabilized shunt-wound motor

A shunt-wound motor that has a light series winding added to prevent a rise in speed, or to obtain a slight reduction in speed, with increase of load.

3.4.20 Synchronous motor

A polyphase ac motor with separately supplied dc field and an auxiliary (amortisseur) winding for starting purposes. The operating speed is fixed by the frequency (f) of the system and the number of poles (p) of the motor. (Synchronous speed (r/min) = 120 f/p). Thus the speed of the motor can be varied by varying the frequency of the power source. The synchronous motor generally operates at unity power factor and can be used to improve the system power factor. It is generally the motor of choice for ac propulsion systems.

3.4.21 Torque margin

The increase in torque above rated torque to which a motor may be subjected without the motor pulling out of step. This is of particular concern with electric propulsion systems.

3.4.22 Universal motor

A series-wound or a compensated series-wound motor designed to operate at approximately the same speed and output on either a direct- or single-phase alternating current of a frequency not greater than 60 Hz and of approximately the same rms voltage.

3.4.23 Varying-speed motor

A motor whose speed varies with the load, ordinarily decreasing when the load increases, such as a series-wound or repulsion motor.

3.4.24 Wound-rotor induction motor

An induction motor in which the secondary circuit consists of polyphase winding or coils whose terminals are either short-circuited or closed through suitable circuits. (When provided with collector or slip rings, it is also known as a slip-ring induction motor.)

3.5 Converters

3.5.1 Cycloconverter/synchroconverter

A converter using controlled rectifier or transistor devices that has the capability of adjusting the frequency and proportional voltage of the output waveform to provide speed control of motors.

3.5.2 Direct-current balancer

A machine that comprises two or more similar dc machines (usually with shunt or compound excitation) directly coupled to each other and connected in series across the outer conductors of a multiple wire system of distribution, for the purpose of maintaining the potentials of the intermediate conductors of the system, which are connected to the junction points between the machines.

3.5.3 Dynamotor

A form of converter that combines both motor and generator action, with one magnetic field and with two armatures or with one armature having separate windings.

3.5.4 Motor-generator set

A machine that consists of one or more motors mechanically coupled to one or more generators to convert electric power from one frequency to another, or to create an isolated power source.

3.5.5 Power inverter

A component for converting dc power into ac power.

3.5.6 Rectifier

A component for converting ac to dc by inversion or suppression of alternate half cycles.

3.5.7 Static converter/inverter

A unit that employs solid state devices such as semiconductor rectifiers or controlled rectifiers (thyristors), gated power transistors, electron tubes, or magnetic amplifiers to change ac power to dc power, dc power to ac power, or fixed frequency ac power to variable frequency ac power.

3.5.8 Synchronous converter

A converter that combines both motor and generator action in one armature winding and is excited by one magnetic field. It is normally used to change ac power to dc power, or to create an isolated ac power source.

3.6 Rotating machine ventilation

3.6.1 Enclosed self-ventilated machine

A machine that has openings for the ventilating air circulated by means integral with the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet ducts or pipes may be connected.

3.6.2 Enclosed separately ventilated machine

A machine that has openings for ventilating air circulated by means external to and not a part of the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet duct pipes may be connected to them.

3.6.3 Open machine

A machine that has ventilating openings that permit passage of external cooling air over and around the windings.

3.6.4 Self-ventilated machine

A machine that has its ventilating air circulated by means integral with the machine.

3.6.5 Separately ventilated machine

A machine that has its ventilating air supplied by an independent fan or blower external to the machine.

3.6.6 Totally enclosed fan-cooled machine (TEFC)

A totally enclosed machine equipped for exterior cooling by means of a fan or fans integral with the machine but external to the enclosing parts.

3.6.7 Totally enclosed non-ventilated machine (TENV)

A machine enclosed to prevent the free exchange of air between the inside and outside of the case, but not sufficiently enclosed to be airtight.

3.6.8 Totally enclosed water/air cooled machine (TEWAC)

A totally enclosed machine with integral water-to-air heat exchanger and internal fan to provide closed-loop air cooling of the windings.

3.7 Equipment enclosures

NOTE—NEMA enclosure type designations and IEC enclosure ingress protection (IP) designations are indicated in parentheses, e.g., (NEMA 1) or (IP 11). See Annex A for additional information.

3.7.1 Dripproof enclosure

An enclosure in which the openings are so constructed that drops of liquid or solid particles falling on the enclosure at any angle not greater than 15° from the vertical either cannot enter the enclosure, or if they do enter the enclosure, they will not prevent the successful operation of, or cause damage to, the enclosed equipment (NEMA 2 or 12) (IP 32).

3.7.2 Dustproof enclosure

An enclosure so constructed or protected that any accumulation of dust that may occur within the enclosure will not prevent the successful operation of, or cause damage to, the enclosed equipment (NEMA 5) (IP 54).

3.7.3 Dusttight enclosure

An enclosure constructed so that dust cannot enter (NEMA 4/4X) (IP 66).

3.7.4 Explosionproof enclosure

An enclosure designed and constructed to withstand an explosion of a specified flammable gas or vapor that may occur within it, and to prevent the ignition of flammable gas or vapor in the atmosphere surrounding the enclosure by sparks, flashes, or explosions of the specified gas or vapor that may occur within the enclosure (see Annex A).

NOTE—Explosionproof apparatus should bear a nationally recognized independent testing laboratory approval rating of the proper class and group consonant with the spaces in which flammable volatile liquids, flammable gases, mixtures, or highly flammable substances may be present.

3.7.5 General-purpose enclosure

An enclosure that primarily protects against accidental contact and slight indirect splashing but is neither dripproof nor splashproof (NEMA 1) (IP 11).

3.7.6 Guarded enclosure

An enclosure in which all openings giving direct access to live or rotating parts (except smooth rotating surfaces) are limited in size by the structural parts or by screens, baffles, grilles, expanded metal, or other means to prevent accidental contact with hazardous parts. The openings in the enclosure shall be such that they will not permit the passage of a rod larger than 12 mm (1/2 in) in diameter, except where the distance of exposed live parts from the guard is more than 102 mm (4 in); then the openings may be of such shape as not to permit the passage of a rod larger than 19 mm (3/4 in) in diameter (NEMA 1) (IP 21).

3.7.7 Oilproof enclosure

An enclosure constructed so that oil vapors, or free oil not under pressure, that may accumulate within the enclosure will not prevent successful operation of, or cause damage to, the enclosed equipment (NEMA 13) (IP 65).

3.7.8 Oiltight enclosure

An enclosure constructed so that oil vapors or free oil not under pressure, which may be present in the surrounding atmosphere, cannot enter the enclosure (NEMA 13) (IP 65).

3.7.9 Semi-guarded enclosure

An enclosure in which all of the openings, usually in the top half, are protected as in the case of a “guarded enclosure,” but the others are left open (NEMA 1) (IP 11).

3.7.10 Splashproof enclosure

An enclosure in which the openings are so constructed that drops of liquid or solid particles falling on the enclosure or coming towards it in a straight line at any angle not greater than 100° from the vertical cannot enter the enclosure either directly or by striking and running along a surface (NEMA 3S) (IP 54).

3.7.11 Submersible enclosure

An enclosure constructed so that the equipment within it will operate successfully when submerged in water under specified conditions of submergence depth and time (NEMA 6P) (IP 68).

3.7.12 Waterproof enclosure

An enclosure constructed so that any moisture or water leakage that may occur into the enclosure will not interfere with its successful operation. In the case of motor or generator enclosures, leakage that may occur around the shaft may be considered permissible provided it is prevented from entering the oil reservoir and provision is made for automatically draining the motor or generator enclosure (NEMA 4/4X) (IP 66).

3.7.13 Watertight enclosure

An enclosure constructed so that a stream of water from a hose not less than 25 mm (1 in) in diameter under a head of 10 m (35 ft) from a distance of 3 m (10 ft) can be played on the enclosure from any direction for a period of 15 min without leakage. The hose nozzle shall have a uniform inside diameter of 25 mm (1 in). (NEMA 6) (IP 67).

3.8 Control apparatus and switchgear

3.8.1 Across-the-line starter

A device that connects the motor to the supply without the use of a resistance or autotransformer to reduce the voltage. It may consist of a manually operated switch or a master switch, which energizes an electromagnetically operated contactor.

3.8.2 Automatic starter

A starter in which the influence directing its performance is automatic.

3.8.3 Autotransformer starter

A starter that includes an autotransformer to furnish a reduced voltage for starting a motor. It includes the necessary switching mechanism and is frequently called a compensator or autostarter.

3.8.4 Circuit breaker interrupting rating (rated short-circuit current)

For an unfused circuit breaker, the designated limit of available (prospective) current at which the circuit breaker is required to perform its short-circuit current duty cycle at rated maximum voltage under the prescribed test conditions. This current is expressed as the rms symmetrical value envelope at a time ½ cycle after short-circuit is initiated. (For dc breakers, the rated interrupting current is the maximum value of direct current.)

3.8.5 Constant-torque resistor

A resistor for use in the armature or rotor circuit of a motor in which the current remains practically constant throughout the entire speed range.

3.8.6 Control circuit

The circuit that carries the electric signals of a control apparatus or system directing the performance of the controller but that does not carry the main power circuit.

3.8.7 Electric controller

A device (or group of devices) that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected.

3.8.8 Fan duty resistor

A resistor for use in the armature or rotor circuit of a motor in which the current is approximately proportional to the speed of the motor.

3.8.9 Full magnetic controller

An electric controller having all of its basic functions performed by devices that are operated by electromagnets.

3.8.10 Indicating circuit

That portion of the control circuit of a control apparatus or system that carries the results of logic functions to visual or audible devices that indicate the state of the apparatus controlled.

3.8.11 Manual controller

An electric controller having all of its basic functions performed by devices that are operated by hand.

3.8.12 Master switch

A switch that dominates the operation of contactors, relays, or other remotely operated devices.

3.8.13 Molded-case circuit breaker

A circuit breaker assembled as an integral unit in a supporting and enclosing housing of insulating material; the overcurrent and tripping means being of the thermal type, the magnetic type, the electronic type, or a combination thereof.

3.8.14 Overcurrent protection (overload protection)

The effect of a device, operative on excessive current (but not necessarily on short circuit), to cause and maintain the interruption of current flow to the device governed.

3.8.15 Overload relay

An overcurrent relay that functions at a predetermined value of overcurrent to cause the disconnection of the power supply.

NOTE—An overload relay is intended to protect the motor or controller and does not necessarily protect itself.

3.8.16 Rated continuous current

The designed limit in rms amperes or dc amperes that a switch or circuit breaker will carry continuously without exceeding the limit of observable temperature rise.

3.8.17 Resistor

A device with the primary purpose of introducing resistance into an electric circuit. (A resistor as used in electric circuits for purposes of operation, protection, or control, commonly consists of an aggregation of units. Resistors, as commonly supplied, consist of wire, metal, ribbon, cast metal, or carbon compounds supported by or embedded in an insulating medium. The insulating medium may enclose and support the resistance material as in the case of the porcelain tube type or the insulation may be provided only at the points of support as in the case of heavy duty ribbon or cast iron grids mounted in metal frames.)

3.8.18 Semimagnetic controller

An electric controller having only part of its basic functions performed by devices that are operated by electromagnets.

3.8.19 Solid state controller

An electric controller that utilizes a static power converter as the primary switching device.

3.8.20 Starter

An electric controller that is used to accelerate a motor from rest to normal speed and to stop the motor. (A device designed for starting a motor in either direction of rotation includes the additional function of reversing and should be designated a controller.)

3.8.21 Step-back relay

A relay that operates to limit the current peaks of a motor when the armature or line current increases. A step-back relay may, in addition, operate to remove such limitations when the cause of the high current has been removed.

3.8.22 Temperature compensated overload relay

A device that functions at any current in excess of a predetermined value essentially independent of the ambient temperature.

3.8.23 Undervoltage or low-voltage protection

The effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power in the main circuit.

3.8.24 Undervoltage or low-voltage release

The effect of a device, operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit, but not to prevent the re-establishment of the main circuit on return of voltage.

3.9 Insulation system

An assembly of insulating materials in a particular type of equipment. The class of the insulation system may be designated by letters, numbers, or other symbols. An insulation system class utilizes material having an appropriate temperature index and operates at such temperatures above stated ambient temperatures as the equipment standard specifies based on experience or accepted test data. The system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy.

3.10 Types of circuits and terms

3.10.1 Appliance branch circuit

A circuit that supplies energy to one or more outlets to which appliances are connected. These circuits have no permanently connected lighting fixtures that are not a part of an appliance.

3.10.2 Attachment plug

A device that, by insertion in a receptacle, establishes connection between the conductors of an attached cord and the conductors connected permanently to the receptacle.

3.10.3 Branch circuit (or final subcircuit)

That portion of a wiring system that extends beyond the final overcurrent device protecting the circuit.

3.10.4 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.

3.10.5 Controller

A device or group of devices used to control in a predetermined manner the electric power delivered to the apparatus to which it is connected.

3.10.6 Demand factor

The ratio of the operating load demand of a system or part of a system to the total connected load of the system or part of the system under consideration.

3.10.7 Disconnecting means

A device or group of devices used to disconnect the conductors of a circuit from the source of supply.

3.10.8 Distribution center (load center)

Enclosed apparatus that consists of automatic protective devices connected to bus bars, to subdivide the feeder supply and provide control and protection of subfeeders or branch circuits.

3.10.9 Distribution panel

A panel that receives energy from a switchboard or a distribution center and distributes power to energy-consuming devices.

3.10.10 Emergency switchboard

A switchgear and control assembly that receives energy from the emergency generating plant and distributes directly or indirectly to all emergency loads.

3.10.11 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.)

3.10.12 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. Test conditions generally consider opening, shorting, grounding, or field wiring, along with failures in the circuit. See ANSI/UL 913-1988 for specific information on test conditions.

3.10.13 Lighting branch circuit

A circuit that supplies energy to lighting outlets. A lighting branch circuit may also supply portable desk or bracket fans, small heating appliances, motors of 190 W (1/4 hp) and less, and other portable apparatus of not over 600 W each.

3.10.14 Lighting outlet

An outlet intended for the direct connection of a lamp holder or a lighting fixture.

3.10.15 Motor branch circuit

A branch circuit that supplies energy to one or more motors and associated motor controllers.

3.10.16 Motor control center (MCC)

A group of devices assembled for the purpose of switching and protecting a number of load circuits. The control center may contain transformers, contactors, circuit breakers, protective, and other devices intended primarily for energizing or de-energizing load circuits.

3.10.17 Outlet

A point on the wiring system at which current is taken to supply utilization equipment.

3.10.18 Power (or ship service) switchboard

A switchgear and control assembly that receives energy from the main generating plant and distributes directly or indirectly to all equipment supplied by the generating plant.

3.10.19 Receptacle

A device installed in a receptacle outlet to accommodate an attachment plug.

3.10.20 Receptacle outlet

An outlet where one or more receptacles is installed.

3.10.21 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, fire fighting, emergency power, emergency lighting, electronics, and communications functions. The identification of all vital services in a particular vessel is generally specified by the government regulatory agencies.

3.11 Automatic or centralized control systems

3.11.1 Centralized control

The local, remote, or programmed operations of more than one equipment or system from one central control station in a common area or room by a broadly skilled operator or supervisory system.

3.11.2 Computer-assisted system

A system that utilizes separate and standalone computers or processors for arithmetic computational and logic functions. All data manipulation and evaluation (e.g., alarm condition annunciation) functions are performed by the system.

3.11.3 Computer-based system

A system that utilizes one or more embedded computers or processors to perform its functions.

3.11.4 Control space

A dedicated area or compartment provided with equipment such as control consoles, gauge boards, control bench boards, switchboards, instrumentation, displays, control switches, communications, and other equipment for the local, remote, or programmed control and monitoring of equipment. The control system equipment may be operated by one or more individuals acting together or independently.

3.11.5 Failsafe

A characteristic where, upon failure or malfunction of a component, subsystem, or system, the output automatically reverts to a predetermined design state of least critical consequence. Typical failsafe states are listed as follows:

Typical failsafe states

System or component	Preferred failsafe states
Cooling water valve	As is or open
Alarm system	Annunciate
Burner valve	Shutdown, limited, or as is an alarm
Propulsion speed control	As is
Feedwater valve	As is or open
Controllable pitch propeller	As is
Propulsion safety trip	As is and alarm

3.11.6 Line replaceable unit (LRU)

The smallest or lowest piece of equipment or subassembly that is replaceable onboard the vessel. Systems and subsystems may contain multiple numbers of LRUs. Typical LRUs include circuit cards, sealed bearings, and drive motors.

3.11.7 Machinery control room

An enclosed or separated space generally located within the machinery spaces that functions as a central control station.

4. Power system characteristics

4.1 Standard systems

The following distribution systems are recognized as standard:

a) Two-wire with single-phase ac, or dc
b) Three-wire with single-phase ac, or dc
c) Three-phase, three-wire, ac
d) Three-phase, four-wire, ac

4.2 Standard voltages

The following voltages are recognized as standard:

Standard	AC (V)	DC (V)
Power utilization	115-200-220-230-350-440-460-575-660-2300-3150-4000-6000-10600-13460	115 and 230
Power generation	120-208-230-240-380-450-480-600-690-2400-3300-4160-6600-11000-13800	120 and 240

4.3 Standard frequency

For ac lighting and power systems, 50 Hz and 60 Hz are standard frequencies.

4.4 Selection of voltage and system type

For small vessels having minimal power apparatus (up to 15 kW), 120 V, three-phase or single-phase generators may be used, with 115 V, three-phase or single-phase distribution for power and lighting. Single-phase lighting feeders should be balanced at the switchboard to provide approximately equal load on the three-phase system.

For intermediate size vessels with power apparatus (up to 100 kW), generators may be 230 V, three-phase or 240 V, three-phase; the power utilization at 220 V or 230 V three-phase, respectively; and lighting distribution at 120 V, three-phase, three-wire or, 208/120 V three-phase, four-wire. Power and lighting utilization should be at 200/115 V, three-phase.

For large vessels of a size and type that require a dual voltage system (two systems isolated by transformers operating at different voltages), first consideration should be given to 450 V, 480 V, 600 V, or 690 V generation with power utilization at 440 V, 460 V, 575 V or 660 V, respectively, and lighting distribution at 120 V or 230 V three-phase, three-wire; or 120/208 V, three-phase, four-wire.

For vessels having a very large electrical system requiring higher-voltage power generation, consideration should be given to generating at 6600 V, 4160 V, or 2400 V with some power utilization at 6000 V, 4000 V, or 2300 V, three-phase, respectively, with lower utilization voltages to be derived from transformers.

For vessels requiring dc power generation, and having little power apparatus, 120 Vdc generators are recommended with a 115 Vdc lighting and power distribution system. Where an appreciable amount of dc power apparatus is provided, 240/120 Vdc, three-wire generators and 230 Vdc power distribution system and 230/115 Vdc three-conductor lighting feeders may be selected. Branch circuits from lighting panelboards should be 115 Vdc two-wire.

4.5 AC power system characteristics

Power distribution systems should maintain the system characteristics described in Table 4-1 under all operating conditions. Power-consuming equipment should operate satisfactorily under the conditions described in Table 4-1, and should be designed to withstand the power interruption, transient, EMI, RFI, and insulation resistance test conditions inherent in the system. Power-consuming equipment requiring a non-standard voltage or frequency for successful operation should have integral power conversion capability. Power-consuming equipment should not have inherent characteristics that degrade the power quality of the supply system described in Table 4-1.

4.6 Power quality and harmonics

Solid-state devices such as motor controllers, computers, copiers, printers, and video display terminals produce harmonic currents due to line-notching during semiconductor device commutation. These harmonic currents may cause additional heating in motors, transformers, and cables. The sizing of protective devices should consider the harmonic current component. Harmonic currents in nonsinusoidal current waveforms may also cause electromagnetic interference (EMI) and radio frequency interference (RFI). EMI and RFI may result in interference with sensitive electronics equipment throughout the vessel.

Isolation, both physical and electrical, should be provided between electronic systems and power systems that supply large numbers of solid-state devices, or significantly sized solid-state motor controllers. Active or passive filters and shielded input isolation transformers should be used to minimize interference. Special care should be given to the application of isolation transformers or filtering as the percentage of power consumed by solid-state power devices compared to the system power available increases. Small units connected to large power systems exhibit less interference on the power source than larger units connected to the same source. Solid-state power devices of vastly different sizes should not share a common power circuit. Where kilowatt ratings differ by more than 5 to 1, the circuits should be isolated by a shielded distribution system transformer. Surge suppressers or filters should only be connected to power circuits on the secondary side of the equipment power input isolation transformers.

To preclude radiated EMI, main power switchboards rated in excess of 1 kV and propulsion motor drives should not be installed in the same shipboard compartment as ship service switchboards or control consoles.

IEEE Std 519-1992 provides additional recommendations.

Table 4-1–Alternating current (ac) power characteristics (low-voltage systems)

Characteristics	Limits
Frequency	
a) Nominal frequency	50/60 Hz
b) Frequency tolerances	±3%
c) Frequency modulation	½%
d) Frequency transient:	
1) Tolerance	±4%
2) Recovery time	2 s
e) The worst-case frequency excursion from nominal frequency resulting from b), c), and d)1) combined, except under emergency conditions.	±5 ½%
Voltage	
a) User voltage tolerance:	
1) Average of the three line-to-line voltages	±5%
2) Any one line-to-line voltage, including a)1) and line voltage unbalances b)	±7%
b) Line voltage unbalance	3%
c) Voltage modulation	5%
d) Voltage transient:	
1) Voltage transient tolerances	±16%
2) Voltage transient recovery time	2 s
e) Voltage spike (peak value includes fundamental)	±2500 V (380–600 V) system; 1000 V (120–240 V) system.
f) The maximum departure voltage resulting from a)1) and d) combined, except under transient or emergency conditions.	±6%
g) The worst case voltage excursion from nominal user voltage resulting from a)1), a)2), and d)1) combined, except under emergency conditions.	±20%
Waveform voltage distortion	
a) Maximum total harmonic distortion	5%
b) Maximum single harmonic	3%
c) Maximum deviation factor	5%
Emergency conditions	
a) Frequency excursion	–100 to +12%
b) Duration of frequency excursion	Up to 2 min
c) Voltage excursion	–100 to +35%
d) Duration of voltage excursion:	
1) Lower limits (–100%)	Up to 2 min
2) Upper limit (+35%)	2 min

Table 4-1–Alternating current (ac) power characteristics (low-voltage systems) *(Continued*)

Definitions
1. Frequency a) *Nominal frequency:* The designated frequency in hertz. b) *Frequency tolerance:* The maximum permitted departure from nominal frequency during normal operation, excluding transient and cyclic frequency variations. It includes variations caused by load changes, environment (temperature, humidity, vibration, inclination), switchboard meter error, and drift. Tolerances are expressed in percentage of nominal frequency. c) *Frequency modulation:* The permitted periodic variation in frequency during normal operation that might be caused by regularly and randomly repeated loading. For purposes of definition, the periodicity of frequency modulation should be considered as not exceeding 10 s. $$\text{Frequency Modulation (\%)} = \frac{\{f_{maximum} - f_{minimum}\}}{\{2 \times f_{nominal}\}} \times 100$$ d) *Frequency transient tolerance:* A sudden change in frequency that goes outside the frequency tolerance limits, returns to, and remains inside these limits within a specified recovery time after initiation of the disturbance. Frequency transient tolerance is in addition to frequency tolerance limits. e) *Frequency transient recovery time:* The time period from the start of the disturbance until the frequency recovers and remains within frequency tolerance limits.
2. Voltage a) *User voltage tolerance:* The maximum permitted departure from nominal user voltage during normal operation, excluding transient and cyclic voltage variations. It includes variations such as those caused by load changes, environment (temperature, humidity, vibration, inclination), switchboard meter error, and drift. b) *Line voltage unbalance tolerance (three-phase system):* The difference between the highest and lowest line-to-line voltages. $$\text{Line Voltage Unbalance Tolerance (\%)} = \frac{\{E_{maximum} - E_{minimum}\}}{\{E_{nominal}\}} \times 100$$ c) *Voltage modulation (amplitude):* The periodic voltage variation (peak to valley) or the user voltage that might be caused by regularly or randomly repeated pulsed loading. The periodicity or voltage modulation is considered to be longer than 1 Hz and less than 10 s. Voltages used in the following equation shall be all-peak or all-rms: $$\text{Voltage Modulation (\%)} = \frac{\{E_{maximum} - E_{minimum}\}}{\{2 \times E_{nominal}\}} \times 100$$ d) *Voltage transient* 1) Voltage transient tolerance: A sudden change (excluding spikes) in voltage that goes outside the user voltage tolerance limits and returns to and remains within these limits within a specified recovery time longer than 1 ms after the initiation of the disturbance. The voltage transient tolerance is in addition to the user voltage tolerance limits.

Table 4-1–Alternating current (ac) power characteristics (low-voltage systems) *(Continued)*

Definitions *(Continued)*
2) Voltage transient recovery time: The time elapsed from initiation of the disturbance until the voltage recovers and remains within the user voltage tolerance limits. e) *Voltage spike:* A voltage change of very short duration (less than 1 ms). **3. Waveform** a) *Total Harmonic Distortion (THD)(of a sine wave):* The ratio in percentage of the rms value of the residue (after elimination of the fundamental) to the rms value of the fundamental. b) *Single Harmonic (of a sine wave):* The ratio in percentage of the rms value of that harmonic to the rms value of the fundamental. c) *Deviation Factor (of a sine wave):* The ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superimposed in such a way that they make the maximum difference as small as possible. $\text{Deviation factor }(\%) = \frac{\{\text{maximum deviation}\}}{\{\text{maximum ordinate of the equivalent sine wave}\}} \times 100$
4. Emergency conditions A situation or occurrence of a serious nature that may result in electrical power system interruptions or deviations, such as the occurrence of ship service generator failure and the emergency generator coming on line.

5. Generating sets

5.1 Installation and location

Generating sets should be located in a dry, well-ventilated place. They should not be installed in immediate proximity to water and steam piping, etc., and should be protected from dripping liquids such as water and oil. Horizontal rotating machines should be installed with the shaft in a fore and aft direction. In cases where the shaft will be located athwartship, special consideration should be given to bearings and lubrication.

The generating sets, and all their auxiliary devices, should be capable of normal operation under the following inclinations (or any combination thereof):

transverse (athwartship), static	15°
roll (each side), dynamic	up to 22.5°
trim (fore and aft), static	5°
pitch (fore and aft), dynamic	up to 7.5°

Emergency installations should operate satisfactorily when the ship is inclined 22.5° and/or when the trim of the ship is 10°.

The location and installation of generating sets should allow access for maintenance and repair. There should be at least 460 mm (18 in) between the set and surrounding objects to provide accessibility. Sufficient room should be provided to permit removal of the rotor or armature.

When diesel engine or gas turbine-driven generating sets are located in deck houses, the enclosing structure should be steel or other fireproof material.

5.2 Generating sets—main or ship service

In determining the number and capacities of generating sets to be provided for a vessel, careful consideration should be given to the normal and maximum demands as well as for the safe and efficient operation of the vessel when at sea and in port. The number and ratings of the main generating sets should be sufficient to provide one spare generating set (one set not in operation) at all times, including in port.

For vessels propelled by electric power and having two or more constant-voltage, constant-frequency, main power generators, the ship service electric power may be derived from this source and additional ship service generators need not be installed, provided that with one main power generator out of service, a speed of 7 kn or one-half of the design speed (which-ever is the lesser) can be maintained. The combined normal capacity of the operating generating sets should be least equal to the maximum peak load at sea. If the peak load and its duration is within the limits of the specified overload capacity of the generating sets, it is not necessary to have the combined normal capacity equal to the maximum peak load.

A generator driven by a main propulsion unit (shaft generator) that is intended to operate at constant speed (e.g., a system where vessel speed and direction are controlled only by varying propeller pitch) may be considered to be one of the required ship service generators provided it is able to supply the required power even with the propeller shaft stopped.

Shaft generator installations that do not comply with the above criteria may be fitted in addition to the above required generators provided that an alternative source of electrical power, having a capacity sufficient for the loads necessary for propulsion and safety of the vessel, can be brought on line automatically within 45 s when the shaft generator fails to maintain voltage and frequency within prescribed limits. If shaft generators are employed at sea, where the shaft speed is not constant, then suitable means of control should be provided so that the speed of the main engine does not drop below the shaft generator critical operating speed until an auxiliary generator is automatically started. This will enable a load transfer to be made to prevent a blackout while not impairing the ability of the vessel to be maneuvered from the navigating bridge.

A single propulsion unit should be connected to only one generator, via a clutch that will enable the generator to be disconnected from the propeller shaft.

In selecting the capacity of an ac generating plant, particular attention should be given to the starting current of ac motors supplied by the system. With one generator held in reserve and with the remaining generator set(s) carrying the minimum load necessary for the safe operation of the ship, the voltage dip resulting from the starting current of the largest motor on the system should not cause any motor already running to stall or control equipment to drop out.

5.3 Generating sets—emergency

Every vessel should be provided with a self-contained emergency source of electric power, generally a diesel engine or gas turbine-driven generator or storage batteries. These emergency sources of power and an emergency switchboard should be located in a space that is above the uppermost continuous deck, aft of the collision bulkhead, outside the main machinery compartment, and readily accessible from the open deck. When a compartment containing the emergency source of electric power, or vital components thereof, adjoins a space containing either the ship’s service generators or machinery necessary for the operation of the ship’s service generators, all common bulkheads and decks should be protected by structural insulation. This protection should prevent an excessive temperature rise in the space containing the emergency source of electric power, or vital components thereof, for a period of at least 1 h in the event of fire in the adjoining space.

Emergency generating sets should be self-contained and designed to start automatically and assume rated load within 45 s while in their cold condition at a temperature of 0 °C (32 °F). Each emergency generator should be equipped with starting devices with an energy storage capability of at least six consecutive starts. A single source of stored energy, with the capacity for six starts, should be protected to preclude depletion by the automatic starting system, or a second source of energy should be provided for an additional three starts within 30 min. If, after three attempts, the generator set has failed to start, an audible and visual “start failure” alarm should be activated in the main machinery space control station and on the navigation bridge. The starting sequence should be automatically locked-out until an operator can initiate the final three starting attempts from the emergency generator space.

The capacity of the emergency generating sets and storage batteries for the various groups of vessels is given in Clause 26.

The fuel used should have a flash point of not less than 43 °C (110 °F).

When emergency storage batteries are supplied, appropriate means should be furnished for providing power from the batteries to ac loads.

5.4 Voltage regulation

5.4.1 General

Separate voltage regulators should be provided for each generator. Voltage regulation should be automatic and should function under steady-state load conditions between 0% and 100% load at all power factors that can occur in normal use. Voltage regulators should be capable of maintaining the voltage within the range of 97.5% to 102.5% of the rated voltage. A means of adjustment should be provided for the voltage regulator circuit. Voltage regulators should be capable of withstanding shipboard conditions and should be designed to be unaffected by normal machinery space vibration.

Under overload or short circuit conditions, the generator and voltage regulator together with the prime mover and excitation system should be capable of maintaining a current of such magnitude and duration as required to properly actuate the associated electrical protective devices, with a value of not less than 300% of generator full-load current for a duration of 2 s, or of such additional magnitude and duration as required to properly actuate the associated protective circuit breakers.

5.4.2 AC generators

The combined effect of the speed regulation of the prime mover in accordance with 5.6, the performance of the excitation and voltage regulating equipment and the characteristics of the generator system performance should be as described in the subclauses below. Means should be provided to automatically and proportionately divide the reactive power between generators when two or more generators are operating in parallel.

5.4.2.1 Main or ship service generators

For single-generator operation (no reactive droop compensation), the steady-state voltage for any increasing or decreasing load between zero and full load at rated power factor under steady-state operation should not vary at any point more than ±2.5% of rated generator voltage.

Under transient conditions, when the generator is driven at rated speed at its rated voltage, and is subjected to a sudden change of symmetrical load within the limits of specified current and power factor, the voltage should not fall below 88% nor exceed 112% of the rated voltage. The voltage should then be restored to within ±2.5% of the rated voltage in not more than 1.5 s. In the absence of precise information concerning the maximum values of the sudden loads, the following conditions should be assumed: 150% of rated current with a power factor of between 0.4 lagging and zero to be applied with the generator running at no-load, and then removed after steady-state conditions have been reached.

For two or more generators with reactive droop compensation, the reactive droop compensation should be adjusted for a voltage droop of no more than 4% of rated voltage for a generator. The system performance should then be such that the average curve drawn through a plot of the steady-state voltage vs. load for any increasing or decreasing load between zero and full load at rated power factor, droops no more than 4% of rated voltage and no recorded point varies more than ±1% of rated generator voltage from the average curve.

Isochronous operation of a single generator operating alone is acceptable. However, where two or more generators are arranged to operate in parallel, only one machine should be operating in the isochronous mode unless voltage regulation with isochronous cross-current compensation reactive load-sharing capabilities are provided. Care should be taken when operating machines in parallel in the droop/isochronous modes to ensure that the system minimum load does not decrease below the output set point of the droop machine(s), as this may cause a frequency change in the system and the machine operating in the isochronous mode to motor.

5.4.2.2 Emergency generating set (no reactive droop compensation)

The system performance should be such that the steady-state voltage for any increasing or decreasing load between zero and full load at rated power factor should not vary at any point more than ±3.5% of rated generator voltage between reactive load change from zero to 60% of the continuous kilovoltampere rating of the highest and lowest points attained. For emergency sets under transient conditions, the values may be increased to ±4% in not more than 5 s.

5.4.3 DC generators

5.4.3.1 Shunt-wound or stabilized shunt-wound generating sets

These sets should be designed as to speed regulation and governing of the prime mover and inherent regulation of the generator so that at full-load operating temperature, there will be a rise in voltage of not more than 8% when the load is gradually reduced from 100% load to 20% load and so that there will be a drop in voltage of not more than 12% when the load is gradually increased from 20% load to 100% load, based on applicable percent speed regulation (drop in speed from no-load to full-load) of the prime mover. When testing to verify performance for each condition, the field rheostat should be set for normal rated voltage at the beginning of each test. When lighting loads are supplied by the ship's service generator, a voltage regulator should be supplied for each generator and the regulator should regulate the output voltage to the system equal to that required for compound-wound generators covered in 5.4.3.2.

5.4.3.2 Compound-wound generators

Compound-wound generators should be designed as to governing of prime mover as well as to compounding and regulation of the generator, so that with the generator at full-load operating temperature, and starting at 20% load with voltage within 0.5% of rated voltage, it should give, at full load, a voltage within 1.5% of rated voltage. The average of the ascending and descending voltage regulation curves between 20% and full load should not vary more than 3% from rated voltage.

5.4.3.3 Three-wire generators

In addition to meeting the recommendations of either 5.4.3.1 or 5.4.3.2, the voltage regulation of a three-wire generator should be such that when operating at rated current on the heavier loaded side, with

a) Either positive or negative load;
b) Rated voltage between the positive and negative leads; and
c) A current of 25% of the generator current rating in the neutral wire.

The resulting difference in voltage between the positive and neutral leads and the negative and neutral leads should not exceed 2% of the rated voltage between the positive and negative leads. The speed regulation curve of the prime mover should not vary more than 1% from a straight line drawn between the speeds at 20% load and 100% load.

The voltage regulation and compounding tests should be made at the manufacturer's facility in accordance with standard testing practice, using an approximately straight-line speed regulation from 20% to 100%, at loads specified by the prime mover builder.

If shunt or stabilized shunt-wound generators are part of an electric plant in which larger generators are also installed, and the large and small generators are to be operated in parallel, the following should be met: When the dc load on the smaller unit is gradually reduced from 100% to 20%, the dc regulation should be not more than 12%, based on the applicable speed regulation percentage of the prime mover. The prime mover speed regulation is based on varying combined load on the prime mover from zero to 100%.

Connections for dc machines should be as indicated in Figure 5-1 through Figure 5-10.

5.5 Parallel operation

5.5.1 General

Generating sets should be capable of operating successfully in parallel. Successful parallel operation is attained if the load on any generator does not differ by more than ±15% of its proportionate share of the combined kilowatt load, based on generator ratings, for any steady-state condition of the combined load between 20% and 100% of the sum of the rated loads of all the generators. The starting point for determination of the foregoing load distribution requirements should be at 75% load with each generator carrying its proportionate share.

When tests are made to determine if successful parallel operation of dc generating sets is obtained, the following should be met:

a) The generators should be at normal operating temperatures.
b) The speed of the generators should be constant or slightly decreasing with increase in load with the change in speed approximately proportional to load.
c) For compound-wound dc machines, series field equalizer connections should be provided.

The ratio of the resistance of the equalizer connections to the resistance of the series field and its connection, both to the point of paralleling, should be no more than 0.5. In no case should the cross-sectional area of the longest equalizer conductor from a generator be less than the cross-sectional area of the generator's main power conductors.

5.5.2 Operation on a grounded system

For generators operated in parallel on a grounded system, the equalizing current resulting from harmonics should not exceed 20% of the current rating of the smallest rated generator.

5.6 Prime movers

Each prime mover should be fitted with an efficient speed regulating governor as well as an automatic overspeed trip. The automatic overspeed trip should function to shut down the unit automatically when the speed exceeds the designed maximum service speed by more than 15%. The overspeed trip should also be equipped with a means for manual tripping. Each prime mover should, in addition, be under control of an efficient operating governor capable of limiting the speed, when full load is suddenly removed, to at least 5% less than that of the overspeed trip setting. The prime mover and regulating governor should also limit the momentary speed variation to 5.5% of the rated speed when 75% of the rated load of the generator is suddenly applied followed by the remaining 25% after an interval sufficient to restore the speed to steady state. The speed should return to within 1% of the final steady-state speed as follows:

Load	Response time	Speed deviation
±75%	2.0 s	5.5%
±100%	5.0 s	7.5%

Emergency generator sets should accept 100% rated kilowatt load in one step.

All sets of 100 kW capacity and above should be provided with a coupling fitted to the rotor or armature shaft.

Each generator should be driven by a separate prime mover that, if used to drive other auxiliary loads, should have sufficient capacity for the total load, unless it is not possible to use the generator and the other auxiliary load simultaneously. Generating sets that operate in parallel should be provided with a switch that trips the generator circuit breaker when the overspeed device is actuated.

5.7 Motor generator sets—overspeed protection

Motor generator sets having dc motors driving ac or dc generators that will operate in parallel with other units and that are of a frame size corresponding to a rating of 11 kW (15 hp), 1750 r/min or above, should be provided with overspeed protection.

5.8 Accessibility

The design of generating sets should provide for accessibility to all parts requiring inspection during operation or disassembling for repairs.

5.9 Mountings

The generator and its driving unit should be mounted on a common rigid sub-base to ensure proper alignment. Each unit comprising the set should be provided with ample supporting feet secured to the sub-base.

5.10 Winding insulation

Table 5-1 and Table 5-2 provide the limits of observable temperature rise for generators for the various insulation classes. Insulating materials and insulated windings should be resistant to moisture, salt air, and oil vapor. All form-wound coils for ac generators, all assembled armatures, and the armature coils for open-slot dc armature construction should utilize vacuum-pressure impregnated solventless epoxy insulation systems. The assembled and wound stators of ac generators and the wound dc armatures for open slot construction should be immersed or flow coated with insulating varnish and baked. All assembled ac machine field coils and wound dc field coils should be treated with epoxy while being wound or vacuum-pressure impregnated with a solventless epoxy insulating material. The finished windings should be water and oil resistant with a Class B temperature rise.

Abnormal brush wear and slipring or commutator maintenance may occur on generators with even a slight amount of silicone insulation, especially if the machine is enclosed. Insulation and construction processes using silicones should be avoided where brushes are installed.

5.11 Lubrication

All generating sets should lubricate and operate satisfactorily without spilling oil, in a 10 s period, under the conditions of inclination, roll, and pitch specified in 5.1. If the shaft is to be located athwartships, the manufacturer should be advised so that any special requirements for this orientation are addressed. All prime movers for main power and ship service generating sets (not emergency sets) that depend upon forced lubrication should be arranged to shut down automatically on loss of oil pressure. The shutting down of the prime mover should cause the tripping of the generator circuit breaker. An alarm system should be provided and arranged to function on low oil pressure as recommended in 27.9.

Emergency generator sets should lubricate and operate satisfactorily when permanently inclined to an angle of 22.5° athwartships and 7.5° fore and aft. Units depending upon forced lubrication should be provided with an audible and visual alarm activated by loss of oil pressure while running.

5.12 Corrosion-resistant parts

Interior bolts, nuts, pins, screws, terminals, brushholder studs, springs, and other small parts that could be damaged by corrosion should be made of corrosion-resistant materials or suitably protected against corrosion. Steel springs should be treated to resist moisture in such a manner as not to impair their spring quality. See 1.8.1.

5.13 Terminal arrangements

Generators should be provided with terminals leads suitably secured to the generator frame and provided with connectors approved by the administration or classification organization to permit ready connection of the incoming cables. See 13.3 for recommendations on terminal lugs on incoming cables. The terminal leads may be of cabling or suitably insulated straps.

The generator terminals should be enclosed in a dripproof terminal box so constructed that the incoming cables can be led individually through an insulating cover screwed or bolted to the box bottom. Individual terminal tubes should be used for top or side cable entry to dripproof terminal boxes.

Terminal boxes should be of sufficient size to accommodate the terminal leads and any other incoming cabling without crowding or exceeding their bend radius. Each box should be of adequate mechanical strength and rigidity to protect the contents and to prevent distortion under all normal conditions of service. Cables of differing voltage should not be included in the same terminal box unless each voltage is clearly and permanently identified and effective barriers provided within the enclosure to separate each voltage.

Totally enclosed generators with commutators or slip rings should have a terminal box that is airtight with respect to the machine interior to permit the connection of incoming shipboard cables utilizing silicone conductor insulation.

5.14 Nameplates

Generators should be supplied with nameplates of corrosion-resistant material marked with the following information:

a) Name of manufacturer
b) Manufacturer's type and frame designation
c) Manufacturer's serial number
d) Output: in kilovoltamperes for ac generators; in kilowatts for dc generators
e) Voltage rating
f) Current rating
g) Power factor rating for ac generator
h) Frequency rating for ac generator
i) Number of phases for ac generator
j) Rated temperature rise
k) Service factor (or intermittent duty rating)
l) Ambient temperature rating
m) Revolutions per minute at rated load
n) Excitation voltage at rated load for ac generator
o) Excitation current at rated load and power factor for ac generator
p) dc generator winding type—shunt, stabilized shunt, or compound wound

5.15 Tests

Sufficient full-load and other tests should be made at the manufacturer's factory to ensure that the machine is in accordance with these recommendations. When a machine is a duplicate of one already completely tested, only such check tests need be made as may be necessary to demonstrate that the machine operates successfully. Spare rotors and armatures should be given regular insulation voltage and dynamic balance tests, but need not be given any running test.

Tests should be in accordance with the following standards, or other equivalent national standards:

— For synchronous machines, IEEE Std 115-1995
— For dc machines, ANSI/NEMA MG 1-1993

5.16 Limits of temperature rise

5.16.1 AC generators

The limits of temperature rise of each of the various parts of ac generators should not exceed the values given in Table 5.2. All temperatures should be measured by the methods given in the table. These final temperatures are based on an ambient temperature of 50 °C (122 °F). Where provision is made for ensuring an ambient temperature being maintained at 40 °C (104 °F) or less, as by air cooling or by location outside of the boiler and engine rooms, the temperature rises of the windings may be 10 °C (50 °F) higher.

5.16.2 DC generators

The limits of temperature rise of each of the various parts of dc generators should not exceed the values given in Table 5-1 and Table 34-1. All temperatures are to be measured by the methods given in the tables. These final temperatures are based on an ambient temperature of 50 °C (122 °F).

Balance coils for three-wire dc generators, when mounted separately from the machines, should not exceed temperature rises, as given in Table 34-1.

5.16.3 Temperature detectors

AC generators rated above 500 kVA should be provided with means for obtaining the temperatures of the stationary windings. A minimum of one embedded temperature detector per phase should be provided for this purpose on the hot end to be indicated at a convenient location, preferably the generator control panel.

5.17 Ambient temperature

Generators should be designed for an ambient temperature of 50 °C (122 °F); except in cases where generators are provided with enclosed ventilating systems with coolers designed to maintain 40 °C (104 °F) ambient temperature under the worst conditions of operation.

5.18 Insulation tests

Insulation tests should be made with the machine windings in a clean, dry condition. The results obtained from tests depend not only on the characteristics of the insulation materials and the way they are applied but also on the test conditions. It is therefore necessary to record these conditions, particularly those concerning the ambient temperature and the degree of humidity at the time of the test. The Polarizing Index for the machine windings should be evaluated to verify its condition. This is especially important on older machines or where it is not possible to record the temperature and humidity at the time of testing. The following guidelines apply:

Condition	Polarization Index
Dangerous	<1.0
Poor	<1.5
Questionable	1.5–2.0
Fair	2.0–3.0
Good	3.0–4.0
Excellent	>4.0

5.19 Insulation resistance

The resistance should be measured with all circuits of equal voltages above ground connected together; circuits or groups of circuits of different voltages above ground should be tested separately. This test is to be made at a dc voltage of 500 V for a minimum of 1 min. The recommended minimum insulation resistance *Rm* for ac and dc machine armature windings and for field windings of ac and dc machines can be determined as follows

$$Rm = \text{kV} + 1$$

where

Rm = recommended minimum insulation resistance in MΩ at 40 °C (104 °F) of entire machine winding
kV = rated machine terminal to terminal potential, in rms kilovolts

The actual winding insulation resistance to be used for comparison with the recommended minimum value *Rm* is the observed insulation resistance, corrected to 40 °C (104 °F), obtained by applying direct potential to the entire winding for one minute to obtain the initial value and for ten minutes to obtain the value for the polarization index.

The minimum insulation resistance of the fields of machines separately excited with voltage less than the rated voltage of the machine is to be of the order of one MΩ.

5.20 Dielectric strength of insulation

a) *Standard Voltage Test.* The insulation of all generators should be tested with the parts completely assembled and not with the individual parts. The dielectric strength of the insulation should be tested by the continuous application for 60 s of an alternating voltage having crest value equal to the $\sqrt{2}$ times the specified test voltage and frequency of 25 to 60 Hz. The standard test voltage for all generators should be twice the normal voltage of the circuit to which it is applied plus 1000 V, except for the following:
Exceptions to Standard Voltage Test. Field windings of ac generators should be tested with ten times the excitation voltage but in no case less than 1500 V.
b) *DC Test.* A standard voltage test using a dc source equal to 1.7 times the required ac voltage would be acceptable.
c) *Application.* The dielectric test voltage should be applied between each electric circuit/phase insulated from one another and between each electric circuit/phase and grounded metal parts. For dc generators the test voltage should be applied between brush rings of opposite polarity. Interconnected polyphase windings should be considered as one circuit. All windings except those under test should be connected to ground. The test should be undertaken immediately following the temperature rise test.

5.21 Space heaters

Space heaters should be supplied integral with all generators as indicated below. These heaters should be automatically energized when the generator is stopped and should be energized at any time that the temperature of the windings or metal parts of the generator are lower than the ambient temperature. These heaters should meet the recommendations in the following subclauses.

5.21.1 Location

The heaters should be placed in such location that warm air will pass over the windings (and the commutator, if dc generator). This movement of warm air may be accomplished by convection or forced circulation. For small generators, the heaters may be mounted outside of the frame to supply heat to the interior of the generator by conduction.

5.21.2 Type

Heaters should be of a type that is sealed to prevent the absorption of moisture.

5.21.3 Size

The following table shows recommended heater ratings based upon generator weight (excluding shaft):

Weight of generator, kg (lb)	Space heater rating, W
0–455 (1000)	None
(1000)–1365 (3000)	250–500
(3000)–2730 (6000)	500–1000
(6000)–4550 (10 000)	1000–1250
Above 4550 (10 000)	200 W/1000 kg

5.22 Spare parts stowage

Storage space or spaces should be provided and should have the necessary bins, etc. for stowing electric spare parts. Spare rotors and armatures should be protected and provided with means for obtaining insulation resistance without disturbing the protective enclosure. Insulated parts, such as coils, should be protected against moisture and rodents, and should be stored in a room in which the temperature is maintained fairly constant. Coils should be stored so their original form will be maintained. All exposed surfaces, such as bearings, should be protected against corrosion and damage, and should not be allowed to come in contact with hygroscopic substances.

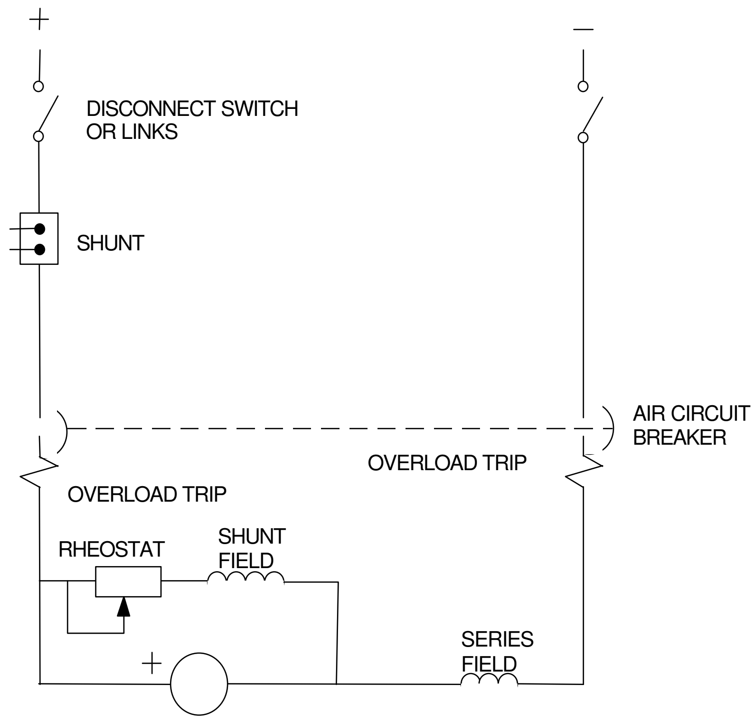


Figure 5-1—Two-wire compound-wound generator for nonparallel operation

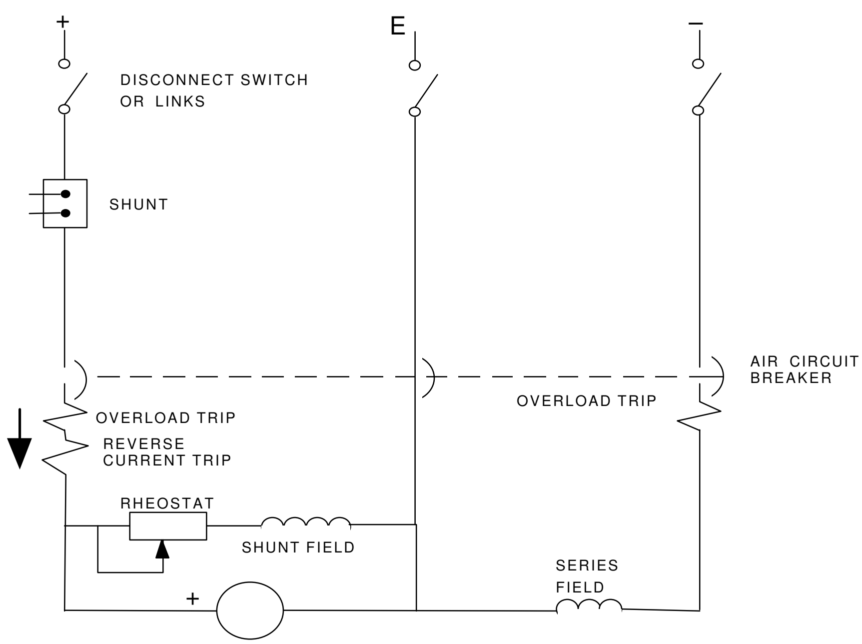


Figure 5-2—Two-wire compound-wound generator for parallel operation

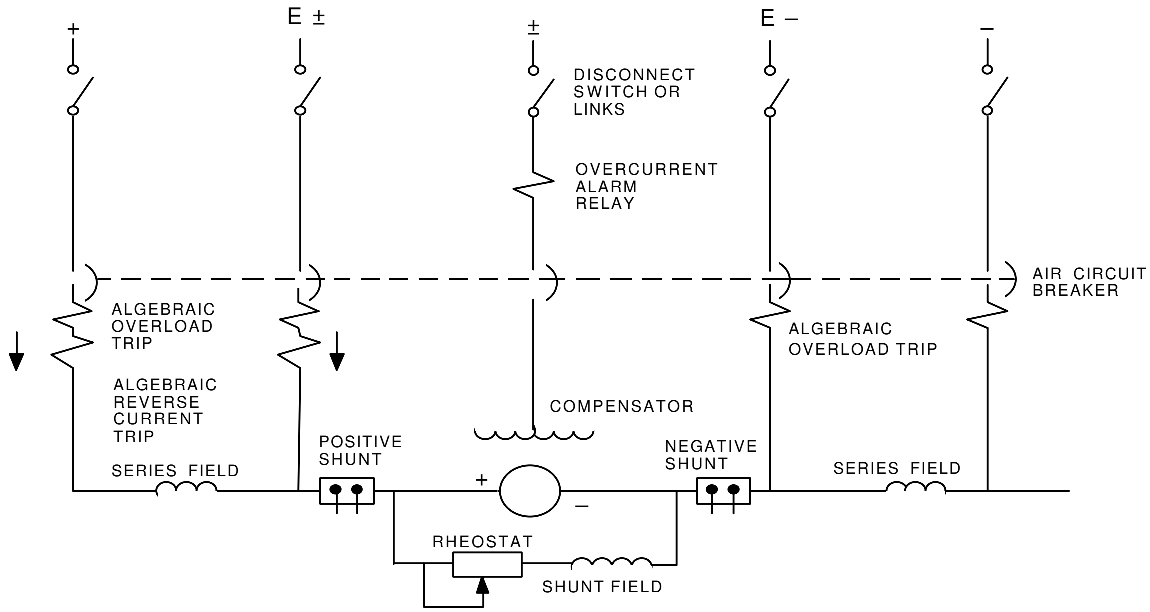


Figure 5-3—Three-wire compound-wound generator for parallel operation

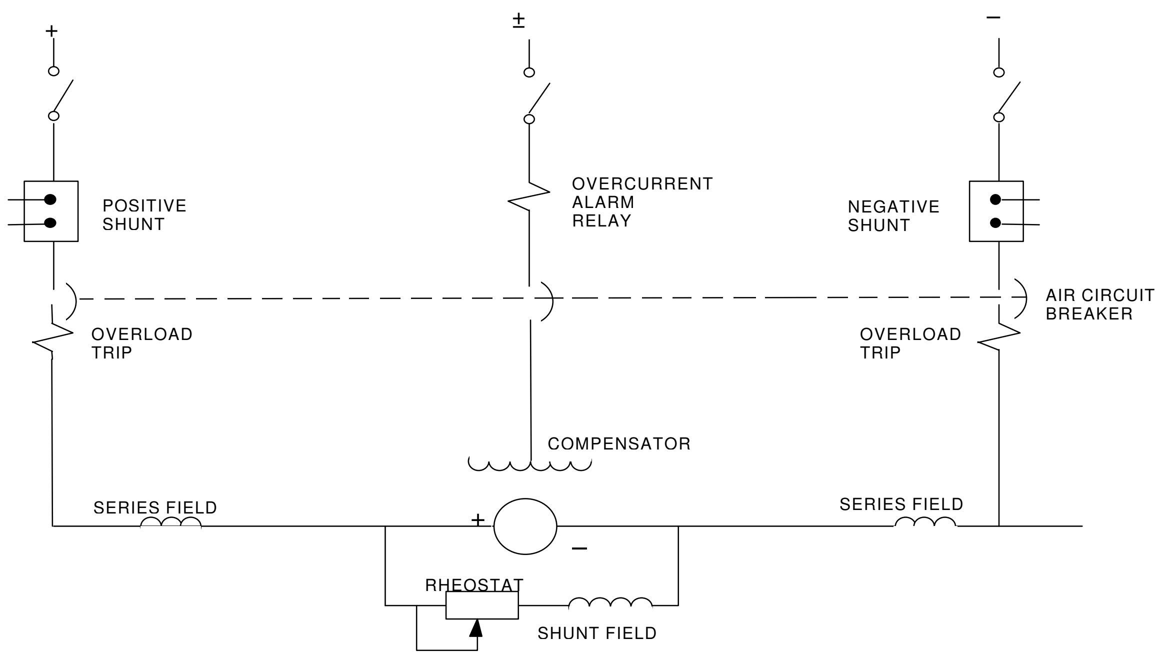


Figure 5-4—Three-wire compound-wound generator for nonparallel operation

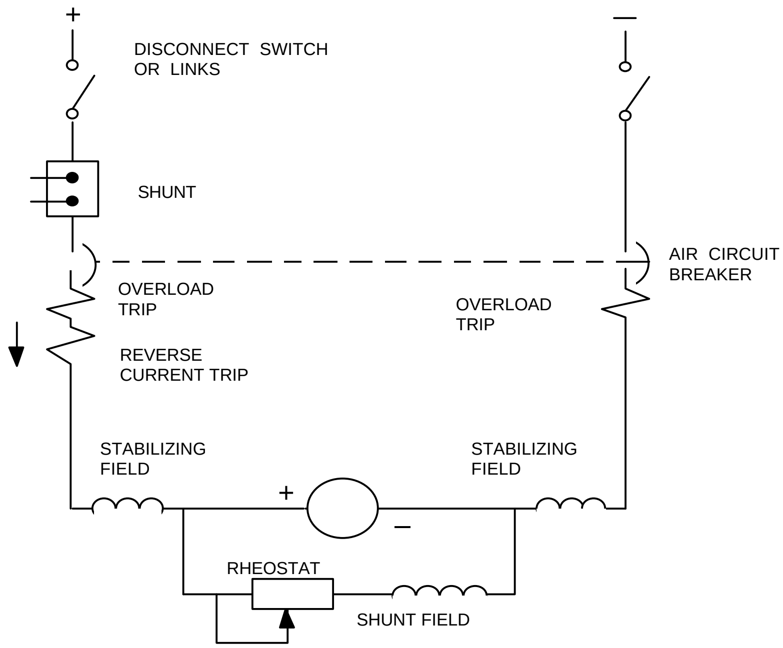


Figure 5-5—Two-wire stabilized shunt-wound generator for parallel operation

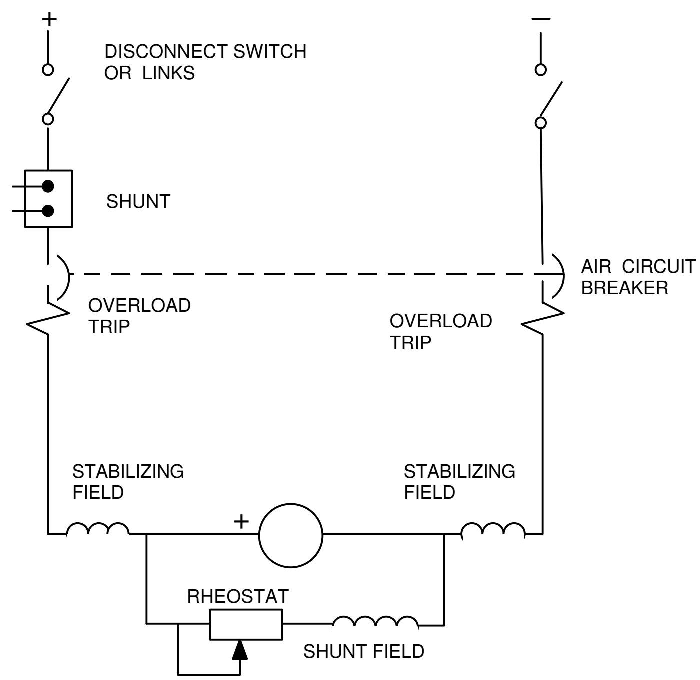


Figure 5-6—Two-wire stabilized shunt-wound generator for nonparallel operation

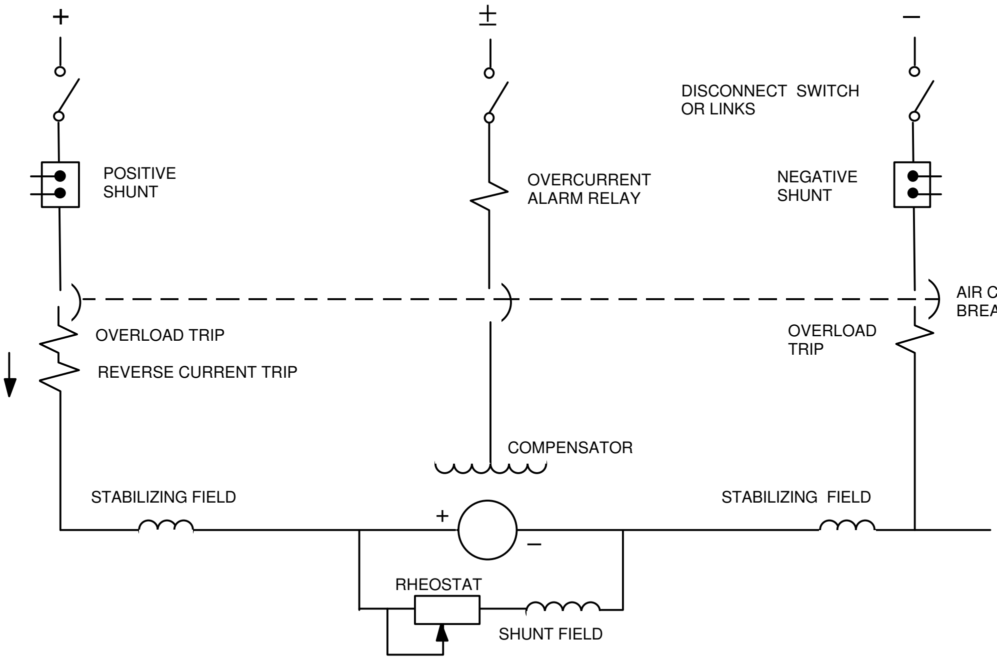


Figure 5-7—Three-wire shunt-wound generator for parallel operation

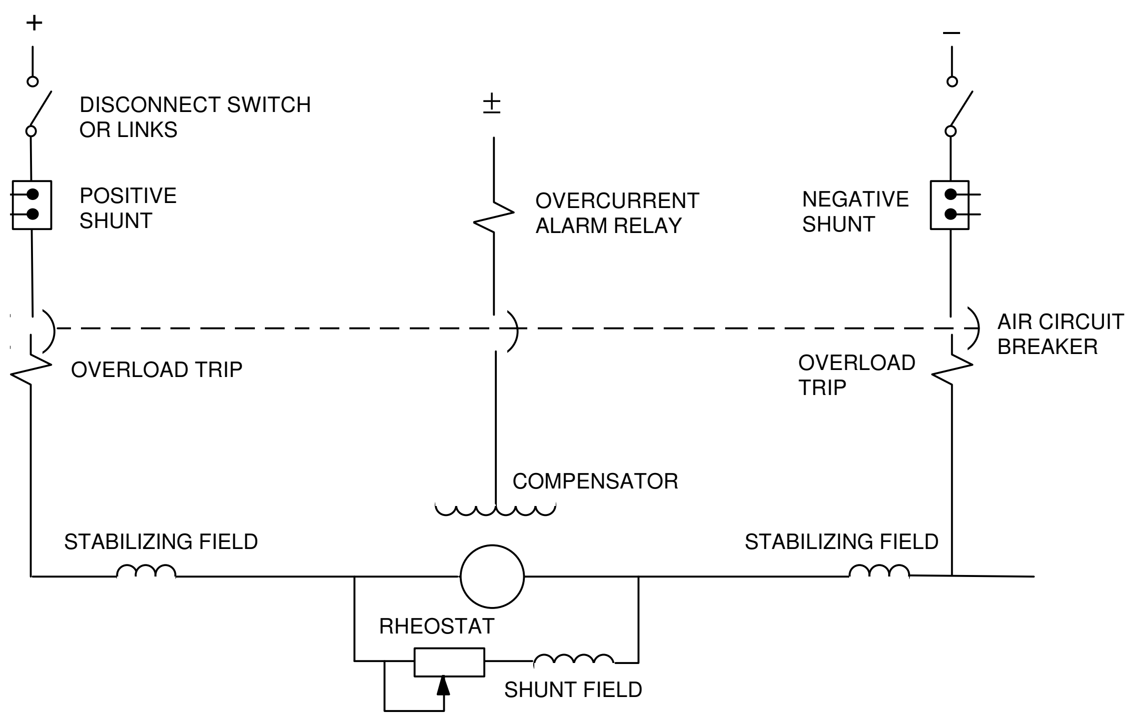


Figure 5-8—Three-wire shunt-wound generator for nonparallel operation

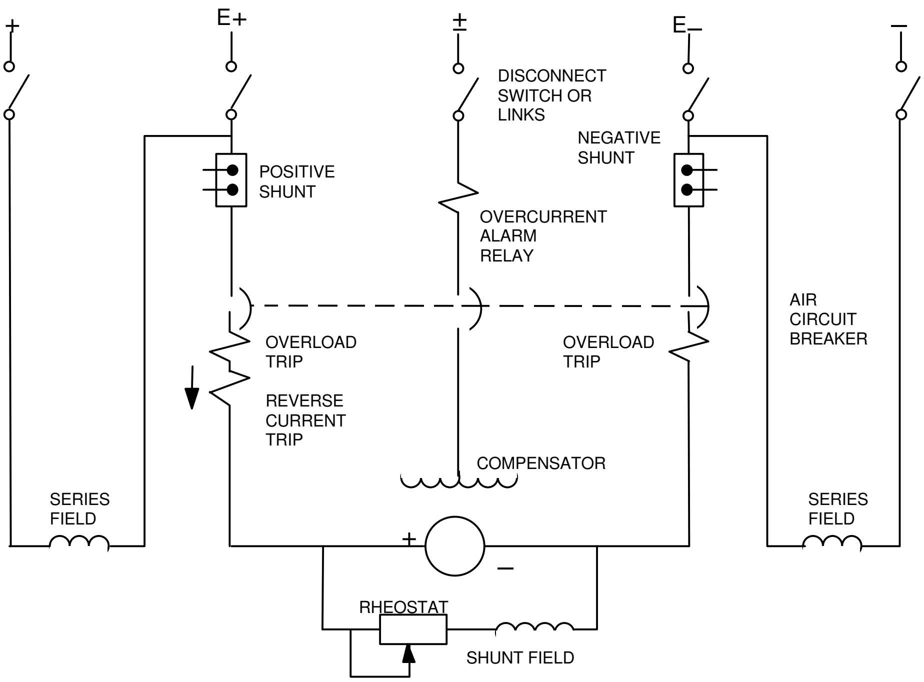


Figure 5-9—Alternative arrangement for three-wire compound-wound generators for parallel operation

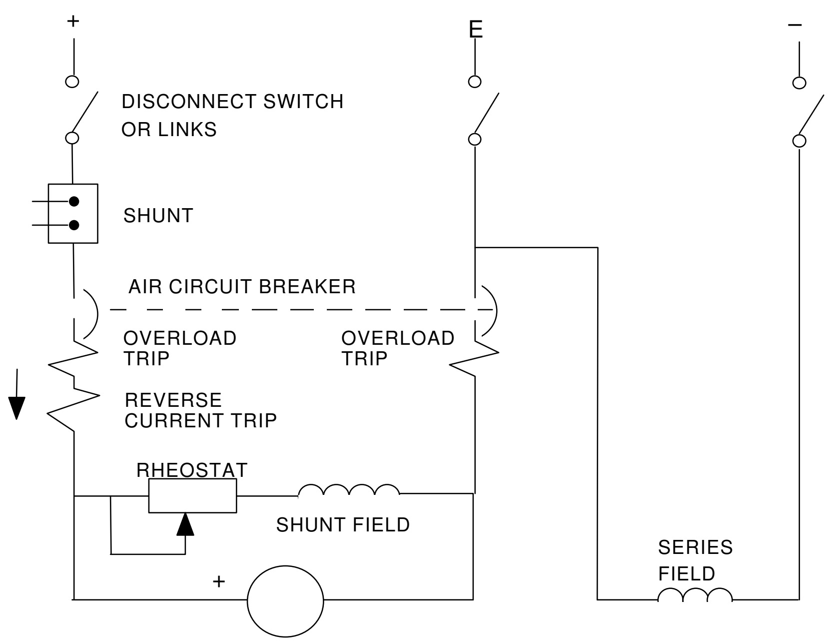


Figure 5-10—Alternative arrangement for two-wire compound-wound generators for parallel operation

Table 5-1—Limits of observable temperature rise for dc generators and motors based on 50 °C (122 °F) ambient temperatures

Item	Machine part	Type of enclosure	Method of temperature determination	Class of insulation A	B	F	H
1	Armature windings	Dripproof and open	Thermometer	40	60	80	100
			Resistance	60	90	120	145
		Totally enclosed	Thermometer	45	65	85	105
			Resistance	60	90	120	145
2	Multilayer field winding	Dripproof and open	Thermometer	40	60	80	100
			Resistance	60	90	120	145
		Totally enclosed	Thermometer	45	65	85	105
			Resistance	60	90	120	145
3	Single-layer field windings with exposed uninsulated surfaces and bare copper windings	Dripproof and open	Thermometer	50	70	95	120
			Resistance	60	90	120	145
		Totally enclosed	Thermometer	55	75	100	125
			Resistance	60	90	120	145
4	Cores and mechanical parts in contact with or adjacent to the insulation	Dripproof and open	Thermometer[a]	40	60	80	100
		Totally enclosed	Thermometer[a]	45	65	85	105
5	Commutators and collector rings	All	Thermometer	55	75	95	115

NOTE 1—The temperature attained by miscellaneous parts (such as brushholders, brushes, pole tips, etc.) should not injure the machine in any respect.
NOTE 2—Where two methods of temperature measurement are listed, temperature rise within the values listed in the table, measured by either method, demonstrates conformity.
NOTE 3—The temperature rises in the foregoing table are based on ambient temperature of 50 °C (122 °F). For 40 °C (104 °F) ambient, the temperature rises may be increased 10 °C (50 °F). See 5.17 for ambient temperatures of totally enclosed water-air cooled machine.
NOTE 4—All machines have a 1.0 service factor.
NOTE 5—For totally enclosed short-time rated motors only, the temperature rise by resistance method only may be increased 10 °C (50 °F) above the value listed in the table.

[a] Applies only when winding temperatures are measured by the thermometer method.

Table 5-2—Limits of observable temperature rise for ac generators based on 50 °C (122 °F) ambient temperature

Machine part	Method of temperature determination	Class of insulation			
		A	B	F	H
Armature windings					
a) All kVA ratings	Resistance	50	70	95	115
b) 1563 kVA and less	Embedded detector	60	80	105	130
c) Over 1563 kVA	Embedded detector	55	75	100	125
Field windings					
a) Salient pole	Resistance	50	70	95	115
b) Cylindrical rotor	Resistance	—	75	95	115

NOTE 1—The temperatures attained by cores, amortisseur windings, and mechanical parts (such as collector rings, brushholders, etc.) should not injure the machine in any respect.

NOTE 2—The temperature rises in the foregoing table are based on ambient temperature of 50 °C (122 °F). For 40 °C (104 °F) ambient, the temperature rises may be increased 10 °C (50 °F). See 5.17 for ambient temperatures of totally enclosed water-air cooled machines.

NOTE 3—All machines have a 1.0 service factor.

6. Storage batteries

6.1 General

The recommendations of this clause apply to permanently installed power, control, and monitoring storage batteries. These batteries may be either lead-acid or alkaline type batteries. Additionally, the batteries should be of the vented or sealed-gelled electrolyte type. When selecting the type of battery, consideration should be given to the suitability of the battery type for the specific application.

Vented batteries are batteries in which the electrolyte can be replaced, which freely release gas during periods of charge and overcharge.

Sealed-gelled electrolyte batteries minimize the quantity of gas released through a pressure relief valve by recombining the products of electrolysis. The electrolyte in this type of battery cannot be replaced.

Each battery consists of one or more cells with the cells connected in series or parallel, depending on the desired output voltage and capacity. Each cell contains an anode (reducing material or fuel), a cathode or oxidizing agent, and the electrolyte (which provides the necessary internal ionic conductivity).

6.2 Construction and assembly

Batteries should be constructed to withstand all conditions that may be encountered in the shipboard application. Batteries should be constructed to the following standards:

a) Have the capability to withstand vessel pitch, vibration, and roll as indicated in Clause 1.
b) Have the capability to minimize the emission of electrolyte spilling or spray due to vessel motion.
c) Have the capability of battery cell to incline up to 30º from the vertical and not spill electrolyte.
d) Have the capability to withstand exposure to moisture-laden, salt-water atmosphere.
e) Each positive plate of a lead-acid battery for a general alarm system or an emergency lighting and power system, except for an engine cranking system, should be at least 6.4 mm (0.25 in) thick.
f) Except as noted in e) above, each positive plate of a lead-acid battery should be at least 3.2 mm (0.125 in) thick.
g) Plates should be of rigid construction, and should be designed for the least practicable shedding of active material.
h) The specific gravity of acid electrolyte, with the battery in fully charged condition, should be from 1.210 to 1.220 at a temperature of 25 °C (77 °F).

Batteries for starting diesel engines should have electrolyte of 1.270 to 1.285 specific gravity.

6.2.1 Battery assembly

Cells should be assembled in trays of suitable material and rigid construction and equipped with handles for convenient lifting. The number of cells in a tray will depend on the weight and on the space available for installation. It is recommended that the weight of trays not exceed approximately 110 kg (250 lb). Battery trays should be arranged so that the trays are accessible and should have a minimum of 250 mm (10 in) of head room.

Each cell/battery tray should have a nameplate securely attached to the tray or molded onto the tray case. The nameplate should contain the following:

a) Battery manufacturer's name or trademark
b) Battery type designation
c) Ampere hour rating at some specific rate of discharge (rating and rate of discharge should correspond to the specific application of the tray)
d) Specific gravity of electrolyte when charged (for lead-acid batteries)

Intercell connections and terminals for connections between trays and for external wiring should be suitable for the maximum current produced by the cells/batteries. For diesel engine cranking batteries with high discharge rates, copper inserts in posts or other special provisions may be required.

6.3 Installation and arrangement

6.3.1 Battery category

Battery installations are classified based on the power output of the battery charger. These categories are large, moderate sized, and small.

6.3.1.1 Large battery installation

A large battery installation is one connected to a charging device with an output of more than 2 kW computed from the highest possible charging current and the rated voltage of the battery installation.

6.3.1.2 Moderate-sized battery installation

A moderate-sized battery installation is one connected to a charging device with a power output of 0.2 kW up to and including 2 kW computed from the highest possible charging current and the rated voltage of the battery installation.

6.3.1.3 Small battery installation

A small battery installation is one connected to a charging device with a power output of less than 0.2 kW computed from the highest possible charging current and the rated voltage of the battery installation.

6.3.2 Battery installation

6.3.2.1 General

Batteries should be located where they are not exposed to excessive heat, extreme cold, spray, steam, or other conditions that would impair performance or accelerate deterioration. Batteries for emergency service, including emergency diesel engine cranking, should be located where they are protected as far as practicable from damage due to collision, fire, or other casualty.

Alkaline batteries and lead-acid batteries should not be installed in the same compartment or enclosure. In addition, on every vessel where both alkaline and lead-acid storage batteries are installed, a separate set of necessary maintenance tools and equipment for each battery type should be provided.

Sealed-gelled electrolyte batteries may be installed in locations containing standard marine or industrial electrical equipment if protected from falling objects and mechanical damage provided all ventilation requirements are met.

Where more than one charging device is installed for any battery or group of batteries in one location, the total power output should be used to determine battery installation requirements.

6.3.2.2 Large battery installation

Large storage batteries, such as for emergency lighting, should be installed in a room assigned to the battery only, but may be installed in a suitable deck locker or box on the open deck if such a room is not available. See 33.11 for additional equipment recommendations.

Each battery conductor, except conductors for engine cranking batteries, should have an overcurrent protective device located as stated in 6.8. Cranking batteries should be located as closely as practicable to the engine or engines served, to limit voltage drop in cables with the high current required. Electric cables, other than those for the battery or battery room lighting, should not be installed in the battery room.

A securely attached danger notice should be installed on each door of a battery room and each battery box cover stating that a naked light or smoking is not allowed in the room.

6.3.2.3 Moderate-sized battery installation

Batteries of moderate size, such as those for engine cranking, communications supply, etc., should be installed in a battery room, in a box on deck, or in a box or locker (or lockers) in another space such as the emergency generator room, machinery space, storeroom, or other suitable location. It is recommended that the space contain the emergency lighting battery. If a moderate-sized installation is in a ventilated compartment such as the engine room and is protected from falling objects, then the batteries do not have to be installed in a box or locker. Moderate-sized batteries should not be installed in sleeping quarters. Engine cranking batteries should be located as closely as practicable to the engine or engines served, to limit voltage drop in cables with the high current required.

6.3.2.4 Small battery installation

Small batteries, such as those for emergency radio supply, etc., should be installed in a battery box located as desired in well-ventilated spaces. Small batteries may be installed in an open position if protected from falling objects and mechanical damage. Small battery installations should not be within 2.0 m (6 ft) of radio apparatus or other delicate equipment that would be made inoperative by slight corrosion from battery gases. Small batteries should not be located in closets, storerooms, or similar spaces. Small batteries should not be located in sleeping quarters unless hermetically sealed.

6.3.3 Arrangement

Batteries should be arranged to permit ready access to each cell or tray of cells from the top and at least one side for inspection, testing, watering, and cleaning. Shelves in battery rooms should be not more than 760 mm (30 in) deep. There should be at least 300 mm (12 in), with 380 to 460 mm (15 to 18 in) recommended, clear space above the levels of the filling openings. Trays should be readily removable for repair or replacement.

When batteries are arranged in two or more tiers, each shelf should have at least 51 mm (2 in) of space front and back for air circulation.

6.3.4 Battery trays

Battery trays should be securely chocked with wood strips or equivalent to prevent movement. Each tray should be fitted with nonabsorbent insulating supports, not less than 20 mm (0.75 in) high on the bottom, and with similar spacer blocks at the sides, or with equivalent provision to ensure 20 mm (0.75 in) of space around each tray for air circulation. Each battery tray should be accessible with at least 250 mm (10 in) of head room.

6.3.5 Battery storage lining

Each battery room or locker should have a watertight lining for the storage of batteries as follows:

a) Storing batteries on shelves: Install lining to a minimum height of 76 mm (3 in) with lining thickness and material as follows:
    1) For vented lead-acid type batteries: 1.6 mm (1/16 in) minimum lead or other material that is corrosion-resistant to the battery electrolyte.
    2) For alkaline type batteries: 0.8 mm (1/32 in) minimum steel or other material that is corrosion resistant to the battery electrolyte.
b) Alternatively, a battery room may be fitted with a watertight lead (steel for alkaline batteries) pan over the entire deck, carried up not less than 150 mm (6 in) on all sides.

Battery boxes should have a watertight lining to a height of 76 mm (3 in) with the same thickness requirements as shelf-lining requirements above.

The interior of all battery compartments, including shelves and other structural parts therein, should be painted with corrosion-resistant paint.

6.4 Ventilation

6.4.1 General

All rooms, lockers, and boxes for storage batteries should be arranged and ventilated to avoid accumulation of flammable gas. Particular attention should be given to the fact that the gas involved is lighter than air, and will tend to accumulate in any pockets at the top of the space.

6.4.2 Battery rooms

All battery rooms should be adequately ventilated. Natural ventilation may be employed where the number of air changes are small and if ducts can be run directly from the top of the room to the open air above, with no part of the cut more than 45º from vertical. If natural ventilation is impracticable, mechanical exhaust ventilation should be provided.

If mechanical ventilation is to be provided, the following recommendations should be adhered to:

a) Battery room ventilation system should be separate from ventilation systems for other spaces.
b) Ventilation intakes should be at the top of the room.
c) Each blower should have a non-sparking fan.
d) Fans should be capable of completely changing the air in a maximum of 2 min.
e) Electric fan motors should be outside the duct and compartment.
f) Electric fan motors should be explosionproof for a Class I, Division 1, Group B location.
g) Electric fan motors should be at least 3 m (10 ft) from the exhaust end of the duct.
h) The ventilation system should be interlocked with the battery charger such that the battery cannot be charged without operating the ventilation system.
i) Interior surfaces of ducts and fans should be painted with corrosion-resistant paint.
j) Adequate openings for air inlet should be provided near the floor.

6.4.3 Battery lockers

Battery lockers should be ventilated, if practicable, similarly to battery rooms by a duct led from the top of the locker to the open air or to an exhaust ventilation duct. However, in machinery spaces and similar well-ventilated compartments, the duct may terminate not less than 910 mm (3 ft) above the top of the locker. Louvers or the equivalent should be provided near the bottom of the locker for entrance of air.

6.4.4 Battery boxes

Deck boxes should be provided with a duct from the top of the box to at least 1.2 m (4 ft) above the box ending in a goose neck, mushroom head, or equivalent to prevent the entrance of water. Holes for air entrance should be provided on at least two opposite sides of the box. The entire deck box, including openings for ventilation, should be sufficiently weathertight to prevent entrance of spray or run.

Boxes for small batteries should have openings near the top to allow the escape of gas.

6.4.5 Large battery installation ventilation

Large battery installations should be in battery rooms having a power exhaust ventilation system with openings for intake air near the floor. These openings should be of sufficient size and number to allow for the passage of the quantity of air that must be expelled by the ventilation system.

The quantity of expelled air should be at least as follows:

$$Q = 110In$$

where

Q is the quantity of air expelled in l^3/h
I is the maximum charging current during gas formation, or 25% of the maximum obtainable charging current of the facility, whichever is greater, in amperes
n is the number of cells in series

or

$$Q = 3.89In$$

where

Q is the quantity of air expelled in ft^3/h
I is the maximum charging current during gas formation, or 25% of the maximum obtainable charging current of the facility, whichever is greater, in amperes
n is the number of cells in series

The ventilation rate for sealed-gelled electrolyte batteries may be reduced to 25% of the ventilation rate for large battery installations.

6.4.6 Moderate-sized and small battery installation ventilation

Battery rooms or battery lockers for moderate-sized or small battery installations should have louvers near the bottom of the room or locker for the intake of ventilation air. The ventilation rate for moderate-sized and small battery installations should meet the same requirements as for large battery installations.

6.5 Cables

If a cable enters a battery room, the penetration through the bulkhead, deck, or overhead should be made watertight. 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-carrying capacity of a connecting cable should be at least equal to the maximum charging current or maximum discharge current, whichever is greater.

6.6 Battery rating

The capacity of any battery should have minimum output sufficient for its application and duty. In determining battery capacity, consideration should be given to time and rate of discharge.

The capacity of batteries for emergency lighting and power should be as stated in Clause 26. Where the voltage of the emergency lighting system is the same as the voltage of the general lighting system, battery voltage, at the rated rate of discharge, should be a maximum of 105% of generator voltage when fully charged, and a minimum of 87.5% of generator voltage at the end of rated discharge.

Batteries for diesel engine cranking should have a maximum output sufficient to ensure breakaway torque at the lowest expected temperature. The battery should have a capacity capable of providing a minimum of 1.5 min of cranking at a speed sufficient to ensure engine starting and have sufficient capacity to provide a minimum of six consecutive engine starts without recharging.

6.7 Charging facilities

Charging facilities should be provided for all secondary batteries such that they can be completely charged from a completely discharged state in a reasonable amount of time with regards to the battery service requirements.

Suitable means, such as an ammeter and a voltmeter, should be provided to control and monitor the charging of batteries and to protect them against discharge into the charging circuits.

For floating circuits or other conditions where the load is connected to the battery while the battery is charging, the maximum battery voltage should not exceed a safe value for any connected apparatus. A voltage regulator should be used for any application where safe voltage cannot otherwise be assured. The voltage characteristics of the generator, or generators, that will operate in parallel with the battery must be suitable for each application. Where a low-voltage battery is floated on a circuit with a resistor in series, all connected apparatus shall be capable of withstanding line voltage to ground.

When the voltage of the emergency lighting battery is the same as the ship's dc supply, the battery may be arranged for charging in two equal sections with a charging resistor provided for each section. A booster generator may provided to supply charging voltage as an alternative to charging the battery in two equal sections. With either method, the arrangement of the automatic transfer switch should be such that emergency power is available whether the battery is being charged or not.

If boost charge facilities are provided, they should be arranged such that the boost charge is automatically disconnected if battery compartment ventilation fails.

Except for batteries that normally stand idle for long periods of time, the charging facilities for any battery should completely charge the battery in a maximum of 8 h without exceeding a safe charging rate. For those batteries that normally stand idle for long periods of time, a trickle charge to neutralize internal losses should be provided where practicable. For low-voltage batteries provided in duplicate for communications supply (one in service, the other on charge), the charging rate should be commensurate with the average discharge rate.

Where sealed-gelled electrolyte batteries are installed, a device independent of normal charging arrangements should be provided to prevent gas evolution in excess of manufacturer's design quantity.

6.8 Overload protection

An overload protective device should be in each battery conductor, except conductors of engine cranking batteries and batteries with a nominal voltage of 6 V or less. For large battery installations, the overcurrent protective device should be located next to, but outside of, the battery room.

Except when a rectifier is used, charging equipment for all batteries with a voltage more than 20 % of line voltage should be provided with automatic protection against current reversal.

Fuses may be used for the protection of emergency lighting storage batteries instead of circuit breakers up to and including 600 A rating.

7. Switchboards

7.1 Installation and location

Generator switchboards should be in the same space as the generators they control. An environmental enclosure for the switchboard, such as may be provided by a machinery control room situated within the machinery casing, is not considered to separate the switchboard from the generator. The switchboards should be installed in a dry place, away from steam, water, and oil pipes. When piping must be in the vicinity of the switchboard, dripproof shielding should be installed and piping joints should be welded. The switchboard should be accessible from the front and rear, except for switchboards that are enclosed at the rear and can be fully serviced from the front. Access entrances, and operating clearances in front and rear of the switchboards, should be in accordance with ANSI/NFPA 70-1996 (NEC) Articles 110-16 and 110-34 except as modified by this standard.

Working clearances

Nominal voltage to ground	Condition	Clearance	Reduced clearance in way of stiffeners and frames
0–150	1	0.91 m (3 ft)	0.61 m (2 ft)
0–150	2	0.91 m (3 ft)	0.76 m (2.5 ft)
0–150	3	0.91 m (3 ft)	0.91 m (3 ft)
151–600	1	0.91 m (3 ft)	0.76 m (2.5 ft)
151–600	2	1.07 m (3.5 ft)	0.91 m (3 ft)
151–600	3	1.22 m (4 ft)	1.07 m (3.5 ft)
601–2500	1	0.91 m (3 ft)	0.76 m (2.5 ft)
601–2500	2	1.22 m (4 ft)	1.07 m (3.5 ft)
601–2500	3	1.52 m (5 ft)	1.22 m (4 ft)
2501–9000	1	1.22 m (4 ft)	1.07 m (3.5 ft)
2501–9000	2	1.52 m (5 ft)	1.22 m (4 ft)
2501–9000	3	1.82 m (6 ft)	1.52 m (5 ft)
9001–25 000	1	1.52 m (5 ft)	1.22 m (4 ft)
9001–25 000	2	1.82 m (6 ft)	1.52 m (5 ft)
9001–25 000	3	2.74 m (9 ft)	1.82 m (6 ft)
25001–35 000	1	1.82 m (6 ft)	1.52 m (5 ft)
25001–35 000	2	2.44 m (8 ft)	1.82 m (6 ft)
2501–35 000	3	3.05 m (10 ft)	2.44 m (8 ft)

Where the “conditions” are as follows:

a) Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by suitable insulating materials. Insulated wire or insulated busbars operating at not over 300 V shall not be considered live parts.

b) Exposed live parts on one side and grounded parts on the other side.

c) Exposed live parts on both sides of the work space (not guarded as in condition a)) with the operator between.

d) Working space shall not be required in both of assemblies such as dead-front switchboards where there are no renewable or adjustable parts such as fuses or switches on the back and where all connections are accessible from locations other than the back.

The space in the front of the switchboard should be unobstructed and ample for operation, maintenance, and removal of equipment, in general not less than 910 mm (36 in). Clearances should be provided for current-carrying parts to ground in accordance with 7.10. Switchboards should be installed on a foundation that rises above the adjacent deck plating. To avoid excessively high foundations, consideration may be given to protecting the lower portion of the switchboard by watertight barriers and suitable drains. Switchboards may be self-supporting, or braced to the bulkhead or deck above. If a switchboard is braced, the means of bracing must be flexible to allow deflection of the ship’s structure without buckling the switchboard assembly. An electrical insulating deck covering, mat, or grating should be provided on the deck in front of any switchboard, extending the entire length of the switchboard and of sufficient width to suit the operating clearance specified.

When the space in the rear of the switchboard could be accessible to unauthorized personnel, the rear spaces should be protected within an enclosed lockable area. The area enclosure may be constructed of expanded metal sheets, or solid metal sheets with suitable ventilating louvers at the top and bottom. Where this arrangement is not feasible, rear covers may be mounted on the switchboard framework that are bolted on and easily removable. Alternatively, hinged covers may be used such that the cover may be fully opened.

7.2 Construction for low-voltage (1000 V or less) switchboards

All switchboards should be of the dead-front, metal-enclosed type and arranged to provide ready access to devices for replacement and maintenance. Switchboard devices operating at 55 V or greater that are mounted on hinged panels should be include physical guards to prevent accidental electrical shock by maintenance personnel. Front-panel switchboard sections supporting instruments, relays, switches, or other devices should be hinged to permit periodic access. Hinged panel sections exceeding a height of 1100 mm (45 in) or a width of 610 mm (24 in) should be provided with panel positioners. Bolted-on, removable panel sections may be used where periodic inspection, adjustment, or maintenance is not required. If the switchboard is not accessible from the rear, components and bus bar connections (except bus connections for draw-out circuit breakers) should be within 460 mm (18 in) from the front of the switchboard.

Switchboard end covers should be made of metal provided with ventilating louvers or grilles at the top and bottom when required for heat dissipation. Side covers may be made a permanent part of the structure when removal is not required for maintenance or access purposes.

Insulating material used for panels, bases, bus, and connection supports should be made of moisture-resistant, flame-resistant, incombustible material having high dielectric and mechanical strength.

A nonconducting hand rail or rails attached to the front of the switchboard or panels should be provided across the full length of the switchboard. A horizontal rail is recommended, but vertical handrails on individual sections are acceptable. Nonconducting guard rail protection should also be provided across the rear of all switchboards, even if removable rear covers are provided.

Terminal blocks should be provided on the framework or on interior panels mounted to the framework, closely adjacent to the wiring loop to hinged panels for disconnecting the wires. Terminal blocks, properly marked, should be provided for all outgoing instrument and control wires and for wire connections from one shipping section of the switchboard to another, except for instrument shunt leads or meter shunt leads. All current transformer secondaries should be wired through current transformer shorting terminal blocks prior to connecting to components and additionally for all outgoing current transformer secondary circuits.

Internal wiring for control circuits should be SIS Type wiring not smaller than AWG (American Wire Gauge) #14 stranded, unless required to fit the terminals on a device. Internal wiring for instrument circuits should be of a construction such as SIS Type wiring and not be smaller than AWG #20. SIS type wiring should be used and wiring should be capable of passing vertical flame test VW-1 in accordance with ANSI/UL 1581-1991. Connections to hinged panels should be with extra-flexible type wire.

All groups of internal wiring should be adequately secured to the switchboard panels or framework in such a manner as to prevent chafing, cutting of the insulation, or excessive motion caused by vibration. All power cables should be secured adequately to prevent motion caused by vibration and to withstand the maximum short-circuit current.

All levers, handles, hand wheels, interlocks, and their connecting links, shafts, and bearings for the operation of circuit breakers, switches, and contactors should be of such proportions that they will not be broken or distorted by manual operation.

7.3 Construction for medium-voltage (1001 V to 15 kV rms) switchboards

All medium-voltage switchboards should be of metal-clad construction in accordance with IEEE Std C37.20.2-1993. Generally, the construction should be similar to that described in 7.2 for low-voltage switchboards but with the following additional features:

Metal-clad switchboards should be provided with metal barriers between primary sections of adjacent units and between major primary sections of each circuit. Primary sections include the bus compartment, the primary entrance compartment, the removable element compartment, the potential transformer(s) compartment, and the control transformer(s) compartment. To minimize the possibility of communicating faults between primary sections, the barriers between primary sections should have no intentional openings. Automatic shutters should be provided in the stationary structure to prevent accidental contact with live parts of the primary circuit when the circuit breaker is in the test position, disconnected position, or has been removed. Primary or power-carrying buses, conductors, and connections should be covered with flame-retardant insulating material throughout. Each conductor should have an insulating covering that by itself will withstand the maximum rated line-to-line voltage between the conductor and outside surface of the insulating covering for a period of 1 min. Where possible, joints should be completely covered by insulating material at the factory; for joints that must be made on shipboard, insulating material should be supplied for application in accordance with the switchboard manufacturer’s instructions.

Mechanical interlocks should be provided on metal-clad switchboards as follows:

a) To prevent moving the circuit breaker to or from the connected position when the switching device is in the closed position.
b) To prevent closing the switching device unless the primary disconnecting devices are in full contact or are separated by a safe distance.
c) To positively hold the circuit breaker in place in the housing when it is in either the connected or test position. When a separate disconnected position is provided with the door closed, the circuit breaker should be positively held in this position.
d) To prevent the disconnection of and access to fuses on the primary side of control power transformers unless the secondary circuit is open.
e) To prevent the release of the stored energy mechanisms on a circuit breaker unless the mechanisms have been fully charged.
f) To prevent the complete withdrawal of the circuit breaker from the housing when the stored energy mechanism is in the fully charged position. In lieu of the interlock, a suitable device may be provided that prevents the complete withdrawal of the circuit breaker until the closing function is blocked.

Instruments, meters, relays, secondary control devices, and their wiring should be isolated by grounded metal barriers from all primary circuit elements with the exception of short lengths of wire such as at instrument transformer terminals.

The door through which the circuit interrupting device is inserted into the housing may serve as an instrument or relay panel and may also provide access to a secondary or control compartment within the housing.

Potential transformers and their fuses should be mounted in a separate compartment with means for disconnecting from the primary circuit before access can be obtained to either the transformer or its primary fuses. Provision should be made for disconnecting or automatically grounding the secondary circuits when disconnecting the primary circuit. Provision should be made for momentarily grounding the primary of potential transformers during the disconnecting operation.

Internal wiring connections between the housing and the circuit breaker should be provided with means for automatic disconnection when the circuit breaker is moved from the connected position and to reinstate them in the test position unless means are provided to sustain control connections between connected and test positions.

One set of test jumpers or their equivalent should be provided for each installation to complete all secondary connections for test in the disconnected position.

Where accessible to unauthorized personnel, metal-clad switchgear should be equipped with lockable front hinged panels with hand-operated latches and bolted rear covers. Ducts or grilles for venting exhaust gases should be so constructed as to prevent foreign materials from entering the circuit breaker.

7.4 Device design characteristics

The design of all current-carrying devices or parts of switchboards should conform to the latest standards specified in the related sections of nationally recognized standards except as these characteristics may be modified herein.

All devices should be capable of withstanding shipboard vibration without damage or faulty operation and should operate successfully when inclined at an angle of 45° in any direction from the vertical.

All switching devices, applied on or operated from power switchboards, should have a rated capacity at least as great as the maximum continuous current rating of the apparatus controlled. For apparatus having an overload rating of 30 min or more, all switching devices should have a rated capacity at least as great as the apparatus overload rating. For apparatus having high short-time current ratings, all switching devices should have a short time rating equal to or greater than the apparatus being supplied.

All electrical indicating instruments should be in accordance with the requirements of ANSI C39.1-1981. All instruments should be of the switchboard type, except those for battery charging equipment, which may be of the panel type having an accuracy class of 2.0 or less. The switchboard-type instruments should have 1% accuracy and preferably be of the 250° nominal scale type.

Voltmeter scales should be based on the voltage systems used on the vessel as follows:

Range of system voltage	Voltmeter scale
115–120	0–150
220–240	0–300
440–480	0–600
575–600	0–700
2400	0–3000
4160	0–5250

Ammeter and wattmeter scales should be of sufficient range to indicate maximum current or power under normal operating conditions and should indicate not less than 110% to 150% of the normal current or power rating for circuits that are not subjected to other than momentary overload. For circuits that may be subject to 25% overloads, the ammeter or wattmeter scale should be a minimum of 135% of nominal. Instruments should indicate the nominal rated or full-load value in the upper 25% of the full deflection.

Voltage regulator elements should be provided with enclosing cases to protect them from damage.

Double-throw switches of the open type (live-front) mounted within the switchboard enclosure should preferably be mounted horizontally. Where vertically mounted, they should be provided with suitable means for retaining blades in the "open" position in accordance with ANSI/NFPA 70-1996.

Feeder and branch circuits should be connected to the fuse end of switches and coil end of circuit breakers. When a switch or links are provided to disconnect the generator circuit breaker from the bus or when the generator circuit breaker is of the draw-out type, generator connections may be made to either end of the breaker.

Corrosion-resistant parts should be in accordance with 1.8.1.

7.5 Circuit breakers

The current rating of circuit breakers should be the current value that the circuit breakers will carry continuously without exceeding the specified temperature rise. Low-voltage power (open-frame or insulated case) circuit breakers may be equipped with overcurrent trip devices of the electromechanical or electronic type. The overcurrent devices may be equipped with time overcurrent trips (long time, short time, or both), instantaneous trips, and any combination thereof. The time overcurrent trips should be adjustable on power circuit breakers but need not be adjustable on molded-case circuit breakers.

Low-voltage circuit breakers should have an integral trip device with tripping power being derived internally from the overcurrent.

Medium-voltage class circuit breakers normally utilize separate electromechanical or electronic type relays for overcurrent sensing, but direct acting overcurrent units may be used. Separate overcurrent relays should have a current sensor in each phase. Control power for tripping medium-voltage circuit breakers should be from an internal battery source with an automatic charger, or capacitor type storage may be used on ac circuit breaker trip units.

Arcing contacts, except those used in molded case circuit breakers, should be easily renewable. All circuit breakers should be of the trip-free type.

All circuit breakers of the molded-case type should be mounted or arranged in such a manner that the circuit breaker may be removed from the front without disconnecting the copper or cable connections or de-energizing the supply to the breaker. Use of plug-in or draw-out type breakers that do not require use of an insulated wrench for removal is preferred.

For all other requirements, circuit breakers and knife switches should conform to the requirements of the appropriate national or international standards.

7.6 Temperatures

Switchboard apparatus primarily designed for use in a maximum ambient temperature of 45 °C (113 °F) may be used in a 50 °C (122 °F) ambient temperature provided that the primary contacts and joints are silver surfaced or equivalent and provided that normal operation does not result in total temperatures in excess of the following:

a) 90 °C (194 °F) for class 90 insulation
b) 105 °C (221 °F) for class 105 insulation
c) 130 °C (266 °F) for class 130 insulation
d) 155 °C (311 °F) for class 155 insulation

In addition to these limits on insulating materials, the total temperature specified in other national or international standards for various switchboard parts, circuit breakers, fuses, and similar devices will also apply for these switchboard applications in a 50 °C (122 °F) ambient temperature.

7.7 Arrangement of switchboard equipment

The devices that are operated or observed from the front of the switchboard should be arranged to provide the greatest degree of safety and convenience for operating personnel. Molded-case circuit breakers may be mounted vertically or horizontally. The center line of manually operated 400 A frame size and larger circuit breakers should not be mounted higher than 1800 mm (72 in) above the bottom of the switchboard. When interrupting devices, such as air circuit breakers, are mounted one above the other, there should be adequate spacing for the arcing or otherwise protective barriers installed. Barriers should also be provided, if necessary, to prevent arcing to other adjacent equipment.

A minimum clearance of 200 mm (8 in) between live parts and the bottom of the switchboard should be maintained.

Particular attention should be given to the arrangement of buses and connections to provide space for cables and accessibility for making cable connections.

In general, all fuses, including those for instrument and control circuits, should be accessible from the front of the switchboard.

When rheostats or other devices that may operate at high temperatures are mounted in the switchboard, they should be located or isolated by barriers and naturally ventilated so as to prevent excessive temperature rise of the device or adjacent devices. When this cannot be accomplished, the heat-producing rheostat or other devices should be mounted away from the switchboard.

On ac switchboards, the synchroscope and synchronizing lamps should be located so as to be readily visible from the position at which the operator controls the incoming generators. Voltage-adjusting potentiometers should be located close to their respective generator voltmeters. Each frequency meter should be readable from the prime mover speed control switch, or potentiometer.

If voltage regulators and their accessories for two or more generators are installed in the switchboard and located in the same section, the devices for each generator should be isolated by a barrier.

Buses and primary connections should be arranged so that, for three-phase assembled switchboards, the phase sequence is A, B, C, and for dc assembled switchboards, the polarities are positive, neutral, negative, front to back, top to bottom, and left to right, as viewed from the front of the switchboard.

7.8 Protective functions

The automatic protective functions in 7.8.1 through 7.8.7 should be provided.

7.8.1 Protection general

Refer to 11.28.

7.8.2 Generator protection

7.8.2.1 General

Molded-case circuit breakers may be used in place of power circuit breakers for generators rated less than 25 kW, and not arranged for parallel operation.

Each generator circuit breaker should be provided with a device that will trip the breaker under the conditions described in 5.6.

7.8.2.2 Alternating-current (ac) generators

Generators should be protected by means of trip-free, low-voltage power circuit breakers having long-time overcurrent trip units, or by medium-voltage circuit breakers and overcurrent relays with long-time pickup characteristics. The pickup setting of the long-time overcurrent trip should not exceed 115% of the generator rating for continuous rated machines and should not exceed 15% above the overload rating for specially rated machines.

Generator low-voltage circuit breakers should also have short time-delay trips. For medium-voltage circuit breakers, the overcurrent relay short-time feature may not be required if the long-time characteristic provides the needed protection. Where three or more generators are operated in parallel, the generator breakers should also have instantaneous trips that are set at a value in excess of the maximum short-circuit contribution of the individual generator.

In order to provide the maximum obtainable degree of protection for the generator, the overcurrent trips should be set at the lowest values of current and time that will comply with the recommendations of 11.28.

When two or more generators are to operate in parallel, each generator should be protected against reverse power flow. The reverse power relays should operate on reverse power values of 15% or greater of the generator rating for diesel driven generators, and of 5% or greater for turbine-driven generators. If reverse power relays are used that may operate at very low values of power reversal, a time-delay feature should be incorporated to prevent the tripping of generator circuit breakers during switching operations.

7.8.2.3 Direct-current (dc) generators

7.8.2.3.1 Generator overload and short circuits

Generators should be protected by means of trip-free circuit breakers having inverse time overcurrent trips as shown in Figure 5-1 through 5-10. The time overcurrent trip should be set at a value not to exceed 115% of the generator rating for continuous rated machines and at a value not to exceed 15% above the overload rating for specially rated machines. All generator circuit breakers should be provided with an instantaneous trip set below the maximum generator short-circuit current to reduce the likelihood of, and minimize the damage from, commutator flashover. In order to provide the maximum obtainable degree of protection for the generator, the instantaneous trip should be set at the lowest value of current that will coordinate with the trip settings of bus-tie or feeder circuit breakers in the generator distribution switchboard.

7.8.2.3.2 Generator neutral overcurrent

Provision should be made to indicate overcurrent in the neutral of three-wire generators by means of a relay and alarm system. The relay should be set to function at a value of current equivalent to 25% of the rating of the generator or at a value not exceeding the rating at the generator neutral, whichever is less. No overload trip feature should be provided on the neutral pole of the generator circuit breaker, but the neutral pole should operate simultaneously with the other poles of the generator circuit breaker.

7.8.2.3.3 Generator reverse current

Where generators are operated in parallel, the generator circuit breakers should be provided with a reverse-current relay that will operate to trip the breaker prior to current reversals of sufficient magnitude to cause injurious effects on the machine or prime mover. The reverse-current relays should operate on reverse current values of 15% or greater of the generator rating for diesel-driven generators, and of 5% or greater for turbine-driven generators.

When reverse-current relays are used that may operate at very low values of power reversal, a time-delay feature should be incorporated to prevent the tripping of generator circuit breakers during switching operations.

7.8.2.3.4 Generator shutdown

The generator circuit breaker should be provided with an undervoltage device connected so that it will be tripped anytime the generator is shutdown. See 5.6.

7.8.3 Feeder cables—overload and short-circuit protection

For each distribution circuit, a circuit breaker with a pole for each conductor should be provided, except for three-phase grounded systems where the grounded conductor need not be opened. Circuit breakers of the power or molded-case type should be used and are preferred. Fused switches may be used up to 200 A. Overcurrent protection should be provided for all ungrounded conductors. Fuses should not be, and circuit breaker overload trips need not be, provided for the neutral conductor of a three-wire dc grounded system.

7.8.4 Control circuits—overload and short-circuit protection

All control circuits except those listed in the following paragraph should be protected by fuses, one in each line, located as closely as possible to the source of power.

Fuses should not be installed in any circuit where the opening of the fuse might introduce an operating hazard, such as

a) Electric propulsion control circuits
b) Circuit breaker tripping control circuits
c) Supply circuits for voltage regulators, static exciters, and governors
d) Supply circuits for reverse power relays

NOTE—On electric propulsion installations having very complex control circuits and a large quantity of grouped wiring, consideration may be given to the use of protective fuses. The capacity of the fuses should be not less than 500% of the normal current of the circuits protected so that they will function only on fault currents. Fuses should have blown fuse indicators.

7.8.5 Potential circuit overcurrent protection

Each conductor for potential circuits to instruments, pilot lamps, and ground detector lamps should be protected by fuses. In addition, potential transformers, provided they are not installed in any circuit where the opening of a fuse would introduce an operating hazard, should be protected from short circuit by fuses in the primary. If instruments are connected to the secondaries of potential transformers that are also connected to reverse power relays, the instruments should be fused in a manner that does not affect the reverse power relays in the event of a fuse opening. The transformer and its primary fuse protection should be designed so that in the event of short circuit on the secondary side, the primary fuse will open. The primary fuse size should be no greater than 6 A.

NOTE—The potential transformer should operate satisfactorily with a temperature rise of 30 °C (86 °F) based on an ambient temperature of 55 °C (131 °F).

7.8.6 Steering gear feeder circuit breaker

Steering gear feeder circuit breakers should have instantaneous trip only, and should have contacts to operate audible alarms located at the principal control station and the navigating bridge in accordance with 18.3.2.

7.8.7 Shore power feeder protection

The shore power feeder should have a circuit breaker with a pole for each ungrounded conductor installed in the switchboard for connecting power from the shore connection panel to the ship service distribution bus. An indicating light should be illuminated when power is available from shore, and one of the generator voltmeters should have selector switch capability to read shore power voltage. Mechanical or electrical interlocking of the shore power circuit breaker with the generator circuit breakers should be installed unless load transfer paralleling capability is provided.

7.9 Grounding

The switchboard framework should be positively grounded to the hull. Metal cases of instruments and other devices should be grounded. The secondary windings of instrument transformers should be grounded. See 11.39.

7.10 Bus bars and connections

All switchboards should be fitted with copper or aluminum bus bars and connections, applied on the basis of the cross-sectional area required for the circuit ampere rating, except as noted herein. Bus bars and connections should be braced to withstand vibration and the maximum mechanical forces imposed by inrush current and all available system short-circuit currents.

All bus-bar connection points should be silver or tin-plated. Plating should not peel off under normal operating conditions. Aluminum bus bar connector and fastener materials should accommodate the thermal expansion of aluminum and should not be galvanically active with aluminum. An antioxidant should be used between aluminum bus-bar connections.

The bus size should be selected on the basis of limiting the bus-bar temperature rise to 50 °C (122 °F) at rated current. Table 7-1 may be used in determining the required bus-bar size.

Bus-bar current carrying-capacity should be determined on the basis of generator and feeder full-load currents. For a single generator, the generator bus should have a current capacity equal to the full-load rating of the generator plus any overload rating in excess of 30 min duration. For more than one generator with all generating capacity feeding through one section of the bus, the capacity of the bus for the first generator should be the same as for a single-generator installation. For each subsequent generator, the bus capacity should be increased by 80% of the continuous rating of the added generator. The capacity of connection buses for each generator unit should be equal to the continuous rating of the generator plus any overload rating in excess of 30 min duration. In order to limit the size of bus for generator switchboards, it is recommended that consideration be given to locating generator sections in the center or at each end of the switchboard.

If the aggregate generating capacity connected to a generator switchboard exceeds 3000 kW, the switchboard bus should be divided into at least two sections. The connections of the generators and any other duplicated distribution services should be divided equally between the bus sections as far as is practicable. The bus sectioning device may be a bolted splice connection, an automatic or nonautomatic circuit breaker, bus-disconnect links, or other suitable device.

Table 7-1—Ampere rating of rectangular bus bars placed on edge [based on 50 °C (122 °F) ambient and 50 °C (122 °F) rise]

Number of bars in parallel	Size of bars (in)	Ampere rating, dc copper bars	Ampere rating, ac 60 Hz copper bars	Ampere rating, dc aluminum bars	Ampere rating, ac 60 Hz aluminum bars
One	3/4 × 1/8	250	250	190	190
	1 × 1/8	330	330	245	245
	1-1/2 × 1/8	500	500	335	335
	1-1/2 × 3/16	580	570	435	430
	2 × 3/16	760	745	570	565
	1 × 1/4	490	480	415	410
	1-1/2 × 1/4	685	675	570	565
	2 × 1/4	920	900	700	685
	3 × 1/4	1380	1280	1000	975
	4 × 1/4	1730	1650	1300	1275
	5 × 1/4	2125	2000	1600	1550
	6 × 1/4	2475	2300	1925	1825
	8 × 1/4	3175	2875	2425	2250
Two (1/4 in apart)	2 × 1/4	1525	1450	1175	1100
	3 × 1/4	2225	2050	1675	1560
	4 × 1/4	2800	2550	2150	2000
	5 × 1/4	3100	2975	2625	2350
	6 × 1/4	4000	3450	3075	2775
	8 × 1/4	5100	4250	3925	3450
Three (1/4 in apart)	3 × 1/4	3035	2550	2300	2025
	4 × 1/4	2875	3225	2925	2600
	5 × 1/4	4700	3880	3575	3075
	6 × 1/4	5500	4400	4175	3600
	8 × 1/4	6875	5300	5300	4450
Four (1/4 in apart)	3 × 1/4	3300	3050	2800	2375
	4 × 1/4	4500	4250	4000	3075
	5 × 1/4	5425	5000	4950	4000
	6 × 1/4	6300	6000	5750	5000
	8 × 1/4	7200	7100	6500	6225

For distribution sections of switchboards, the buses should have a capacity of not less than 75% of the combined full-load rated rms current of all loads, including 50% of the frame rating of all spare circuit-breaker capacity, both installed and designed reserve space. The capacity of the feeder buses need not be greater than the generator buses that supply them. Bus connections to individual feeder circuit breakers should be designed on the basis of the frame rating of the breakers when the frame rating is 600 A or less. For frame ratings above 600 A, the bus connections should not be less than the breaker trip rating.

For certain high-current capacity installations, the use of copper or aluminum channel bus bars, angle bus bars, or an arrangement of rectangular bars with an increased spacing between bars may offer an appreciable reduction in cross-section requirements. Such arrangements should be used where practicable.

All bus bars should be accurately formed, and all holes should be made in a manner that will permit bus bars and connections to be fitted into place without being forced.

Bus bars, connection bars, and wiring on the back of the switchboard should be arranged so that maximum accessibility is provided for cable connections. Consideration should also be given to the arrangement of cables so they may be connected to the switchboard in an orderly manner. The electrical clearance between parts of opposite polarity and between live parts and ground should be in accordance with the following table. The distances may be less at device terminals, but should be kept as great as possible.

Voltage (ac or dc)	Creepage on surface	Clearance in air
Up to 125	19 mm (0.75 in)	13 mm (0.5 in)
125 to 250	32 mm (1.25 in)	20 mm (0.75 in)
251 to 600	51 mm (2.0 in)	25 mm (1.0 in)

Bolts, nuts, and washers used to maintain contact on bus and connection bars should be of nonferrous material or of steel, with a corrosion-resistant treatment described in 1.8.1.

Conductors should be terminated directly on the bus bar. If current-carrying nuts are used, they should be made of a copper alloy having adequate conductivity and should be of sufficient size to provide the necessary area to carry circuit current without exceeding the temperature rise specified for copper alloy. Current-carrying nuts should be plated and compatible with the connections. For high-capacity buses in excess of 4000 A, consideration should be given to the use of nonmagnetic-type bus hardware to prevent excessive temperatures at joints and connections.

All nuts and connections should be fitted with efficient locking devices to prevent loosening due to vibration. Bolts for bus-bar joints should be lubricated and tightened to the recommended torque values in Table 7-2. Connections to circuit breaker terminals should be tightened to the recommended values in Table 7-3.

Table 7-2—Recommended torque values for bus bar joints

Bolt size (in)	Steel		Silicon bronze	
	Minimum (ft·lbf)	Maximum (ft·lbf)	Minimum (ft·lbf)	Maximum (ft·lbf)
3/8	14	16	10	11
1/2	30	33	15	17
5/8	50	55	35	39

Table 7-3—Recommended torque values for circuit breaker terminal connections

Copper stud size (in)	Steel cap screw size (in)	Torque (ft·lbf)	
		Minimum	Maximum
3/8		7	8
1/2		15	17
3/4		25	28
1-1/8		40	44
	5/8	50	55
	1	130	145

Current and potential transformers, etc., should be rigidly supported.

In order to prevent excessive heating in ac installations, no magnetic material should be located between phase conductors.

7.11 Wire and conductor terminal lugs

All wire and cable connections for power, lighting, communications, and electronics circuits external to the switchboard should be connected to devices or buses by means of compression/crimp type terminal lugs in accordance with ANSI/UL 486A-1991. All terminal boards or connectors for external circuits should be located where they are accessible for cable connection.

7.12 Nameplates

Each switchboard should be fitted with a nameplate stating that it has been constructed for a marine application and should provide the voltage and ampere rating of the main bus, the manufacturer's name, and the date of manufacture. Nameplates of nonabsorbent and corrosion-resistant material should be provided for each piece of apparatus to clearly indicate its service. Nameplates for generator, bus-tie, feeder, and branch circuit breakers should include the circuit number and designation, and the rating of the circuit breaker trip elements, or fuse sizes, required for the circuit.

7.13 Minimum equipment for generator switchboards

7.13.1 Alternating-current (ac) generators

The following equipment should be provided:

a) A drawout or plug-in generator circuit breaker for each generator. Insulated case power circuit breakers with frames rated 800 A or greater should have operating handle extensions. Where more than one power source (generators and/or shore power) is available and the sources are not intended to operate in parallel, a mechanical or electrical circuit breaker interlock to prevent paralleling should be provided. Where automatic paralleling is required, electrically operated circuit breakers with closing speeds of 5 cycles or less should be provided.
b) On low-voltage systems, an undervoltage trip auxiliary device on each generator circuit breaker for automatic tripping when a generator shuts down or a protective relay operates. Medium-voltage circuit breakers have shunt-trip devices, inherent in their design, that should be used for this purpose.

c) For each electrically operated circuit breaker, a circuit breaker control switch and open and closed indicator lights.
d) An ammeter for each generator with a selector switch to read the current of each phase.
e) A voltmeter for each generator with a selector switch to connect the voltmeter between each phase of the generator and to one phase of the bus. One of the voltmeters and selector switches should also read the voltage between each phase of the shore connection.
f) When two or more generators are to operate in parallel, an indicating wattmeter for each generator.
g) A power factor meter connected to the bus.
h) A frequency meter with selector switch to connect to any generator and one frequency meter for the bus, or a frequency meter for each generator.
i) For each generator rated 400 kW and above, a temperature detection instrument with a selector switch having positions to read all temperature detectors (RTDs) in each winding.
j) An indicator light permanently connected to the generator side of each generator circuit breaker.
k) A speed control device for the prime mover of each generator capable of parallel operation.
l) A circuit breaker to feed the space heater in each generator via a relay or auxiliary contacts on the generator circuit breaker See 5.21.
m) When two or more generators are to operate in parallel, a reverse power relay for each generator.
n) When two or more generators are to operate in an automatic start and parallel mode, a frequency permissive underfrequency relay and a voltage permissive undervoltage relay for each generator.
o) Where two or more generators are to operate in parallel, a synchroscope and synchronizing lamps with selector switch to permit manual paralleling in any combination. A synchronizing check relay for each generator circuit breaker should be provided to prevent inadvertent out-of-phase paralleling. When fully automatic paralleling, a power management system, or remote operation of the generating plant is provided, an automatic (speed and voltage matching) synchronizing device with dead-bus feature, or a separate dead-bus relay, should be installed. When fully automatic power management is provided, and a dead-bus start of the main generators is required, first start and sequential standby generator selection and sensing logic should be provided to prevent more than one generator from being started and connected to the bus simultaneously, out of phase.
p) A voltage-adjusting device for each generator automatic voltage regulator.
q) Except where the voltage regulators are mounted in the generator enclosure or a separate generator control unit: an automatic voltage regulator, a switch for transferring from automatic to manual voltage regulator control, and manual voltage regulator control rheostat for each generator.
r) Except where the generator utilizes rotating brushless or static exciters: a double-pole field switch with discharge clips and resistor for each generator, when the generator field may be disconnected.
s) Ground-detection provisions for each separate bus of the switchboard.
t) Current and potential transformers, as required. Potential transformers should be used as necessary to ensure a maximum voltage on hinged instrument panels of 120 V.

NOTE 1—If extensive automatic control logic is required in the switchboard for automatic generator starting and paralleling, power management systems or sequential load shedding that would normally require a large number of electromechanical relays, consideration should be given to the use of programmable logic controllers.

NOTE 2—Refer to 11.39 for additional requirements applicable to grounded neutral systems.

7.13.2 For direct-current (dc) generators

The following items should be provided:

a) A drawout or plug-in generator circuit breaker for each generator.
b) An ammeter for each two-wire generator or two ammeters for each three-wire generator, one in the positive line and one in the negative line.
c) An ammeter for the neutral ground connection for each three-wire generators.
d) A voltmeter for each generator with voltmeter switch, depending on the type of generator, for connecting the voltmeter to indicate generator voltage, positive to negative, positive to neutral, and neutral to

negative, bus voltage positive to negative. One of these voltmeter switches should also provide the capability to read the shore connection voltage, positive to negative, positive to neutral, and neutral to negative.

e) An indicator light permanently connected to the generator side of each generator circuit breaker.
f) A reverse current protective device for each generator when two or more generators are required to operate in parallel.
g) A field rheostat for each generator.

NOTE—When voltage regulators are used with constant speed generators, a switch for cutting out the regulator should be provided. When used with variable speed generators, no cutout switch or adjustable field rheostat should be included, unless specified.

7.14 Emergency switchboard and interior communications/electronics switchboard

7.14.1 General

The emergency and interior communications/electronics switchboards should conform to all applicable requirements of 7.1 through 7.13 and 7.15, except that no neutral current ammeter is to be provided. Switchboards should also provide the features recommended in Clause 26 and those described in the following subclauses. Suggested means of implementing these features are indicated in Figure 7-1 through Figure 7-4. These figures are not to be considered as being restrictive or as prohibiting variations to suit specific ship designs.

7.14.2 Alternating-current (ac) switchboards

7.14.2.1 Cargo vessels

The emergency switchboard should be configured to comply with the recommendations in 26.2 and as depicted in Figure 7-1 or Figure 7-2. Generally, a single multibus switchboard will serve the emergency power, lighting, interior communication, and electronics circuits. The emergency switchboard should normally be supplied by the bus-tie circuit from the ship service or main switchboard, with an emergency source from an emergency generator or storage battery via an automatic bus transfer switch (ABT) comprised of two interlocked, electrically operated, power circuit breakers. Transfer to the emergency source should be initiated by failure of the normal source. When an automatically started emergency generator is provided, transfer should occur when the generator is at rated voltage and frequency. When a manually started emergency generator set is provided, a temporary emergency power source should be installed. Distribution sections for emergency lighting, interior communications, and electronics circuits should be provided. Suggested connections for the essential low-voltage dc system are indicated in Figure 7-1 and Figure 7-2.

7.14.2.2 Passenger vessels required to have an emergency generator

The emergency switchboard should be configured to comply with the recommendations in 26.4 and as depicted in Figure 7-3 or Figure 7-4. The emergency switchboard distribution sections should have three sets of buses. The final emergency bus should feed power loads not required to be fed from a temporary emergency bus, and should be normally supplied by the bus-tie circuit from the ship service or main switchboard, with an alternate emergency source supplied by the emergency generator via an automatic bus transfer switch. The transfer switch should be comprised of two interlocked, electrically operated, power circuit breakers in the generator section of the emergency switchboard. Failure of the normal power source should initiate emergency generator starting, with transfer to the emergency source when the generator is at rated voltage and frequency.

The temporary emergency bus should normally be supplied from the final emergency bus via an automatic bus transfer switch, and should be automatically connected to the storage battery/inverter source upon failure of the normal power source. Automatic retransfer to the final emergency bus should occur when power at rated voltage and frequency is available. Distribution sections for emergency lighting, interior communications, and electronics circuits should be provided. Suggested connections for the essential low-voltage dc system are indicated in Figure 7-3 and Figure 7-4.

7.14.2.3 Passenger vessels (coastal and inland waterways)

The emergency switchboard should be configured to comply with the recommendations in 26.5.

7.14.3 Direct-current (dc) switchboards

Except for differences arising from the fact that the emergency generator will be of the dc type, the switchboards should be similar to those described above for ac switchboards. Bus transfer arrangements should be essentially as described for ac switchboards except that the connections should permit the satisfactory supply of all loads on the temporary emergency buses, including those from any final ac emergency buses.

If there is any continuous ac load, a separate ac bus normally supplied from motor-generator sets or inverters fed from a dc ship service source should be provided, with a separate automatic switch for transfer to the emergency storage battery, if required. Emergency lighting and other temporary emergency loads that will operate on either ac or dc should be arranged for automatic transfer from the final emergency bus to the battery bus. Protection should be provided against discharge of the battery into supply circuits. Normal operation should be restored automatically upon restoration of the ship service supply or establishment of emergency generator supply after failure of ship service power.

The interior communications and electronics distribution section should be provided with any or all of the following buses, depending on the distribution system configuration:

a) 120/240 V bus connected directly to the final emergency bus.
b) 120 V or 120/240 V bus connected directly to the temporary emergency bus.
c) 24 V bus supplied from duplicate storage batteries.
d) 120 V single-phase ac bus supplied either from one of duplicate motor-generator sets through a double-throw generator selector switch; or from dc/ac inverters.

If any of the ac circuits are among those classed in 26.4.1 as temporary emergency circuits, the dc/ac motor-generators or inverters should be supplied from the battery bus and arranged for continued operation upon failure of ship service power. An ac voltmeter, ammeter, and frequency meter should be provided. The master switches for motor-generator starting and the motor and generator field rheostats should be mounted on the switchboard.

7.14.4 All vessels

Automatic battery charging equipment, with suitable indicating instruments, should be provided for emergency storage batteries and for emergency generator set engine starting batteries, if installed. See Clause 6 for general requirements applicable to storage battery installations.

Automatic bus transfer switches (ABTs) should utilize interlocked, electrically operated power circuit breakers when installed in switchboards. Independently enclosed and mounted ABTs should preferably be of the circuit breaker or latched contactor type, with coils energized only during the transfer operation. Transfer switches should initiate the transfer to the emergency supply when the normal voltage is reduced to 60% to 70% of nominal value and, if arranged for automatic retransfer, should return to the normal supply when the available voltage is from 85% to 95% of the nominal value. Automatic bus transfer switches feeding motor loads should have sufficient delay to permit low-voltage protection (LVP) motor controllers to open.

All emergency switchboards fed by diesel engine or gas turbine-driven generators, except those of very small kilowatt output ratings, should be arranged to feed back to the ship service or main switchboard all available emergency generator power in excess of that required for the emergency loads. The feedback arrangement should utilize interlocked circuit breakers that prevent paralleling the emergency generator with the main generators, except for momentary transfer of loads where proper synchronizing equipment is provided. When feedback capability is provided, emergency generator overload protection should be installed that will trip the feedback breaker before the generator circuit breaker overload trip is activated.

General emergency alarm feeder circuits, when fed from the essential low-voltage dc system bus, should be connected directly to the bus through fuses or locked-closed circuit breakers.

7.15 Dielectric withstand-voltage test

7.15.1 Factory dielectric withstand tests

The standard factory withstand dielectric test voltage for all switching and interrupting apparatus should be as follows:

Voltage rating (V)		**Withstand test (Vrms)**
Up to 120	ac	1500
121–600	ac	2200
601–1200	ac	5000
1201–2400	ac	15 000
2401–4760	ac	19 000
125–300	dc	1500
301–600	dc	2200

All apparatus and devices in the power circuit should be mounted in the normal location during the tests, but removable drawout mounted circuit breakers need not be tested in the assembly if they are tested separately. Where the standards for devices other than the switching or interrupting devices, such as potential transformers, call for a lower test voltage, the devices may be disconnected during the dielectric test. Such devices should be individually tested in accordance with their applicable standards.

For the control wiring, a 60 Hz test voltage, 1500 V to ground, shall be applied for 1 min after all circuit ground points have been disconnected, and all circuits are wired together with small bare copper wire to short-circuit coil windings.

Dielectric withstand tests should be made at the factory under the temperature and humidity conditions normally obtained under conditions of testing, with appropriate correction factors applied as outlined in IEEE Std 4-1995.

The ac test voltage for the power frequency withstand dielectric tests should have a crest value equal to 1.41 times the rms test value specified in the table above. The wave shape shall be as close to a sine wave as practicable. The frequency shall not be less than the rated frequency of the apparatus tested. The tests should be made phase-to-phase and phase-to-ground. The test voltages should be applied for 1 min.

7.15.2 Shipboard dielectric withstand tests

When dielectric withstand tests are to be made on switchboards after installation in the ship, the assembly may be tested at 0.75 times the test values given in the table in 7.15.1.

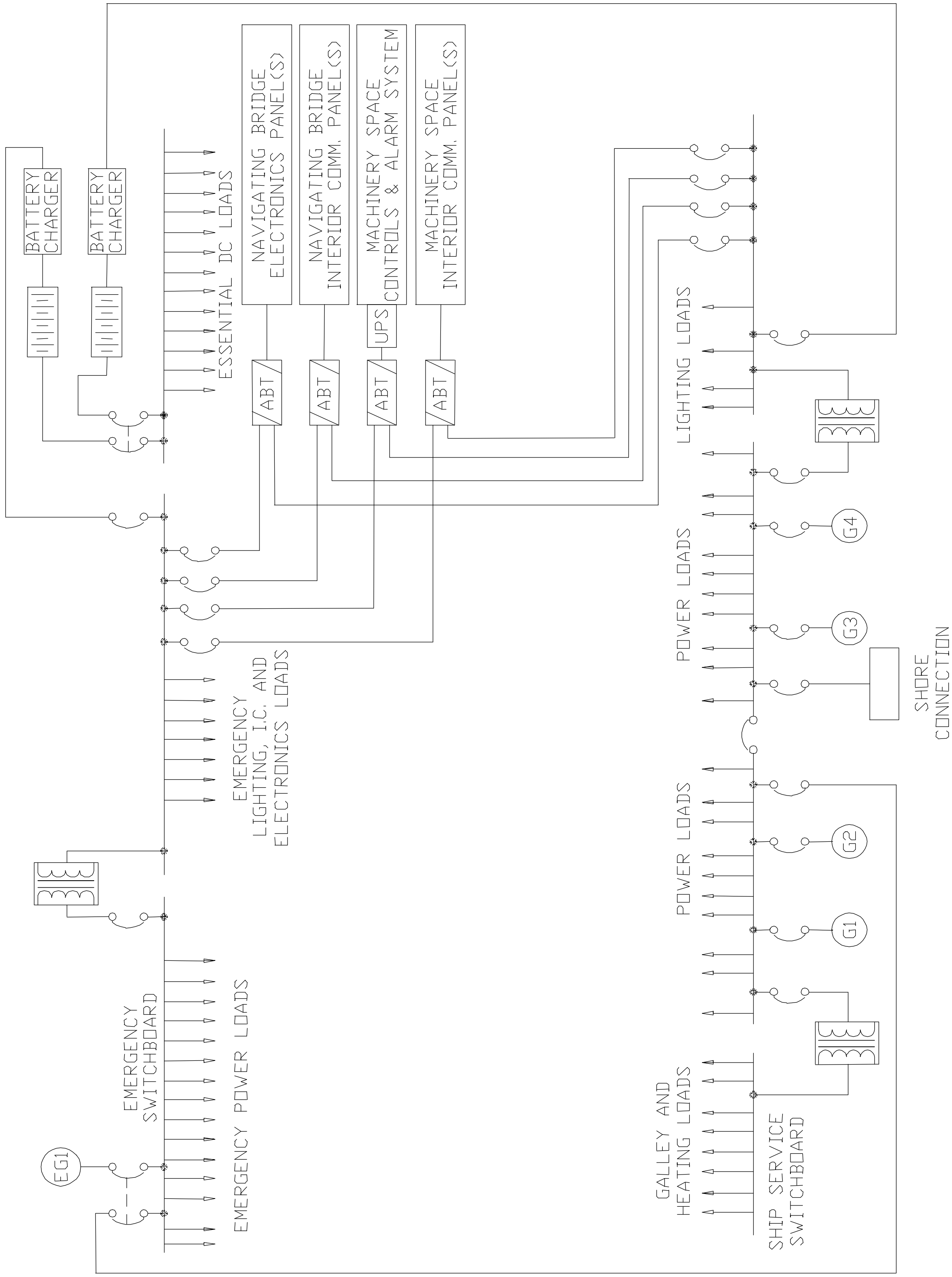


Figure 7-1—Typical electric plant configuration—cargo vessels

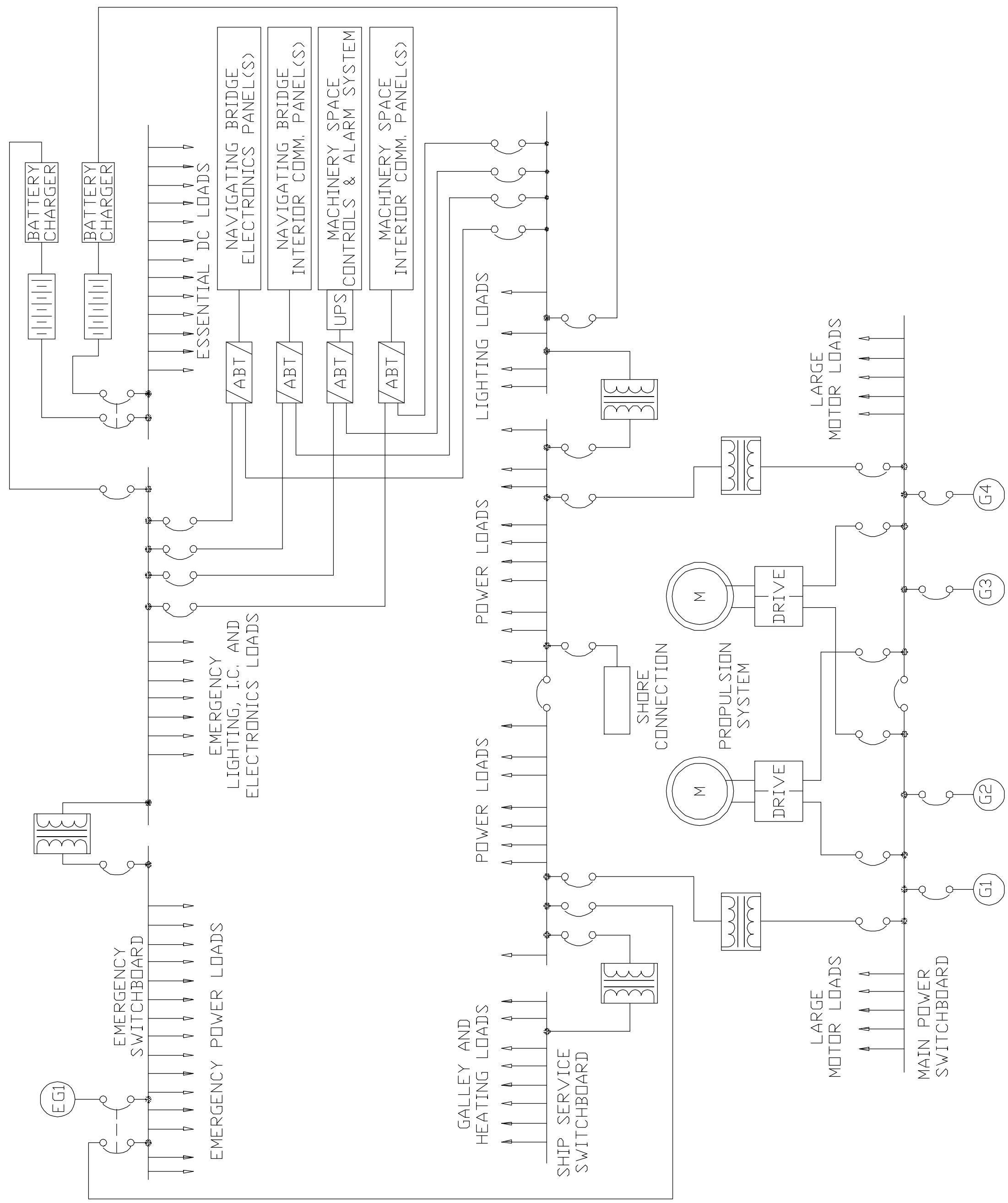


Figure 7-2—Typical integrated electric plant configuration—cargo vessels

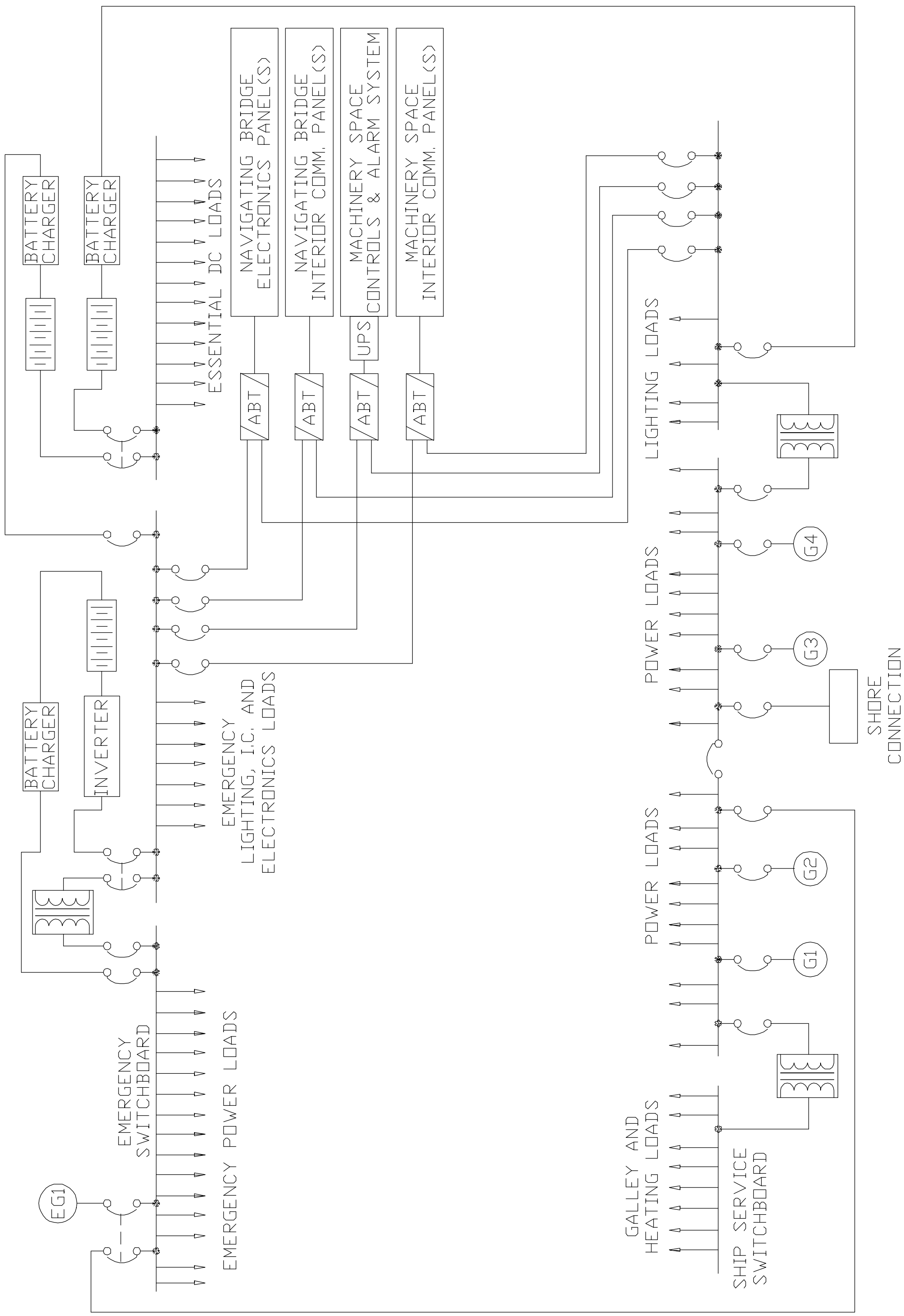


Figure 7-3—Typical electric plant configuration—passenger vessels

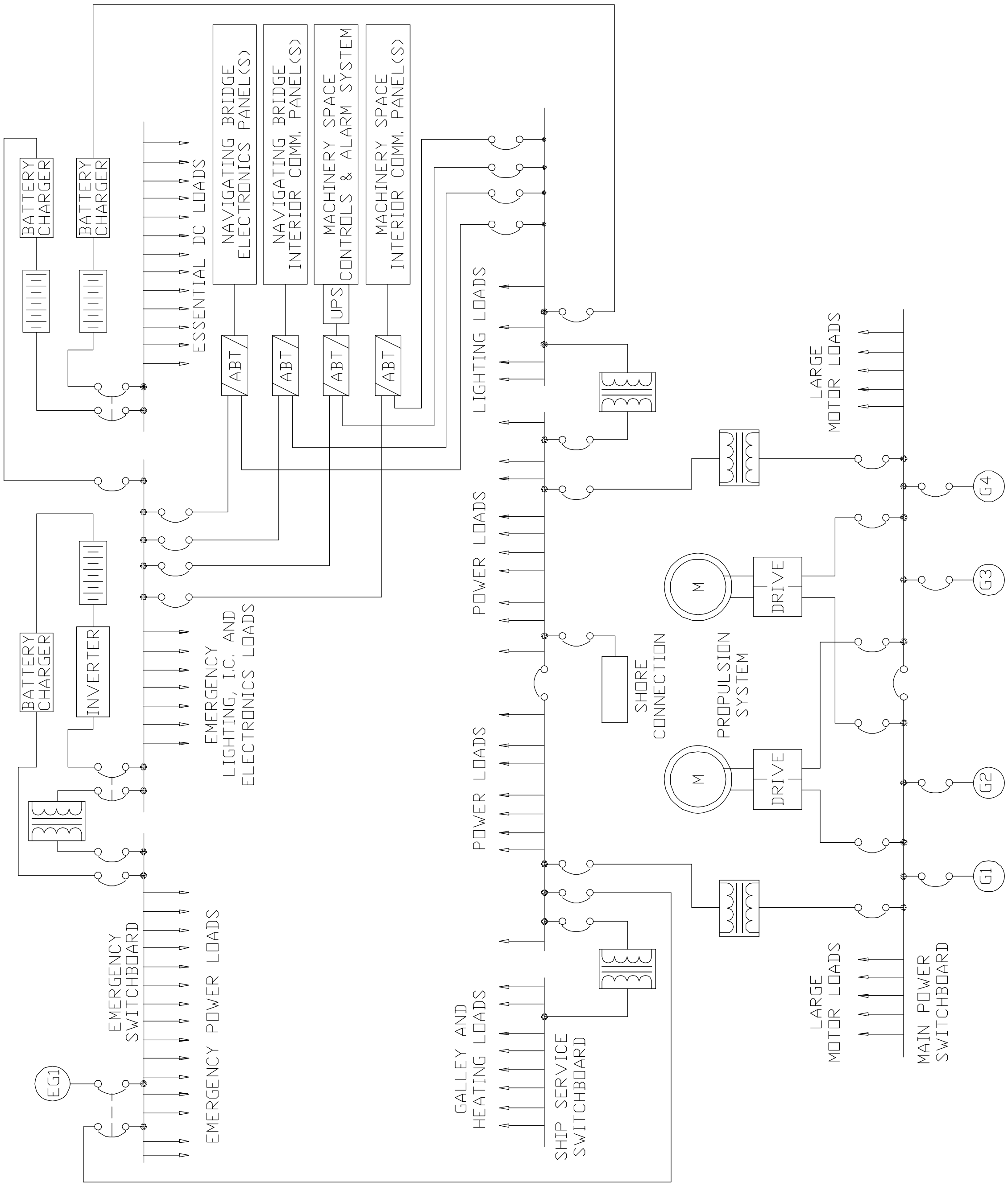


Figure 7-4—Typical integrated electric plant configuration—passenger vessels

8. Cable construction

8.1 Copper conductors

8.1.1 General

The conductors should be of soft annealed copper wire. All conductors should be tinned or alloy-coated where necessary to ensure compatibility with primary insulation.

8.1.2 Composition

Conductors should be manufactured in accordance with the most current edition of following American National Standards:

— ANSI/ASTM B3-95
— ANSI/ASTM B8-95
— ANSI/ASTM B33-94
— ANSI/ASTM B172-95
— ANSI/ASTM B173-95
— ANSI/ASTM B174-95
— ANSI/ASTM B189-95

8.1.3 Stranding

The construction requirements and nominal resistances of standard Class B concentric conductors may be found in Table 8-1. Combination stranded, compressed stranded to a reduction in diameter of 3% maximum of concentric stranded conductors, or flexible rope stranded conductors may be substituted for concentric stranded conductors. The construction requirements of extra flexible stranded conductors for portable cords (see 9.6.1) should conform to ANSI/UL 62-1991 or Table 8-2.

8.1.4 Conductor shielding

Conductor shielding should be used on conductors of cables rated above 2000 V.

Conductor shielding should be an extruded semiconducting compound to a minimum thickness of 12 mil. It shall be firmly bonded to the overlying layer of insulation with no protrusions into the insulation exceeding 10 mil. A semiconducting nonmetallic tape with a minimum thickness of 2.5 mil may be used over the conductor and under the extruded semiconducting layer.

Extruded conductor shielding should have a maximum volume resistivity of 100 000 Ω-cm at room temperature and at the maximum normal operating temperature of the cable. Extruded conductor shielding should meet the following requirements when tested according to procedure in NEMA WC 8-1988 for Type E, or NEMA WC 7-1988 for Type X:

— Elongation after air oven at 121 ± 1 °C (249.8 °F ± 33.8 °F) for 168 h, minimum 100%
— Brittleness temperature, not warmer than −10 °C (−14 °F)

8.1.5 Separator

Where required to ensure free stripping, a suitable separator tape may be applied to the conductor.

8.2 Insulation

8.2.1 General

The insulation should be one of the following types:

Insulation type designation		Maximum conductor temperature °C (°F)
T	polyvinyl chloride	75 (167)
T/N	polyvinylchloride/nylon	90 (194)
E	ethylene propylene rubber	90 (194)
X	cross-linked polyethylene	90 (194)
LSE	low-smoke-ethylene propylene rubber	90 (194)
LSX	low-smoke-cross-linked polyethylene	90 (194)
S	silicone rubber	100 (212)
P	cross-linked polyolefin	100 (212)

The insulation should be prevented from penetrating between the strands of the conductor by the manufacturing process, or by a separator tape.

8.2.2 Properties

The physical and electrical properties of Type(s) T, T/N, E, X, LSE, LSX, S, and P insulation materials should meet the requirements of Table 8-3, Table 8-4, or Table 8-5. The material of the nylon jacket for Type T/N should additionally meet the requirements of ANSI/ASTM-D4066-94B Type VIII. The manufacturer should perform type tests and periodic testing to ensure that insulation materials meet these requirements.

8.2.3 Thickness of insulation.

The average thickness of T, T/N, E, X, LSE, LSX, S, and P insulation should not be less than the values given in Table 8-7 or Table 8-8. The minimum thickness at any point should not be less than 90% of the measured average value. The maximum thickness at any point should not be greater than 110% of the measured average value.

8.3 Tapes

Where binder or separator tapes are provided, a polyester film tape or compound filled tape should be used. Where a compound filled tape is used, the tape should be made from cloth treated on one or both sides with an insulating compound.

8.4 Braids

Silicone rubber insulated conductors should be covered with glass braids.

8.5 Conductor identification

Where conductor color coding is specified, the identification may be made either by colored conductor insulation or separator tapes, or by printing the color nomenclature on the insulation or its covering. Conductor identification of distribution cables, when colored conductors are used, should be as follows:

two conductors	black, white, or red
three conductors	black, white or blue, red
four conductors	black, white or blue, red, orange, or green[19]
five conductors	black, white, red, green, orange

Conductor identification of control and signal cables should follow the color sequence of Table 8-31 or Table 8-32.

8.6 Cabling

Conductors, pairs, or groups of conductors should be cabled in concentric layers. The direction of lay for adjacent layers should be reversed.

8.7 Fillers

Fillers should be nonhygroscopic, compatible with other cable components, maximizing the filling of all voids. Fillers should be used as required to give the completed cable a substantially circular cross-section. Low-smoke cable fillers shall have a smoke index number not greater than 45 in accordance with NES-711.

8.8 Marker

Cable identification should be provided by a durable printing or embossing on the jacket, or a marker under the cable jacket. Marker material should be suitable for its service. Marking should give the following information at intervals not exceeding 610 mm (24 in). Only cable that is in total conformance with the specific requirements of this standard should bear the IEEE Std 45-1998 designation or use the type designations identified in this standard.

a) Manufacturer
b) Applicable specification and the year of the standard, i.e., IEEE Std 45-1998
c) Year of manufacture
d) Voltage rating
e) Cable designations (see 8.15) inclusive of Table 8-33.
f) The listing (or classification) mark of an independent product testing and certification organization.

8.9 Cable jackets

8.9.1 General

The jacket should be thermoplastic Type T or TPO, thermosetting Type CP, N, or L complying with the requirements of Table 8-9 or Table 8-10. The manufacturer should perform type tests and periodic testing to ensure jacket materials meet these requirements.

8.9.2 Jacket thickness

The average thickness of the cable jacket should not be less than shown in Table 8-11. The minimum thickness at any point should not be less than 80% of the measured average values shown.

[19] If a conductor is functioning as a grounding conductor (normally not a current-carrying conductor) in a distribution system, then it must be colored green.

8.10 Armor

8.10.1 General

Armor should be of the basket-weave type. Armor is not a shield.

8.10.2 Basket weave

The armor should consist of wire laid closely together, flat and parallel, and forming a basket weave that should firmly grip the cable. The wire should be 0.32004 mm (0.0126 in) diameter, ± 0.0127 mm (±0.0005 in), and should be free from cracks, splits, or other flaws. The wire should be either commercial bronze or aluminum. The weave should be either the “one over-one under” or the “two over-two under” type. The selection of the number of ends per carrier and the number of carriers per braider should be such as to produce a basket weave with a braid angle and coverage within the following limits:

Diameter over jacket (in)	Percent coverage		Braid angle (°)	
	min	**max**	**min**	**max**
up to 0.600	88	94	30	60
0.601 to 1.000	88	94	35	60
1.001 to 1.500	88	94	40	70
1.501 to 2.000	88	94	45	70
2.001 and over	88	94	50	80

where the percent coverage = $(2F - F^2) \times 100$

and

$$F = \frac{NPd}{\sin a}$$

where

a = angle of braid with axis of cable:

$$\tan a = \frac{2\pi DP}{C}$$

d = diameter of individual braid wire in inches
C = number of carriers
D = diameter of cable under armor, in inches
N = number of wire per carrier
P = picks per inch of cable length

The maximum number of ends per carrier should conform to the following table:

Cable diameter under armor (in)	Maximum number of ends per carrier	
	“One over-one under”	**“Two over-two under”**
0 to 0.400	8	5
0.401 to 0.800	12	8
0.801 to 1.500	15	10
1.501 and larger	20	10

8.10.3 Aluminum armor

Aluminum armor braid should be aluminum alloy 5154 or an equivalent alloy having a minimum tensile strength of 35 kg/mm^2 (50 000 lb/in^2) and a minimum elongation of 2% in 25 cm (10 in).

8.10.4 Commercial bronze armor

Commercial bronze armor braid should be annealed 90-10 bronze, Copper Development Association (CDA) alloy number 220.

8.10.5 Tin coated copper armor

Tin coated copper armor braid should meet the requirements of ASTM B33-94. An overall sheath is required on cables with a tin coated copper braid armor.

8.10.6 Overall sheath

Where overall sheath is applied, sheath material should be in accordance with requirements for cable jackets in 8.9. The overall sheath will increase the cable diameter and weight.

8.11 Paint

Cables should not be painted except 5000 V types, which may be painted yellow.

8.12 Dimension tolerances

The average measured diameter of the finished cable should meet the nominal values given in Table 8-15 through Table 8-30. A plus or minus tolerance of not more than 5% is permitted on the nominal diameters given in the tables.

8.13 Tests on finished cable

Finished cable should be tested in accordance with the following:

Test to be performed	Test categories		
	Type test (TT)	**Production sample test (PST)**	**Routine test (RT)**
Insulation (Tables 8-3, 8-4, and 8-5)	X	X	—
Jacket (Tables 8-9 and 8-10)	X	X	—
Dimensional tolerance (8.12)	X	X	—
High voltage (8.13.1)	—	X	X
Conductor resistance (8.13.2)	—	—	X
Insulation resistance (8.13.3)	—	—	X
Flammability 18.13.4)	X	X (b1)	—
Ease of stripping (8.13.5)	—	X	—
Salt-water immersion (8.13.6)	X	—	—
Cable immersion in oil 18.13.7)	X	—	—
Pull-through metal plates (8.13.8)	X	—	—
Bending endurance (8.13.9)	X	—	—

a) *Type tests (TT)*: Type tests are the minimum initial testing for a manufacturer to determine compliance with this standard. Unless otherwise specified, TT should be performed on a 3-conductor, 6-AWG cable for power and distribution, 7-conductor 12- or 14-AWG cable for control, and a 7-pair, 18-AWG cable for signal cables. Any other cables in their respective cable designation for distribution, control, or signal that are 23 mm (0.9 in) in diameter and larger may also be considered representative. This does not relieve the manufacturer from ensuring compliance with the test requirements for all cable types and sizes.

b) *Production sample tests (PST)*: Production sample tests should be performed at the frequency established in Part 6 of NEMA WC 8-1988, NEMA WC 7-1988, NEMA WC 3-1992, and NEMA WC 5-1992. Where no frequency is identified, testing frequency shall be determined by the product certification organization.
   (b1) PST for flammability and when invoked for smoke, acid gas, and toxicity tests as related to the insulation/jacket/sheath shall be done at a frequency of every 3 years.
c) *Routine tests (RT)*: Routine tests should be performed on each length of finished cable.

8.13.1 High-voltage test

Each reel of finished cable should be tested and should successfully withstand for a period of 5 min the high-voltage ac test potential given in Table 8-12 as applicable. The ac potential should be applied between conductors and ground. Test should be in accordance with IEEE Std 4-1995.

For cables having from two to five conductors, with or without metallic armor, the voltage tests should be applied in turn between each conductor and all other conductors connected together and to the metal covering, if any.

For cables having more than five conductors, the voltage test should be applied as follows:

a) Between all conductors of uneven number in all layers and all conductors of even number in all layers;
b) Between all conductors of even layers and all conductors of uneven layers;
c) If necessary, between the first and the last conductor of each layer having an uneven number of conductors.

8.13.2 Conductor resistance test

Conductor resistance should be measured on finished cable in accordance with the procedures outlined in NEMA WC 8-1988 or NEMA WC 7-1988, Paragraph 6.3.1, and corrected to 25 °C (89.6 °F). Maximum resistance values should be in accordance with the appropriate standards referenced in 8.1.2.

8.13.3 Insulation resistance test

Each reel of finished cable should be tested and should have an insulation resistance measured between each conductor and ground, of not less than that given in Table 8-13. The current should be measured after 1 min with a continuous dc potential of not less than 100 V nor more than 500 V, the conductor being negative to ground. If the test is made at a temperature different from 15.5 °C (59.5 °F), the measured value should be multiplied with the proper correction factor as given in Table 8-14.

8.13.4 Flammability test

All cable constructions should be flame retardant and should meet IEEE Std 1202-1991.

8.13.5 Ease-of-stripping test

Cable should be tested in accordance with the following procedure:

a) A specimen of multiple conductor cable approximately 380 mm (15 in) long shall have its jacket and filler material cut using a razor blade or similar instrument.
b) The cut shall be longitudinally and vertically down to the insulation for approximately 150 mm (6 in).
c) A second cut around the circumference of the cable is to be made at the end of the first cut.

d) The resulting jacket piece is then to be removed by pulling at right angles away from the cable. Remaining particles that can be removed by light brushing are acceptable.
e) A 76 mm (3 in) length of the insulation shall be stripped from a sample length of the finished stranded conductor and the outer layer of strands opened.

When the jacket is removed, the cable core shall show no evidence of damage. When the insulation is removed, there shall be no evidence of insulation compound beneath the outer layer of conductor strands.

8.13.6 Salt-water immersion test

Cable should be tested in accordance with the following procedure:

Three 1.1 m (3.5 ft) lengths of cable shall be immersed in a 20% (by weight) of common salt (sodium chloride) solution at 60 ± 1 °C (140 ± 1.8 °F) for 240 h. The cable shall be immersed in a "U" bend such that each leg of the "U" bend of the cable is one foot above the water.

After immersion in salt water, the cable shall comply with the following:

a) The cable shall pass the dielectric voltage withstand test described in 8.13.1.
b) The mechanical properties of the jacket or insulation shall not be degraded to the point of cracking when wound around a mandrel having a diameter equal to nine times the sample overall diameter.
c) The insulation and jacket should not degrade to the point where either will crack or separate from the cable during the conditioning or during the testing described in items a) or b) above.

8.13.7 Cable immersion in oil test

Cable should be tested in accordance with the following procedure:

Three 1.1 m (3.5 ft) jacketed lengths of cable shall be immersed in IRM 902 or ASTM oil No. 2 at 121 ± 1 °C (250 ± 1.8 °F) for 18 h or at 75 ± 1 °C (167 ± 1.8 °F) for 60 days. The cable shall be immersed in the oil in a "U" bend such that each leg of the "U" bend is one foot above the surface of the oil.

After immersion in oil, the cable should comply with the following:

a) The cable shall pass the dielectric voltage withstand test described in 8.13.1.
b) The mechanical properties of the jacket or insulation shall not be degraded to the point they will crack when wound around a mandrel having a diameter equal to nine times the sample overall diameter.
c) The insulation and jacket shall not degrade to the point where either will crack or separate from the cable during the conditioning or during the testing described in items a) or b) above.

8.13.8 Pull-through metal plates test

Cable should be tested using the apparatus and procedure described below:

Apparatus

a) The metal plates for the test set-up shown in Figure 8-1 are to be four 150 mm (6 in) or longer lengths of 12 mm (1/2 in) × 100 mm (4 in) cold-rolled steel. Both ends of each length are to be cut perpendicular to the long surfaces.
b) Three holes of the size given in the table shown below are to be bored through the broad faces of each plate as shown in Figure 8-1 (view of broad face). The longitudinal axes of the holes are to be parallel and at an angle of 15° to the horizontal as shown in the end view, and 38 mm (1.5 in) apart. The edges of the hole are to be reamed sufficiently to remove burrs and rough edges caused by the drilling.

Size of hole	
Calculated diameter over finished round cable or length of major axis of finished flat cable (inches)	**Nominal diameter of each hole (inches)**
0–0.710	1–1/8
0.711–0.800	1–1/4
0.801–0.875	1–3/8
0.876–0.950	1–1/2
0.951–1.025	1–5/8
1.026 and larger	1-1/2 times cable OD

An open, rigid, metal frame is to be provided on which four of the plates are to be supported on edge (broad faces vertical) approximately 2.13 m (7 ft) above the floor with their centerlines 406 mm (16 in) apart and parallel to one another in a horizontal plane. The plates are to be secured to the frame with all of their holes inclined in the same direction (longitudinal axes of holes parallel)—see the four end views in Figure 8-1 (top view) and progressively offset a horizontal distance of 150 mm (6 in) as also shown in Figure 8-1, which is a view looking down from above the plates.

Procedure

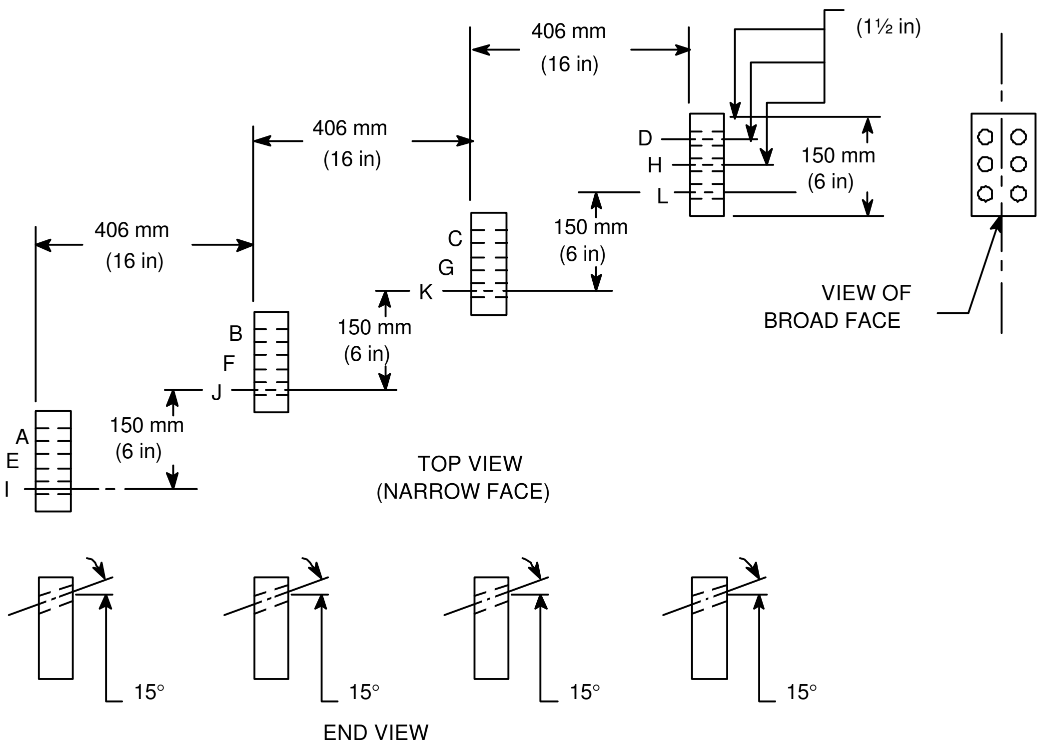


Figure 8-1—Test setup for pull-through metal plates test

a) A reel of finished cable mounted on a stand should be located so that the distance between the bottom of the cable reel and a line perpendicular to the center of the plates is to be 2 m (80 in). The distance between the first plate and a line tangent to the coil at the point where the cable comes off the coil is to be 450 mm (18 in). Upon completion of the period of cooling [24 h @ –10 °C (–14 °F) in air], the procedures described in the following paragraphs are to be carried out immediately.
b) One end of the sample is to be threaded in succession through the holes labeled A, B, C, and D in Figure 8-1. As soon as the first part of the sample has been threaded through the four holes, the end of the sample emerging from hole D (head end) is to be grasped manually, in a position such that the cable emerges

from hole D at an angle of about 45° to the vertical. While maintaining this angle, pull 15 m (50 ft) of the sample entirely through the holes until the end of this sample (tail end) emerges from hole D. The sample is to be pulled through rapidly, and no effort is to be made to straighten or adjust the sample except to remove kinks that would prevent the sample from being pulled completely through the four holes. All of the pulling is to be done from beyond hole D, not from between plates.

c) As soon as the tail end of the sample emerges from hole D, the sample is to be cut to provide a 15 m (50 ft) length, and the head end of this sample is to be threaded in succession through holes E, F, G, and H. The entire length of the sample is to be pulled through in the manner indicated in the preceding paragraph.
d) As soon as the tail end of the sample emerges from hole H, the head end of the sample is to be threaded in succession through holes I, J, K, and L, and the entire length of the sample is to be pulled through in the manner indicated in paragraph b). The overall sample is to be examined visually to determine if the cable is damaged and to assess the degree of damage.

There should be no damage to the overall covering or jacket to the extent that the parts of the cable underlying the covering or jacket are exposed to view.

8.13.9 Bending endurance test

Cable should be tested in accordance with the following procedure:

After a period of 4 h in a cold chamber at a temperature of –25 °C (–13 °F) and while at that temperature, each sample is to be tightly wound for 1/4 turn around a mandrel having a diameter equal to 12 times the overall diameter of the specimen. The specimen is to be straightened to its original position, then bent for a 1/4 turn in the opposite direction, and then straightened. This procedure is to be repeated nine more times for a total of 10 times.

There shall be no evidence of the cable insulation or jacket cracking as a result of this bending test. The specimens are then to be subjected to the dielectric withstand test described in 8.13.1. The results of the dielectric withstand test shall meet the requirements specified for that test.

8.14 IEEE cable types T, T/N, E, X, LSE, LSX and S

8.14.1 Single-conductor, thermoset or thermoplastic insulated, jacketed, with or without armor or armor and sheath (Table 8-7, Table 8-11, Table 8-15)

Types: SET, SETA, SETB, SETBS, SECP, SECPA, SECPB, SECPBS, SEN, SENA, SENB, SENBS

SXT, SXTA, SXTB, SXTBS, SXCP, SXCPA, SXCPB, SXCPBS, SXN, SXNA, SXNB, SXNBS

STT, STTA, STTB, STTBS, ST/N, ST/NTA, ST/NTB, ST/NTBS, ST/ STCP, STCPA, STCPB, STCPBS, ST/NCP, ST/NCPA, ST/NCPB, ST/NCPBS STN, STNA, STNB, STNBS, ST/NN, ST/NNA, ST/NNB, ST/NNBS

Construction details:

First: Stranded conductor tin or alloy coated where necessary to ensure compatibility with insulation
Second: Insulation, Type X, E, T, and T/N
Third: Type T, CP, or N jacket
Fourth: Basket-weave armor (optional)
Fifth: Type T, CP, or N sheath (optional)

8.14.2 Single-conductor, low-smoke (LS) thermoset insulated, jacketed, with or without armor or armor and sheath (Table 8-7, Table 8-11, Table 8-15)

Types: SLSEL, SLSELA, SLSELB, SLSXLBS, SLSXL, SLSXLA, SLSXLB, SLSXLBS

Construction details:

First:	Stranded conductor tin or alloy coated where necessary to ensure compatibility with insulation
Second:	Insulation, Type LSX or LSE
Third:	Type L jacket
Fourth:	Basket-weave armor (optional)
Fifth:	Type L sheath (optional)

8.14.3 Two-, three-, or four-conductor thermoset or thermoplastic insulated, jacketed with or without armor and armor and sheath (Table 8-7, Table 8-11, Table 8-15, Table 8-17)

Types: DXT, DXTA, DXTB, DXTBS, DXCP, DXCPA, DXCPB, DXCPBS, DXN, DXNA, DXNB, DXNBS, DET, DETA, DETB, DETBS, DECP, DECPA, DECPB, DECPBS, DEN, DENA, DENB, DENBS, DTT, DTTA, DTTB, DTTBS, DTCP, DTCPA, DTCPB, DTCPBS, DTN, DTNA, DTNB, DTNBS, DT/NT, DT/NTA, DT/NTB, DT/NTBS DT/NCP, DT/NCPA, DT/NCPB, DT/NCPBS, DT/NN, DT/NNA, DT/NNB, DT/NNBS

TXT, TXTA, TXTB, TXTBS, TXCP, TXCPA, TXCPB, TXCPBS TXN, TXNA, TXNB, TXNBS, TET, TETA, TETB, TETBS, TECP, TECPA, TECPB, TECPBS, TEN, TENA, TENB, TENBS, TTT, TTTA, TTTB, TTTBS, TTN, TTNA, TTNB, TTNBS, TTCP, TTCPA, TTCPB, TTCPBS, TT/NT, TT/NTA, TT/NTB, TT/NTBS, TT/NCP, TT/NCPA, TT/NCPB, TT/NCPBS, TT/NN, TT/NNA, TT/NTB, TT/NNBS

FXT, FXTA, FXTB, FXTBS, FXCP, FXCPA, FXCPB, FXCPBS, FXN, FXNA, FXNB, FXNBS, FET, FETA, FETB, FETBS, FECP, FECPA, FECPB, FECPBS, FEN, FENA, FENB, FENBS, FTT, FTTA, FTTB, FTTBS, FTCP, FTCPA, FTCPB, FTCPBS, FTN, FTNA, FTNB, FTNBS, FT/NT, FT/NTA, FT/NTB, FT/NTBS, FT/NCP, FT/NCPA, FT/NCPB, FT/NCPBS, FT/NN, FT/NNA, FT/NNB, FT/NNBS

Construction details:

First:	Stranded conductor tin or alloy coated where necessary to assure compatability with insulation
Second:	Insulation, Type X, E, T, and T/N
Third:	Two, three, or four conductors cabled with fillers
Fourth:	Binder tape, as required
Fifth:	Type T, CP, or N jacket
Sixth:	Basket-weave armor (optional)
Seventh:	Type T, CP, or N sheath (optional)

8.14.4 Two-, three-, or four-conductor low-smoke (LS) thermoset insulated, jacketed, with or without armor or armor and sheath (Table 8-7, Table 8-11, Table 8-15)

Types: DLSEL, DLSELA, DLSELB, DLSELBS, TLSEL, TLSELA, TLSELB, TLSELBS, FLSEL, FLSELA, FLSELB, FLSELB, DLSXL, DLSXLA, DLSXLB, DLSXLBS, TLSXL, TLSXLA, TLSXLB, TLSXLBS, FLSXL, FLSXLA, FLSXLB, FLSXLBS

Construction details:

First:	Stranded conductor tin or alloy coated where necessary to ensure compatibility with insulation

Second: Insulation, Type LSE or LSX
Third: Two, three, or four conductors cabled with LS fillers
Fourth: Binder tape, as required
Fifth: Type L jacket
Sixth: Basket-weave armor (optional)
Seventh: Type L sheath (optional)

8.14.5 Single-, two-, three-, or four-conductor, thermoset insulated, jacketed, with or without armor or armor and sheath, 2000 V (Table 8-7, Table 8-11, Table 8-15)

Types: SETA 2 kV, SETB 2 kV, SXTA 2 kV, SXTB 2 kV, SECPA 2 kV, SECPB 2 kV, SXCPA 2 kV, SXCPB 2 kV, SENA 2 kV, SENB 2 kV, SXNA 2 kV, SXNB 2 kV

DXT 2 kV, DXTA 2 kV, DXTB 2 kV, DXTBS 2 kV, DXCP 2 kV, DXCPA 2 kV, DXCPB 2 kV, DXCPBS 2 kV, DXN 2 kV, DXNA 2 kV, DXNB 2 kV, DXNBS 2 kV, DET 2 kV, DETA 2 kV, DETB 2 kV, DETBS 2 kV, DECP 2 kV, DECPA 2 kV, DECPB 2 kV, DECPBS 2 kV, DEN 2 kV, DENA 2 kV, DENB 2 kV, DENBS 2 kV

TXT 2 kV, TXTA 2 kV, TXTB 2 kV, TXTBS 2 kV, TXCP 2 kV, TXCPA 2 kV, TXCPB 2 kV, TXCPBS 2 kV, TXN 2 kV, TXNA 2 kV, TXNB 2 kV, TXNBS 2 kV, TET 2 kV, TETA 2 kV, TETB 2 kV, TETBS 2 kV, TECP 2 kV, TECPA 2 kV, TECPB 2 kV, TECPBS 2 kV, TEN 2 kV, TENA 2 kV, TENB 2 kV, TENBS 2 kV

FXT 2 kV, FXTA 2 kV, FXTB 2 kV, FXTBS 2 kV, FXCP 2 kV, FXCPA 2 kV, FXCPB 2 kV, FXCPBS 2 kV, FXN 2 kV, FXNA 2 kV, FXNB 2 kV, FXNBS 2 kV, FET 2 kV, FETA 2 kV, FETB 2 kV, FETBS 2 kV, FECP 2 kV, FECPA 2 kV, FECPB 2 kV, FECPBS 2 kV FEN 2 kV, FENA 2 kV, FENB 2 kV, FENBS 2 kV

Construction details:

First: Stranded conductors tin or alloy coated where necessary to ensure compatibility with overlying materials
Second: Insulation: Type X or E
Third: Conductors cabled with fillers
Fourth: Binder tape, as required
Fifth: Type T, CP, or N jacket
Sixth: Basket-weave armor (optional)
Seventh: Type T, CP, or N sheath (optional)

8.14.6 Single-conductor, thermoset insulated, jacketed, with or without armor or armor and sheath, 5000 V (Table 8-7, Table 8-11, Table 8-21)

Types: SET 5 kV, SETA 5 kV, SETB 5 kV, SETBS 5 kV, SXT 5 kV, SXTA 5 kV, SXTB 5 kV, SXTBS 5 kV, SECP 5 kV, SECPA 5 kV, SECPB 5 kV, SECPBS 5 kV, SXCP 5 kV, SXCPA 5 kV, SXCPB 5 kV, SXCPBS 5 kV, SEN 5 kV, SENA 5 kV, SENB 5 kV, SENBS 5 kV, SXN 5 kV, SXNA 5 kV, SXNB 5 kV, SXNBS 5 kV

Construction details:

First: Stranded conductor tin or alloy coated where necessary to ensure compatibility with overlying material
Second: Conductor shield of semiconducting extruded compound or tape and extruded compound

Third:	Insulation: Type X or E with shield in accordance with NEMA WC 7-1988, or NEMA WC 8-1988, respectively
Fourth:	Type T, CP, or N jacket
Fifth:	Basket-weave armor (optional)
Sixth:	Type T, CP, or N sheath (optional)

8.14.7 Three-conductor, thermoset insulated, jacketed, with or without armor or armor and sheath, 5000 V (Table 8-7, Table 8-11, Table 8-20)

Types: TXT 5 kV, TXTA 5 kV, TXTB 5 kV, TXTBS 5 kV, TET 5 kV, TETA 5 kV, TETB 5 kV, TETBS 5 kV, TXCP 5 kV, TXCPA 5 kV, TXCPB 5 kV, TXCPBS 5 kV, TECP 5 kV, TECPA 5 kV, TECPB 5 kV, TECPBS 5 kV, TXN 5 kV, TXNA 5 kV, TXNB 5 kV, TXNBS 5 kV, TEN 5 kV, TENA 5 kV, TENB 5 kV, TENBS 5 kV

Construction details:

First:	Stranded conductors tin or alloy coated where necessary to ensure compatibility with overlying materials
Second:	Conductor shield of semiconducting extruded compound or tape and extruded compound
Third:	Insulation: Type X or E with shield in accordance with NEMA WC 7-1988, or NEMA WC 8-1988, respectively
Fourth:	Three conductors cabled with fillers
Fifth:	Binder tape, as required
Sixth:	Type T, CP, or N jacket
Seventh:	Basket-weave armor (optional)
Eighth:	Type T, CP, or N sheath (optional)

8.14.8 Single-conductor, silicone insulated, jacketed, with or without armor or armor and sheath (Table 8-7, Table 8-11, Table 8-15)

Types: SST, SSTA, SSTB, SSTBS, SSCP, SSCPA, SSCPB, SSCPBS, SSN, SSNA, SSNB, SSNBS

Construction details:

First:	Stranded copper conductor
Second:	Insulation, Type S
Third:	Glass Braid with finishing coat
Fourth:	Binder tape, as required
Fifth:	Type T, CP, or N jacket
Sixth	Basket-weave armor (optional)
Seventh:	Type T, CP, or N sheath (optional)

8.14.9 Two-, three-, or four-conductor, silicone insulated, jacketed, with or without armor or armor and sheath (Table 8-7, Table 8-11, Table 8-15)

Types: DST, DSTA, DSTB, DSTBS, DSCP, DSCPA, DSCPB, DSCPBS, DSN, DSNA, DSNB, DSNBS,
TST, TSTA, TSTB, TSTBS, TSCP, TSCPA, TSCPB, TSCPBS, TSN, TSNA, TSNB, TSNBS,
FST, FSTA, FSTB, FSTBS, FSCP, FSCPA, FSCPB, FSCPBS, FSN, FSNA, FSNB, FSNBS

Construction details:

First:	Stranded copper conductors
Second:	Insulation Type S

Third:	Glass braid with finishing coat pigmented to provide conductor identification
Fourth:	Two, three, or four conductors cabled with fillers where necessary
Fifth:	Binder tape, as required
Sixth	T, CP, or N jacket
Seventh:	Basket-weave armor (optional)
Eighth:	Type T, CP, or N sheath (optional)

8.14.10 Control cable-multiconductor, thermoset insulated, jacketed, with or without armor or armor and sheath (Table 8-11, Table 8-22)

Types: C14XT, C14XTA, C14XTB, C14XTBS, C14XCP, C14XCPA, C14XCPB, C14XCPBS, C14XN, C14XNA, C14XNB, C14XNBS, C14ET, C14ETA, C14ETB, C14ETBS, C14ECP, C14ECPA, C14ECPB, C14ECPBS, C14EN, C14ENA, C14ENB, C14ENBS

C16XT, C16XTA, C16XTB, C16XTBS, C16XCP, C16XCPA, C16XCPB, C16XCPBS, C16XN, C16XNA, C16XNB, C16XNBS, C16ET, C16ETA, C16ETB, C16ETBS, C16ECP, C16ECPA, C16ECPB, C16ECPBS, C16EN, C16ENA, C16ENB, C16ENBS

C18XT, C18XTA, C18XTB, C18XTBS, C18XCP, C18XCPA, C18XCPB, C18XCPBS, C18XN, C18XNA, C18XNB, C18XNBS, C18ET, C18ETA, C18ETB, C18ETBS, C18ECP, C18ECPA, C18ECPB, C18ECPBS, C18EN, C18ENA, C18ENB, C18ENBS

Construction details:

First:	Stranded conductors, AWG 14, 16, or 18
Second:	Insulation, Type X, E, thickness 0.0762 mm (0.030 in), color coded (Table 8-31)
Third:	Required number of conductors cabled with fillers where necessary
Fourth:	Binder tape, as required
Fifth:	Type T, CP, or N jacket
Sixth:	Basket-weave armor (optional)
Seventh:	Type T, CP, or N sheath (optional)

8.14.11 Control cable-multiconductor, low-smoke (LS) thermoset insulated, jacketed, with or without armor or armor and sheath (Table 8-11, Table 8-22)

Types: C14LSXL, C14LSXLA, C14LSXLB, C14LSXLB, C14SLEL, C14LSELA, C14LSELB, C14LSELBS, C16LSXL, C16LSXLA, C16LSXLB, C16LSXLB, C16LSEL, C16LSELA, C16LSELB, C16LSELBS, C18LSXL, C18LSXLA, C18LSXLB, C18LSXLB, C18LSEL, C18LSELA, C18LSELB, C18LSELBS

Construction details:

First:	Stranded conductors, AWG 14, 16, or 18
Second:	Insulation, Type LSX, LSE, thickness 0.030 in (0.0762 mm), color coded (Table 8-31)
Third:	Required number of conductors cabled with LS fillers where necessary
Fourth:	Binder tape, as required
Fifth:	Type L jacket
Sixth:	Basket-weave armor (optional)
Seventh:	Type L sheath (optional)

8.14.12 Control cable-multiconductor, thermoplastic insulated, jacketed, with or without armor and armor and sheath (Table 8-11, Table 8-22, Table 8-23)

Types: C14TT, C14TTA, C14TTB, C14TTBS, C14TN, C14TNA, C14TNB, C14TNBS, C14T/NT, C14T/NTA, C14T/NTB, C14T/NTBS, C14T/NN, C14T/NNA, C14T/NNB, C14T/NNBS, C14TCP, C14TCPA, C14TCPB, C14TCPBS, C14T/NCP, C14T/NCPA, C14T/NCPB, C14T/NCPBS

C16TT, C16TTA, C16TTB, C16TTBS, C16TN, C16TNA, C16TNB, C16TNBS, C16T/NT, C16T/NTA, C16T/NTB, C16T/NTBS, C16T/NN, C16T/NNA, C16T/NNB, C16T/NNBS, C16TCP, C16TCPA, C16TCPB, C16TCPBS, C16T/NCP, C16T/NCPA, C16T/NCPB, C16T/NCPBS

C18TT, C18TTA, C18TTB, C18TTBS, C18TN, C18TNA, C18TNB, C18TNBS, C18T/NT, C18T/NTA, C18T/NTB, C18T/NTBS, C18T/NN, C18T/NNA, C18T/NNB, C18T/NNBS, C18TCP, C18TCPA, C18TCPB, C18TCPBS, C18T/NCP, C18T/NCPA, C18T/NCPB, C18T/NCPBS

Construction details:

First:	Stranded conductors, AWG 14, 16, or 18
Second:	Insulation, Type T, thickness 0.030 in (0.0762 mm), or Type T/N, thickness 0.015/0.004 in (0.381 mm/0.1016 mm), color coded (Table 8-31)
Third:	Required number of conductors cabled with fillers where necessary
Fourth:	Binder tape, as required
Fifth:	Type T, CP, or N jacket
Sixth:	Basket-weave armor (optional)
Seventh:	Type T, CP, or N sheath (optional)

8.14.13 Signal cable, twisted-pair, thermoplastic insulated, jacketed, with or without armor or armor and sheath, 300 V (Table 8-11, Table 8-25, Table 8-29, Table 8-30,Table 8-32)

Types: TP16TT, TP16TTA, TP16TTB, TP16TTBS, TP16TCP, TP16TCPA, TP16TCPB, TP16TCPBS, TP16TN, TP16TNA, TP16TNB, TP16TNBS, TP16T/NT, TP16T/NTA, TP16T/NTB, TP16T/NTBS, TP16T/NCP, TP16T/NCPA, TP16T/NCPB, TP16T/NCPBS, TP16T/NN, TP16T/NNA, TP16T/NNB, TP16T/NNBS

TP18TT, TP18TTA, TP18TTB, TP18TTBS, TP18TCP, TP18TCPA, TP18TCPB, TP18TCPBS, TP18TN, TP18TNA, TP18TNB, TP18TNBS, TP18T/NT, TP18T/NTA, TP18T/NTB, TP18T/NTBS, TP18T/NCP, TP18T/NCPA, TP18T/NCPB, TP18T/NCPBS, TP18T/NN, TP18T/NNA, TP18T/NNB, TP18T/NNBS

TP20TT, TP20TTA, TP20TTB, TP20TTBS, TP20TCP, TP20TCPA, TP20TCPB, TP20TCPBS, TP20TN, TP20TNA, TP20TNB, TP20TNBS, TP20T/NT, TP20T/NTA, TP20T/NTB, TP20T/NTBS, TP20T/NCP, TP20T/NCPA, TP20T/NCPB, TP20T/NCPBS, TP20T/NN, TP20T/NNA, TP20T/NNB, TP20T/NNBS

Construction details:

First:	Stranded conductors, AWG 16, 18, or 20
Second	Type T insulation, thickness 0.025 in (0.635 mm) or Type T/N insulation, thickness 0.015/0.004 in (0.381 mm/0.1016 mm), color coded (Table 8-32)
Third:	Two conductors twisted together with a maximum lay length of 2.5 in (63.5 mm) to form a pair
Fourth:	The required number of pairs cabled with fillers where necessary
Fifth:	Binder tape, as required
Sixth:	Type T, CP, or N jacket
Seventh:	Basket-weave armor (optional)
Eighth:	Type T, CP, or N sheath (optional)

8.14.14 Signal cable, twisted pair, low-smoke (LS) thermoset insulated, jacketed, with or without armor or armor and sheath (Table 8-11)

Types: TP16LSEL, TP16LSELA, TP16LSELB, TP16LSELBS, TP16LSXL, TP16LSXLA, TP16LSXLB, TP16LSXLBS

TP18LSEL, TP18LSELA, TP18LSELB, TP18LSELBS, TP18LSXL, TP18LSXLA, TP18LSXLB, TP18LSXLBS

TP20LSEL, TP20LSELA, TP20LSELB, TP20LSELBS, TP20LSXL, TP20LSXLA, TP20LSXLB, TP20LSXLBS

Construction details:

First: Stranded conductors, AWG 16, 18, or 20
Second: Type LSE or LSX insulation, thickness 0.025 in (0.635 mm) color coded (Table 8-32)
Third: Two conductors twisted together with a maximum lay length of 2.5 in (63.5 mm) to form a pair
Fourth: The required number of pairs cabled with LS fillers where necessary
Fifth: Binder tape, as required
Sixth: Type L jacket
Seventh: Basket-weave armor (optional)
Eighth Type L sheath (optional)

8.14.15 Signal cable, twisted pair, shielded, thermoplastic insulated, jacketed, with or without armor and armor and sheath, 300 V (Table 8-11, Table 8-22, Table 8-23)

Types: TP16(IS)TT, TP16(IS)TTA, TP16(IS)TTB, TP16(IS)TTBS, TP16(IS)TCP, TP16(IS)TCPA, TP16(IS)TCPB, TP16(IS)TCPBS, TP16(IS)TN, TP16(IS)TNA, TP16(IS)TNB, TP16(IS)TNBS, TP16(IS)T/NT, TP16(IS)T/NTA, TP16(IS)T/NTB, TP16(IS)T/NTBS, TP16(IS)T/NCP, TP16(IS)T/NCPA, TP16(IS)T/NCPB, TP16(IS)T/NCPBS, TP16(IS)T/NN, TP16(IS)T/NNA, TP16(IS)T/NNB, TP16(IS)T/NNBS

TP18(IS)TT, TP18(IS)TTA, TP18(IS)TTB, TP18(IS)TTBS, TP18(IS)TCP, TP18(IS)TCPA, TP18(IS)TCPB, TP18(IS)TCPBS, TP18(IS)TN, TP18(IS)TNA, TP18(IS)TNB, TP18(IS)TNBS, TP18(IS)T/NT, TP18(IS)T/NTA, TP18(IS)T/NTB, TP18(IS)T/NTBS, TP18(IS)T/NCP, TP18(IS)T/NCPA, TP18(IS)T/NCPB, TP18(IS)T/NCPBS, TP18(IS)T/NN, TP18(IS)T/NNA, TP18(IS)T/NNB, TP18(IS)T/NNBS

TP20(IS)TT, TP20(IS)TTA, TP20(IS)TTB, TP20(IS)TTBS, TP(IS)20TCP, TP20(IS)TCPA, TP20(IS)TCPB, TP20(IS)TCPBS, TP20(IS)TN, TP20(IS)TNA, TP20(IS)TNB, TP20(IS)TNBS, TP20(IS)T/NT, TP20(IS)T/NTA, TP20(IS)T/NTB, TP20(IS)T/NTBS, TP20(IS)T/NCP, TP20(IS)T/NCPA, TP20(IS)T/NCPB, TP20(IS)T/NCPBS, TP20(IS)T/NN, TP20(IS)T/NNA, TP20(IS)T/NNB, TP20(IS)T/NNBS

Construction details:

First: Stranded conductors, AWG 16, 18, or 20
Second: Type T insulation, thickness 0.025 in (0.635 mm) or Type T/N insulation, thickness 0.015/0.004 in (0.381 mm/0.1016 mm)
Third: Two conductors twisted together with a maximum lay length of 2.5 in (63.5 mm) to form a pair with stranded tinned drain wire in one interstice
16 and 18 AWG pairs—AWG 20 drain wire
20 AWG pairs—AWG 22 drain wire

Color code (Table 8-32)

Fourth: Shielded by a polyester supported aluminum foil tape spirally wrapped foil face inward. Minimum thickness polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)
Fifth: Required number of shielded pairs cabled with fillers where necessary
Sixth: Binder tape, as required
Seventh: Optional overall tape shield with drain wire may be applied. Add (OS) to type designation, i.e., TP16(IS-OS)TTA
Eighth: Type T, CP, or N jacket
Ninth: Basket-weave armor (optional)
Tenth: Type T, CP, or N sheath (optional)

8.14.16 Signal cable, twisted pair, shielded, low-smoke (LS) thermoset insulated, jacketed, with or without armor or armor and sheath (Table 8-11)

Types: TP16(IS)LSEL, TP16(IS)LSELA, TP16(IS)LSELB, TP16(IS)LSELBS, TP16(IS)LSXL, TP16(IS)LSXLA, TP16(IS)LSXLB, TP16(IS)LSXLBS

TP18(IS)LSEL, TP18(IS)LSELA, TP18(IS)LSELB, TP18(IS)LSELBS, TP18(IS)LSXL, TP18(IS)LSXLA, TP18(IS)LSXLB, TP18(IS)LSXLBS

TP20(IS)LSEL, TP20(IS)LSELA, TP20(IS)LSELB, TP20(IS)LSELBS, TP20(IS)LSXL, TP20(IS)LSXLA, TP20(IS)LSXLB, TP20(IS)LSXLBS

Construction details:

First: Stranded conductors, AWG 16, 18, or 20
Second: Type LSE or LSX insulation, thickness 0.025 in (0.635 mm) Color Coded (Table 8-32)
Third: Two conductors twisted together with a maximum lay length of 2.5 in (63.5 mm) to form a pair with stranded tinned drain wire in one interstice
16 and 18 AWG pairs—AWG 20 drain wire
20 AWG Pairs—AWG 22 drain wire
Color Code (Table 8-32)
Fourth: Shielded by a polyester supported aluminum foil tape spirally wrapped foil face inward. Minimum thickness polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)
Fifth: The required number of shielded pairs cabled with fillers where necessary
Sixth: Binder tape, as required
Seventh: Optional overall tape shield with drain wire may be applied. Add (OS) to type designation, i.e., TP16(IS-OS)LSELA
Eighth: Type L jacket
Ninth: Basket-weave armor (optional)
Tenth: Type L sheath (optional)

8.14.17 Single-conductor, polyolefin insulated, with or without armor or with armor and sheath, 2000 V (Table 8-8, Table 8-11, Table 8-18)

Types: SP 2 kV(HD), SPA 2 kV(HD), SPB 2 kV(HD), SPBS 2 kV(HD)

Construction details:

First: Stranded tinned copper conductor
Second: Separator tape, as required
Third: Insulation, Type P
Fourth: Basket-weave armor (optional)
Fifth: Type CP or N overall sheath (optional)

8.14.18 Two-, three-, four-, or five-conductor, polyolefin insulated, jacketed, with or without armor or armor and sheath (Table 8-8, Table 8-11, Table 8-19)

Types: DPN, DPNA, DPNB, DPNBS, DPCP, DPCPA, DPCPB, DPCPBS, TPN, TPNA, TPNB, TPNBS, TPCP, TPCPA, TPCPB, TPCPBS FPN, FPNA, FPNB, FPNBS, FPCP, FPCPA, FPCPB, FPCPBS QPN, QPNA, QPNB, QPNBS, QPCP, QPCPA,QPCPB, QPCPBS

Construction details:

First:	Stranded tinned copper conductors
Second:	Insulation, Type P
Third:	Required number of conductors cabled with fillers where necessary
Fourth:	Binder tape, as required
Fifth:	Type CP or N jacket
Sixth:	Basket-weave armor (optional)
Seventh:	Type CP or N overall sheath (optional)

8.14.19 Control cable-multiconductor, polyolefin insulated, jacketed, with or without armor or armor and sheath (Table 8-8, Table 8-11, Table 8-24)

Types: CPN, CPNA, CPNB, CPNBS, CPCP, CPCPA, CPCPB, CPCPBS

Construction details:

First:	Stranded tinned copper conductors.
Second:	Insulation, Type P
Third:	Required number of conductors cabled with fillers where necessary
Fourth:	Binder tape, as required
Fifth:	Type CP or N jacket
Sixth:	Basket-weave armor (optional)
Seventh:	Type CP or N overall sheath (optional)

8.14.20 Signal cable, twisted pair, overall shielded, polyolefin insulated, jacketed, with or without armor or armor and sheath (Table 8-8, Table 8-11, Table 8-26)

Types:	TP(OS)PN,	TP(OS)PNA,	TP(OS)PNB,	TP(OS)PNBS
	TP(OBS)PN,	TP(OBS)PNA,	TP(OBS)PNB,	TP(OBS)PNBS
	TP(OS)PCP,	TP(OS)PCPA,	TP(OS)PCPB,	TP(OS)PCPBS
	TP(OBS)CPN,	TP(OBS)PCPA,	TP(OBS)PCPB,	TP(OBS)PCPBS

Construction details:

First:	Stranded tinned copper conductors
Second:	Type P insulation, color coded per Table 8-32
Third:	Two conductors twisted together. Multiple pairs shall be in a systematically varied lay to minimize cross-talk.
Fourth:	The required number of pairs cabled with fillers where necessary
Fifth:	Shielded by a polyester supported aluminum foil tape [minimum thickness; polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)] spirally wrapped with foil face inward in contact with a stranded tinned copper drain wire (no smaller than two conductor sizes below the primary conductor size) in interstice, or an overall tinned copper braid shield.
Sixth:	Binder tape.
Seventh:	Type CP or N jacket.

Eighth: Basket-weave armor (optional)
Ninth: Type CP or N overall sheath (optional)

8.14.21 Signal cable, twisted-pair, individually shielded, or individually shielded and overall shielded with a tape shield or overall tinned copper braid shield, polyolefin insulated, jacketed, with or without armor or armor and sheath (Table 8-8, Table 8-11, Table 8-27)

Types:				
	TP(I/S)PN,	TP(I/S)PNA,	TP(I/S)PNB,	TP(I/S)PNBS
	TP(I/S-OS)PN,	TP(I/S-OS)PNA,	TP(I/S-OS)PNB,	TP(I/S-OS)PNBS
	TP(I/S)(OBS)PN,	TP(I/S)(OBS)PNA,	TP(I/S)(OBS)PNB,	TP(I/S)(OBS)PNBS
	TP(I/S)PCP,	TP(I/S)PCPA,	TP(I/S)PCPB,	TP(I/S)PCPBS
	TP(I/S-OS)PCP,	TP(I/S-OS)PCPA,	TP(I/S-OS)PCPB,	TP(I/S-OS)PCPBS
	TP(I/S)(OBS)PCP,	TP(I/S)(OBS)PCPA,	TP(I/S)(OBS)PCPB,	TP(I/S)(OBS)PCPBS

Construction Details:

First: Stranded tinned copper conductors.
Second: Type P insulation, color coded per Table 8-32
Third: Two conductors twisted together. Shielded by a polyester supported aluminum foil tape [minimum thickness; polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)] spirally wrapped with foil face inward in contact with a stranded tinned copper drain wire (no smaller than two conductor sizes the primary conductor size) in one interstice.
Fourth: The required number of pairs cabled with fillers where necessary
Fifth: Shielded by a polyester supported aluminum foil tape [minimum thickness; polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)] spirally wrapped with foil face inward in contact with a stranded tinned copper drain wire (no smaller than two conductor sizes below the primary conductor size) in one interstice, or an overall tinned copper braid shield.
Sixth: Binder tape
Seventh: Type CP or N jacket
Eighth: Basket-weave armor (optional)
Ninth: Type CP or N overall sheath (optional)

8.14.22 Signal cable, twisted-triad, overall shielded, polyolefin insulated, jacketed, with or without armor or armor and sheath (Table 8-8, Table 8-11, Table 8-28)

Types:				
	TT(OS)PN,	TT(OS)PNA,	TT(OS)PNB,	TT(OS)PNBS
	TT(OBS)PN,	TT(OBS)PNA,	TT(OBS)PNB,	TT(OBS)PNBS
	TT(OS)PCP,	TT(OS)PCPA,	TT(OS)PCPB,	TT(OS)PCPBS
	TT(OBS)CPN,	TT(OBS)PCPA,	TT(OBS)PCPB,	TT(OBS)PCPBS

Construction details:

First: Stranded tinned copper conductors
Second: Type P insulation. Color coding should be black, white, red, sequentially numbered groups starting with Number 1.
Third: Three conductors twisted together. Multiple triad shall be in a systematically varied lay to minimize cross-talk.
Fourth: The required number of triads cabled with fillers where necessary
Fifth: Shielded by a polyester supported aluminum foil tape [minimum thickness; polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)] spirally wrapped with foil face inward in contact with a stranded tinned copper drain wire (no smaller than two conductor sizes below the primary conductor size) in interstice, or an overall tinned copper braid shield.
Sixth: Binder tape

Seventh:	Type CP or N jacket
Eighth:	Basket-weave armor (optional)
Ninth:	Type CP or N overall sheath (optional)

8.14.23 Signal cable, twisted-triad, individually shielded, or individually shielded and overall shielded with a tape shield or overall braid shield, polyolefin insulated, jacketed, with or without armor or armor and sheath (Table 8-8, Table 8-11, Table 8-28)

Types:	TT(I/S)PN,	TT(I/S)PNA,	TT(I/S)PNB,	TT(I/S)PNBS
	TT(I/S-OS)PN,	TT(I/S-OS)PNA,	TT(I/S-OS)PNB,	TT(I/S-OS)PNBS
	TT(I/S)(OBS)PN,	TT(I/S)(OBS)PNA,	TT(I/S)(OBS)PNB,	TT(I/S)(OBS)PNBS
	TT(I/S)PCP,	TT(I/S)PCPA,	TT(I/S)PCPB,	TT(I/S)PCPBS
	TT(I/S-OS)PCP,	TT(I/S-OS)PCPA,	TT(I/S-OS)PCPB,	TT(I/S-OS)PCPBS
	TT(I/S)(OBS)PCP,	TT(I/S)(OBS)PCPA,	TT(I/S)(OBS)PCPB,	TT(I/S)(OBS)PCPBS

Construction details:

First:	Stranded tinned copper conductors
Second:	Type P insulation. Color coding should be black, white, red, sequentially numbered groups starting with Number 1.
Third:	Three conductors twisted together. Shielded by a polyester supported aluminum foil tape [minimum thickness; polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)] spirally wrapped with foil face inward in contact with a stranded tinned copper drain wire (no smaller than two conductor sizes below the primary conductor size) in one interstice.
Fourth:	The required number of triads cabled with fillers where necessary.
Fifth:	Shielded by a polyester supported aluminum foil tape [minimum thickness; polyester 0.0005 in (0.0127 mm), aluminum foil 0.00035 in (0.00889 mm)] spirally wrapped with foil face inward in contact with a stranded tinned copper drain wire (no smaller than two conductor sizes below the primary conductor size) in one interstice, or an overall tinned copper braid shield.
Sixth:	Binder tape
Seventh:	Type CP or N jacket
Eighth:	Basket-weave armor (optional)
Ninth:	Type CP or N overall sheath (optional)

8.15 Cable designations

8.15.1 Cable types T, T/N, E, X, LSE, LSX, and S

The following cable designations should be used in connection with the cables described in 8.14.1 to 8.14.16, inclusive. The designations are made up of letters and number signifying, to the extent shown below, the service, number of conductors, types of insulation, jacket, armor, and conductor size. Specific types include the following additions to the designations shown in Table 8-33. The wire size of distribution cables is designated by adding to the cable symbol the circular mil size in thousands, thus:

— DTTB-4 = AWG 14 (4110 CM), two-conductor, polyvinylchloride-insulated, thermoplastic polyvinyl chloride jacketed, and bronze armored.
— SXNA-250 = 250 000 CM, single conductor, cross-linked polyethylene insulated, thermosetting neoprene jacketed, and aluminum armor.

For 2000 V rated cables a suffix, 2 kV, is added to the symbol.

For 5000 V rated cables a suffix, 5 kV, is added to the symbol.

The wire size of control and signal cable types is designated by inserting the AWG size immediately following the service symbol. The number of conductors of control, and the number of conductor pairs of signal cable, is added to the cable designation, thus:

— C14TCPB-20 = 20 conductor control cable, AWG 14, thermoplastic-insulated, thermosetting chlorosulfonated polyethylene jacketed, and bronze armor.
— TP18TNA-10 = 10 twisted-pair signal cable, AWG 18, thermoplastic-insulated, thermosetting neoprene jacketed, and aluminum armor.

8.15.2 Type P cable

Type P is a polyolefin insulated cable rated 600 V or 2000 V, ac or dc. A bronze armor with or without an overall sheath of chlorosulfonated polyethylene or neoprene may be applied at the option of the user. A heavy-duty insulation thickness is also available (see Table 8-8).

The following cable designations should be used in connection with the cables described in 8.14.7 to 8.14.23, inclusive. The designations are made up of letters and numbers signifying to the extent shown below the cable type, shielding, AWG/MCM size, type of insulation, jacket, armor or armor and sheath, and number of conductors or groups.

Specific types include the following additions to the designations shown in Table 8-33.

The wire size of distribution cables is designated by adding to the cable symbol the AWG or MCM size, thus:

— TPNBS-313 = 3 conductor, 313 MCM, polyolefin insulation with neoprene jacket, bronze armor and overall sheath.

The wire size of control and signal cable types is designated by inserting the AWG size immediately following the cable type, and group shielding symbol, which may be applicable to paired or triad signal cable types. The number of conductors in control cables, and the number of conductor pairs or triads in signal cable, is added to the cable designation, thus:

— C14PCP-3 = 3 conductor, 14 AWG, polyolefin insulated, and chlorosulfonated polyethylene jacketed.
— TP(OS)18PNBS-2 = 2 twisted pairs, 18 AWG with polyolefin insulation, overall tape shield and drain wire, neoprene jacketed, with bronze armor and overall outer sheath.

8.16 U.S. Navy cable types

The cable types manufactured and tested in accordance with U.S. Navy military specifications MIL-C-24643A and MIL-C-24640A may also be used.

The ampacities for these cables are to be in accordance with MIL-HDBK-299. Ampacities at 45 °C (113 °F) are to be determined by dividing the 40 °C (104 °F) ampacities in the MIL-HDBK by the 40 °C (104 °F) factors contained in Note (5) to Table 9-1 for the appropriate insulating material. For double banked installations, the values are to be multiplied by 0.8, in accordance with Note (6) to Table 9-1.

8.17 Other shipboard cable types

Regulatory bodies generally have programs with independent product testing and certification organizations for the evaluation and listing (or classification) of shipboard cable that differ from the construction and/or dimensional requirements for cable identified as IEEE Std 45-1998 shipboard cables. Although these listed cables, such as cables conforming to ANSI/UL 1309-1995, do not bear the marking of 8.8, they are typically evaluated for equivalence to the requirements in this standard. These cables may offer constructions that provide alternative performance characteristics (i.e., circuit integrity during fire, cold weather capability, improved crush resistance, and increased temperature rating). Such cables may be considered for use based on their individual capabilities. Additionally, other requirements (e.g., installation practices) of this standard may not apply to these alternative constructions.

Continuously corrugated metal clad cable (CWCMC) as defined by ANSI/UL 1309-1995 may be used in areas that are not subjected to repeated flexing or bending, high vibration, or twisting and are not subjected to excessive movement between units.

Type MI cable as defined by ANSI/NFPA 70-1996 (NEC), Article 330.

Table 8-1—Construction and resistances of standard class B concentric conductors

Conductor size		Class B stranding			Nominal dc resistance Ω/1000 ft at 25°C	
Area in circular mil	AWG or MCM size	Number of wires	Diameter of wires (mil)	Conductor diameter (in)	Bare	Alloy coated or tinned
643	22	7	10.0	0.030	16.1	16.7
1020	20	7	12.1	0.036	9.97	10.6
1620	18	7	15.2	0.046	6.64	7.05
2580	16	7	19.2	0.058	4.18	4.44
4110	14	7	24.2	0.073	2.63	2.73
6530	12	7	30.5	0.092	1.65	1.72
10 380	10	7	38.5	0.116	1.04	1.08
16 510	8	7	48.6	0.146	0.653	0.679
20 820	7	7	54.5	0.164	0.518	0.539
26 240	6	7	61.2	0.184	0.411	0.427
33 090	5	7	68.8	0.206	0.326	0.339
41 740	4	7	77.2	0.232	0.258	0.269
52 620	3	7	86.7	0.260	0.205	0.213
66 360	2	7	97.4	0.292	0.163	0.169
83 690	1	19	66.4	0.332	0.129	0.134
105 600	1/0	19	74.5	0.373	0.102	0.106
133 100	2/0	19	83.7	0.418	0.0811	0.0843
167 800	3/0	19	94.0	0.470	0.0643	0.0669
211 600	4/0	19	105.5	0.528	0.0510	0.0525
250 000	250	37	82.2	0.573	0.0431	0.0449
300 000	300	37	90.0	0.630	0.0360	0.0374
350 000	350	37	97.3	0.681	0.0308	0.0320
400 000	400	37	104.0	0.728	0.0270	0.0278
500 000	500	37	116.2	0.813	0.0216	0.0222
600 000	600	61	99.2	0.893	0.0180	0.0187
750 000	750	61	110.9	0.998	0.0144	0.0148
1 000 000	1000	61	128.0	1.152	0.0108	0.0111
1 250 000	1250	91	117.2	1.289	0.00863	0.00883
1 500 000	1500	91	128.4	1.429	0.00719	0.00740
2 000 000	2000	127	125.5	1.632	0.00539	0.00555

Table 8-2—Construction and resistance of flexible stranded conductors

Conductor size area in circular mils	Approx. size AWG or MCM	Stranding no. & size each wire in strand	Maximum conductor diameter (in)	Maximum Ω/1000 ft dc resistance @25 °C
754	22	19/34	0.031	16.01
1216	20	19/32	0.039	9.91
1900	18	19/30	0.052	6.34
2413	16	19/29	0.062	4.92
3831	14	19/27	0.074	3.11
6088	12	19/25	0.094	1.96
10 910	10	27/24	0.128	1.125
14 950	8	37/24	0.147	0.7899
24 640	6	61/24	0.207	0.483
36 760	5	91/24	0.244	0.330
42 420	4	105/24	0.264	0.287
50 550	3	125/24	0.288	0.236
60 600	2	150/24	0.325	0.203
90 900	1	225/24	0.390	0.135
111 100	1/0	275/24	0.440	0.110
131 300	2/0	325/24	0.477	0.094
181 800	3/0	450/24	0.565	0.068
222 200	4/0	550/24	0.620	0.055
262 600	262 MCM	650/24	0.660	0.047
313 100	313 MCM	775/24	0.725	0.0393
373 700	373 MCM	925/24	0.795	0.0326
444 400	444 MCM	1100/24	0.870	0.0273
535 300	535 MCM	1325/24	0.970	0.0227
646 400	646 MCM	1600/24	1.060	0.0188
777 700	777 MCM	1925/24	1.130	0.0156
1 111 000	1111 MCM	2750/24	1.340	0.0110

Table 8-3—Insulation, electrical, and physical requirements types E, X, S, T, and T/N

Insulation material	Ethylene propylene rubber		Cross-linked polyethylene		Silicone rubber	Polyvinyl chloride	Polyvinyl chloride/nylon
Insulation-type designation	E		X		S	T	T/N
Voltage rating (V)	0–2000	2001–5000	0–2000	2001–-5000	0–600	0–600	0–600
Insulation resistance constant (K) at 15.6 °C, min	10 000	20 000	10 000	20 000	4000	2000	2000
Accelerated water absorption:							
Electrical method:							
dielectric constant after 1 day, max	6.0	4.0	6.0	3.5	4.0	10.0	10.0
Increase in capacitance, max 1 to 14 days	5.0	3.5	4.0	3.0	10.0	4.0	4.0
7 to 14 days	3.0	1.5	2.0	1.5	3.0	2.0	2.0
Stability factor after 14 days, max	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Gravimetric method:							
Water absorption, max, mg/in^2	15.0	10.0	10.0	10.0	15.0	10.0	10.0
Physical requirements:							
Unaged							
Tensile strength, min, psi	1200	700	1800	1800	800	2000	2000
Elongation at rupture, min, %	150	200	150	250	250	150	150
Aging requirements							
After air oven test							
at °C	121 ± 1	121 ± 1	121 ± 1	121 ± 1	200 ± 2	121 ± 1	121 ± 1
hours	168	168	168	168	168	168	168
Tensile strength % of unaged, min	75	75	85	75	65	80	80
Elongation at rupture, min, % of unaged value	75	75	60	75	50	75[b]	75[b]
Heat distortion, 121 °C, max, % of unaged value							
4/0 AWG and smaller	—	—	30	25	—	25	25
Larger than 4/0 AWG	—	—	10	15	—	25	25
Cold bend, –30°C(–22°F)	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
Mandrel test for nylon jacket	—	—	—	—	—	—	no cracks
VW-1 flame test[a]	optional	N/A	optional	N/A	optional	optional	optional
NEMA test procedure reference	NEMA WC 8		NEMA WC 7		NEMA WC 3	NEMA WC 5	NEMA WC 5

[a] For test procedures refer to ANSI/UL 1581-1991.
[b] For AWG 6 and larger, buffed samples, value is 50%.

Table 8-4—Insulation, electrical, and physical requirements types LSX and LSE

Insulation material	Low-smoke ethylene propylene rubber	Low-smoke cross-linked polyethylene
Insulation-type designation	LSE	LSX
Voltage rating	0–600 V	
Insulation resistance constant (K) at 15.6 °C, min.	2000	10 000
Physical requirements:		
Unaged		
Tensile strength, min. PSI	1200	1500
Elongation at rupture, min., %	150	150
Aging requirements		
After air oven test		
@ °C	121	121
Hours	168	168
Tensile strength Percent of unaged, min.	75	80
Elongation at rupture min., % of unaged value	75	80
Heat distortion, 121 °C max., % of unaged value		
4/0 AWG & smaller	30	30
Larger than 4/0 AWG	10	10
Cold bend, –30 °C (–22 °F)	No cracks	No cracks
Acid gas equivalent[a], Percent, max.	5	2
Smoke Index, max.[b]	45	25
Toxicity Index, max.	1.5	1.5
Hot creep test Per ICEA T-28-562		
Temperature of air oven	150 °C ± 2 °C	
Hot creep elongation, max.	50%	50%
Hot creep set, max.	5%	5%
VW-1 flame test[c]	pass	pass
NEMA test procedure reference	NEMA WC 8	NEMA WC 7

[a] For test procedures refer to MIL-C-24643A.
[b] For test procedures refer to NES 711 and MIL-C-24643, which should be used in conjunction with ASTM E662-97.
[c] For test procedures, refer to ANSI/UL 1581-1991.

Table 8-5—Insulation, electrical, and physical requirements for polyolefin insulation (type P), voltage rating 0–2000 V

Insulation resistance	
constant (K) at 15.6 °C, min.	10 000
Accelerated water absorption:	
Electrical method:	
Dielectric constant, max.	6.0
Increase in capacitance, max. 1 to 14 d	3.0
7 to 14 d	1.5
Stability factor after 14 d, max.	0.5
Gravimetric method:	
Water absorption, max., mg/in^2	8.0
Physical requirements:	
Unaged	
Tensile strength, min, lb/in^2	1800
Elongation at rupture, min., %	250
Aging Requirements	
After air oven test at °C	158 ± 1
hours	168
Tensile strength % of unaged, min	90
Elongation at rupture, min., % of unaged value	50
Heat distortion, 150 °C, max., % of unaged value	
4/0 AWG and smaller	20
Larger than 4/0 AWG	10
Cold bend –55 °C (–67 °F)	no cracks; and shall withstand voltage test of NEMA WC 7-1988
Cold impact –40 °C[a]	No cracks or dielectric failure
Ozone	
After 24 h exposure in concentration of .03% by vol. @90 °C ± 2 °C[b]	No cracks
Tension set	
NEMA WC 7-1988, 6.4.11.4 except gauge marks 4 in apart	3 specimens not to exceed tension set of 30%.
Corrosivity	
Copper Mirror 16 h @ 175 °C ± 2 °C[c]	Not more than 5% removal of copper film
Hot oil resistance	
The insulated conductor diameter increase (swell) shall not exceed values shown below after the center 1 ft section of a two foot length of insulated conductor with ends stripped of 2 in of insulation and exposed for 100 h to the following fluids and temperatures:	No cracks; and shall withstand voltage test of NEMA WC 7-1988

Fluid	Temperature	Allowable % Swell
#2 Oil *	150°C	60
Diesel(Fuel) Oil	60°C	60

The test shall be performed on 12 AWG cable and the swell shall be measured no longer than 48 h after immersion.

*NOTE—ASTM #2 oil may be replaced by IRM 902.

Table 8-5—Insulation, electrical, and physical requirements for polyolefin insulation (type P), voltage rating 0–2000 V *(Continued)*

VW-1 flame test[d]	Pass
Hot creep test	
Per ICEA T-28-562-1995[e]	
With the following modifications:	
Temperature of air oven 175°C ± 1°C	
Hot creep elongation, max.	25%
Hot creep set, max.	2%
NEMA test procedure reference	NEMA WC 7-1988

[a]For test procedures, refer to CSA C22.2 No. 38-1995.
[b]For test procedures, refer to NEMA WC 3-1992.
[c]For test procedures, refer to ASTM-D2671-1995.
[d]For test procedures, refer to ANSI/UL 1581-1991.
[e]For test procedures, refer to ICEA T-28-562-1995.

Table 8-6—Skin-effect ratios

Area in circular mil	Number of wires	Diameter of wires (mil)	Conductor diameter (in)	Skin-effect ratio, 65 °C at 60 Hz
2 000 000	127	125.5	1.632	1.236
1 500 000	91	128.4	1.412	1.143
1 250 000	91	117.2	1.289	1.102
1 000 000	61	128.0	1.152	1.067
800 000	61	114.5	1.031	1.044
750 000	61	110.9	0.998	1.039
600 000	61	99.2	0.893	1.025
500 000	37	116.2	0.813	1.018
400 000	37	104.0	0.728	1.011
350 000	37	97.3	0.681	1.009
300 000	37	90.0	0.630	1.006
250 000	37	82.2	0.573	1.005
up to 4/0				1.000

NOTE 1—The above includes-skin effect only.
NOTE 2—For close spacing such as multiconductor cables, there will be additional apparent resistance due to proximity loss and sheath eddy-current effects.
NOTE 3—For intermediate values, interpolation is recommended.

Table 8-7—Distribution cables, thickness of extruded insulations

		Insulation Thickness (mil)				
Rated voltage phase to phase (V)	Conductor size (AWG or kcmil)	Type E, X thermosetting	Type LSE, LSX thermosetting	Type S silicone rubber	Type T Thermoplastic	Type T/N thermoplastic/ nylon
0–600	14–11	30	30	45	45	15 (4)
	10–9	30	30	45	45	20 (4)
	8–5	45	45	60	60	30 (5)
	4–2	45	45	60	60	40 (6)
	1–4/0	55	55	80	80	50 (7)
	225–500	65	65	95	95	60 (8)
	525–1000	80	80	110	110	70 (9)
601–2000	14–9	45				
	8–2	55				
	1–4/0	65				
	225–500	75				
	525–1000	90				
2001–5000	8–4	90				
	2–3/0	90				
	4/0–1000	90				

Table 8-8—Distribution, control, and signal cables; thickness of extruded type P insulation

	Rated voltage		
Conductor size (AWG or kcmil)	600 (mil)	2000 (mil)	2000 (HD)[a] (mil)
22–10	30	45	
8–2	45	55	
1–3/0	55	65	
4/0	55		105
262–444	65		105
535–777	80		120
1111	110		120

[a]Heavy-duty (HD) insulation thicknesses should be considered for applications where installations and service conditions are such that the additional mechanical protection is considered necessary. Heavy-duty (HD) constructions are permitted in *single* conductor sizes 4/0 AWG and larger for applications as cable *external* to enclosures for interconnection purposes.

Table 8-9—Jacket properties; types T, CP, and N

Jacket material	Thermoplastic polyvinyl chloride	Thermosetting chlorosulfonated polyethylene	Thermosetting neoprene
Jacket-Type			
Designation	T[a]	CP[b]	N[c]
Physical requirements			
Unaged:			
Tensile strength, min, lb/in^2	1500	1800	1800
Elongation at rupture, min., %	100	300	250
Set, max., %	–	30	20
Aging requirements: After air oven at			
°C	100 ± 1	100 ± 1	100 ± 1
hours	120	168	168
Tensile strength % of unaged, min.	85	85	80
Elongation at rupture, % of unaged, min.	60	65	60
After oil immersion			
at °C	70 ± 1	121 ± 1	121 ± 1
hours	4	18	18
Tensile strength % of unaged, min.	80	60	80
Elongation at rupture, % of unaged, min.	60	60	60
Heat distortion			
121 °C ± 1, max %	50	—	—
Heat shock, 121°C±/–1	No cracks	—	—
Cold Bend, no cracks, °C[d]	–25	–40	–40
Cold Impact, °C[d]	—	–35	–35
Mechanical water absorption, mg/in^2	25	100	130
Weatherometer test[e]	Pass	Pass	Pass
Tear—lb/in thickness, min[f]	35	35	35

[a]For test procedures, refer to NEMA WC 5-1992.

[b]For test procedures, refer to NEMA WC 3-1992.

[c]For test procedures, refer to NEMA WC 8-1988.

[d]For test procedures, refer to ANSI/UL 62 or ANSI/ASTM G23-96, type D.

[e]For test procedures, refer to CSA C22.2 No. 38-1995, clause 6.4.7. Cables intended for arctic or severe cold application should be capable of passing both cold bend at –40 °C and cold impact at –40 °C.

[f]For test procedures, refer to ANSI/ASTM D470-93.

Table 8-10—Low-smoke jacket properties, type L (XLPO) and TPO (TPPO)

Jacket material	Thermosetting cross-linked polyolefin (XLPO)	Thermoplastic polyolefin (TPPO)
Jacket type designations	L	TPO
Physical requirements		
Unaged:		
Tensile strength, min., psi	1300	1400
Elongation at rupture, min, %	160	100
Aging requirements:		
After air oven at		
°C	121 ± 1	100± 1
hours	168	168
Tensile strength % of unaged, min.	60	75
Elongation at rupture, % of unaged, min.	60	60
After Oil Immersion (ASTM No. 2 or IRM 902)		
°C	121 ± 1	—
hours	18	—
Tensile strength, lb/in^2, % retention	50	—
Elongation, % retention	50	—
Heat distortion	121°C ± 1	90°C ± 1
max., %	30	25
Cold bend, no cracks, °C[a]	–40	–25
Weatherometer test[b]	Pass	Pass
Acid gas equivalent[c], % max	2	2
Halogen content[c], % max	0.2	0.2
Smoke index, max[c]	25	25
Toxicity index, max[c]	5	5
Hot creep test		
Per ICEA T-28-562-1995 with the following modifications:		
Temperature of air oven 200 °C ± 2 °C		
Hot creep elongation, max.	25%	—
Hot Creep Set, max.	5%	—
Tear: lb/in thickness, min.[d]	35	—
NEMA test procedure reference	NEMA WC 3, NEMA WC 3, and NEMA 57	

[a] For test procedure refer to CSA C22.2 No. 38-1995, clause 6.4.6. The insulation system used for this test shall be representative of the final product.
[b] For test procedure refer to ANSI/UL 1581-1991.
[c] For test procedure refer to MIL-C-24643.
[d] For test procedure refer to ANSI/ASTM D470-1993.

Table 8-11—Thickness of jackets

Calculated diameter of cable under jacket (in)	Jacket thickness (mil)
0–0.425	45[a]
0.426–0.700	60
0.701–1.500	80
1.501–2.500	110
2.501 and larger	140

[a] 60 mil optional for heavy duty use of type P.

Table 8-12—High-voltage ac test potentials; types E, S, X, T, T/N, LSE, LSX and P cables

	Test potentials (kV)			
Conductor size AWG or circular mil	300 V	600 V	601–2000 V	2001–5000 V
	Types T, T/N	Types E, X, S, T, LSE, LSX, T/N, and P	Types E, X and P	Types E, X
20	0.5			
18	1.0	1.5		
16	1.0	1.5		
14 to 9		3.5	5.5	13.0
8 to 2		5.5	7.0	13.0
1 to 4/0		7.0	8.0	13.0
250 000 to 525 000		8.0	9.5	13.0
525 000 to 1 000 000		10.0	11.5	13.0
1 000 050 and over		10.0	11.5	13.0

Table 8-13—Minimum insulation resistance (based on MΩ/1000 ft at 15.5 °C)

Conductor size AWG or Circular mil	Types T,T/N	Types E,X,P, LSX[a]	Types E and X	Type S	Type LSE
	0–600 V	0–2000 V	2001–5000 V	0–600 V	0–600 V
20–16	550	3000	—	1100	625
14–9	350	1600	—	700	325
8–2	300	1200	3700	600	225
1–4/0	250	800	2300	500	150
250–525 000	200	650	1650	400	120
525 and larger	150	550	1200	300	100

NOTE 1—The values are based on the insulation resistance K constant in Table 8-3, Table 8-4, and Table 8-5 calculated for the largest conductor in each size range.

NOTE 2—To adjust above insulation resistance values for temperatures other than 15.6 °C, see Table 8-14.

[a] LSX is limited to 600 V maximum.

Table 8-14—Temperature correction factors for insulation resistance

Temperature		Multiplying factor		
°C	°F	Type S	Types E, X, P LSX, LSE	Type T, T/N
5	41	0.57	0.75	0.098
10	50	0.73	0.83	0.29
15.5	60	1.00	1.00	1.00
20	68	1.28	1.20	2.50
25	77	1.68	1.57	6.60
30	86	2.24	2.10	16.50

NOTE—Values in Table 8-14 must be interpolated to the nearest 1° increment before being applied as an insulation resistance correction factor.

Table 8-15—Dimensions and weights; single-, two-, three-, and four-conductor 600 V; type E, X, S, LSE, LSX, and T distribution cables

		Unarmored		Armored		Armored and sheathed	
		Approximate		Approximate		Approximate	
Number of conductors	AWG/ MCM size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
1	14	0.225	35	0.280	80	0.370	105
1	12	0.245	45	0.300	90	0.390	120
1	10	0.270	60	0.325	105	0.415	135
1	8	0.330	90	0.385	145	0.475	180
1	7	0.345	110	0.400	165	0.490	205
1	6	0.365	130	0.420	190	0.510	230
1	5	0.390	155	0.445	224	0.565	280
1	4	0.415	185	0.470	263	0.590	325
1	3	0.440	225	0.495	305	0.615	370
1	2	0.475	275	0.530	356	0.650	425
1	1	0.565	355	0.620	461	0.740	540
1	1/0	0.605	435	0.660	541	0.780	625
1	2/0	0.650	530	0.705	645	0.865	760
1	3/0	0.700	650	0.755	770	0.915	985
1	4/0	0.760	800	0.815	930	0.975	1065
1	250 MCM	0.865	970	0.920	1115	1.080	1265
1	300 MCM	0.920	1140	0.975	1295	1.135	1450
1	350 MCM	0.975	1310	1.030	1470	1.190	1635
1	400 MCM	1.020	1480	1.075	1645	1.235	1820
1	500 MCM	1.105	1810	1.160	1987	1.320	2171
1	600 MCM	1.225	2190	1.280	2390	1.440	2590
1	750 MCM	1.330	2695	1.385	2905	1.545	3125
1	1000 MCM	1.485	3520	1.540	3755	1.760	4090
2	14	0.365	70	0.420	130	0.510	170
2	12	0.400	90	0.455	160	0.575	217
2	10	0.450	120	0.505	200	0.625	265
2	8	0.600	205	0.655	315	0.775	395
2	7	0.535	240	0.690	355	0.810	435
2	6	0.675	280	0.730	400	0.890	520
2	5	0.720	330	0.775	455	0.935	585
2	4	0.770	400	0.825	530	0.985	665
2	3	0.865	510	0.920	655	1.080	805
2	2	0.930	615	0.985	770	1.145	925
2	1	1.050	745	1.105	920	1.265	1095
2	1/0	1.135	915	1.190	1100	1.350	1290
2	2/0	1.225	1110	1.280	1300	1.440	1505
2	3/0	1.330	1355	1.385	1565	1.540	1785
2	4/0	1.445	1660	1.500	1885	1.660	2120
2	250 MCM	1.575	1945	1.630	2215	1.850	2575
2	300 MCM	1.745	2385	1.805	2680	2.025	3070
2	350 MCM	1.850	2735	1.905	3045	2.125	3455
2	400 MCM	1.945	3080	2.000	3400	2.220	3835
2	500 MCM	2.115	3755	2.170	4100	2.390	4565
2	600 MCM	2.355	4530	2.410	4910	2.630	5430

Table 8-15—Dimensions and weights; single-, two-, three-, and four-conductor 600 V; type E, X, S, LSE, LSX, and T distribution cables *(Continued)*

		Unarmored		Armored		Armored and sheathed	
		Approximate		Approximate		Approximate	
Number of conductors	AWG/ MCM size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
2	750 MCM	2.565	5550	2.620	5955	2.900	6675
2	1000 MCM	2.930	7390	2.985	7840	3.265	8655
3	14	0.385	90	0.440	163	0.560	220
3	12	0.425	120	0.480	200	0.600	260
3	10	0.475	170	0.530	250	0.650	315
3	8	0.635	280	0.690	395	0.810	480
3	7	0.675	330	0.730	450	0.890	570
3	6	0.715	395	0.770	520	0.930	645
3	5	0.765	470	0.820	600	0.980	735
3	4	0.820	570	0.875	710	1.035	850
3	3	0.920	720	0.975	875	1.135	1035
3	2	0.990	875	1.045	1035	1.205	1205
3	1	1.120	1090	1.175	1270	1.335	1460
3	1/0	1.205	1320	1.260	1510	1.420	1710
3	2/0	1.305	1615	1.360	1825	1.520	2035
3	3/0	1.415	1980	1.470	2205	1.630	2435
3	4/0	1.540	2435	1.595	2700	1.815	3050
3	250 MCM	1.740	2965	1.795	3255	2.015	3645
3	300 MCM	1.860	3485	1.915	3795	2.135	4210
3	350 MCM	1.970	4005	2.025	4326	2.245	4765
3	400 MCM	2.075	4525	2.130	4865	2.350	5325
3	500 MCM	2.255	5545	2.310	5910	2.530	6405
3	750 MCM	2.800	8420	2.855	8845	3.135	9625
3	1000 MCM	3.130	11000	3.185	11450	3.465	12320
4	14	0.420	135	0.475	215	0.595	275
4	12	0.465	175	0.520	255	0.640	320
4	10	0.550	250	0.605	345	0.725	420
4	8	0.695	375	0.750	495	0.910	620
4	7	0.740	415	0.795	545	0.955	675
4	6	0.785	525	0.845	660	1.005	795
4	5	0.880	655	0.935	805	1.095	955
4	4	0.945	795	1.000	950	1.160	1110
4	3	1.010	950	1.065	1115	1.225	1285
4	2	1.090	1150	1.145	1330	1.305	1515
4	1	1.235	1430	1.285	1630	1.445	1835
4	1/0	1.330	1740	1.385	1955	1.545	2175
4	2/0	1.440	2124	1.495	2350	1.655	2585
4	3/0	1.565	2610	1.620	2875	1.840	3230
4	4/0	1.765	3285	1.820	3580	2.040	3975
4	250 MCM	1.920	3890	1.975	4205	2.195	4635
4	300 MCM	2.058	4580	2.115	4925	2.335	5380
4	350 MCM	2.185	5275	2.240	5635	2.455	6115
4	400 MCM	2.295	5960	2.350	6335	2.570	6840
4	500 MCM	2.500	7310	2.555	7710	2.835	8415

NOTE—Weights and diameters given are for cables with Type E and X insulated conductors. Cables with Type T, S, LSE, and LSX insulated conductors will vary slightly from those shown.

Table 8-16—Dimensions and weights; single-, two-, three-, and four-conductor 2000 V; type E and X distribution cables

		Unarmored		Armored		Armored and sheathed	
		Approximate		Approximate		Approximate	
Number of conductors	AWG/ MCM size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
1	14	0.255	40	0.310	95	0.400	125
1	12	0.275	50	0.330	105	0.420	135
1	10	0.295	70	0.350	130	0.440	160
1	8	0.345	100	0.400	175	0.490	205
1	7	0.365	115	0.420	195	0.510	235
1	6	0.385	135	0.440	215	0.560	275
1	5	0.405	160	0.460	245	0.580	305
1	4	0.435	195	0.490	285	0.610	350
1	3	0.460	235	0.515	330	0.635	390
1	2	0.495	285	0.550	380	0.670	450
1	1	0.585	370	0.640	485	0.760	560
1	1/0	0.625	445	0.680	570	0.800	650
1	2/0	0.670	545	0.725	670	0.885	790
1	3/0	0.720	665	0.775	800	0.935	925
1	4/0	0.780	815	0.835	960	0.995	1095
1	250 MCM	0.885	985	0.940	1145	1.100	1295
1	300 MCM	0.940	1160	0.995	1325	1.155	1480
1	350 MCM	0.990	1335	1.045	1505	1.205	1670
1	400 MCM	1.040	1505	1.095	1685	1.255	1855
1	500 MCM	1.125	1840	1.180	2035	1.340	2220
1	600 MCM	1.235	2200	1.290	2410	1.450	2610
1	750 MCM	1.340	2700	1.395	2925	1.555	3140
1	1000 MCM	1.495	3525	1.550	3790	1.770	4130
2	14	0.420	85	0.475	170	0.595	230
2	12	0.460	105	0.515	200	0.635	265
2	10	0.510	135	0.565	240	0.685	310
2	8	0.640	225	0.695	350	0.815	430
2	7	0.675	265	0.730	395	0.890	515
2	6	0.715	310	0.770	445	0.930	570
2	5	0.760	365	0.815	505	0.975	640
2	4	0.810	440	0.865	585	1.025	730
2	3	0.905	560	0.960	720	1.120	875
2	2	0.970	675	1.025	845	1.185	1010
2	1	1.090	835	1.145	1020	1.305	1205
2	1/0	1.170	1005	1.225	1205	1.385	1400
2	2/0	1.260	1220	1.315	1435	1.475	1640
2	3/0	1.365	1490	1.420	1720	1.580	1940
2	4/0	1.480	1825	1.535	2090	1.755	2430
2	250 MCM	1.610	2135	1.665	2420	1.885	2780
2	300 MCM	1.785	2610	1.840	2920	2.065	3320
2	350 MCM	1.890	2995	1.945	3320	2.165	3740
2	400 MCM	1.980	3375	2.035	3710	2.255	4150
2	500 MCM	2.150	4120	2.205	4480	2.425	4955
2	600 MCM	2.370	4920	2.425	5315	2.645	5835

Table 8-16—Dimensions and weights; single-, two-, three-, and four-conductor 2000 V; type E and X distribution cables (*Continued*)

Number of conductors	AWG/ MCM size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and Sheathed Approximate Nom. Dia. (in)	Armored and Sheathed Approximate Weight (lb/1000 ft)
2	750 MCM	2.580	6030	2.635	6440	2.915	7165
2	1000 MCM	2.950	8015	3.005	8465	3.285	9290
3	14	0.445	110	0.500	200	0.620	265
3	12	0.490	145	0.545	240	0.665	310
3	10	0.570	210	0.625	325	0.745	405
3	8	0.675	310	0.730	440	0.890	560
3	7	0.715	365	0.770	500	0.930	630
3	6	0.760	430	0.815	570	0.975	705
3	5	0.805	515	0.860	660	1.020	800
3	4	0.900	660	0.955	820	1.115	975
3	3	0.960	785	1.015	955	1.175	1120
3	2	1.030	955	1.085	1135	1.245	1310
3	1	1.160	1185	1.215	1380	1.375	1575
3	1/0	1.245	1440	1.300	1650	1.460	1855
3	2/0	1.345	1755	1.400	1980	1.560	2200
3	3/0	1.455	2150	1.510	2415	1.730	2750
3	4/0	1.580	2645	1.635	2925	1.855	3285
3	250 MCM	1.780	3200	1.835	3510	2.055	3910
3	300 MCM	1.905	3765	1.960	4090	2.180	4515
3	350 MCM	2.015	4340	2.070	4685	2.290	5135
3	400 MCM	2.115	4895	2.170	5250	2.390	5720
3	500 MCM	2.295	6000	2.350	6380	2.570	6885
3	600 MCM	2.535	7180	2.590	7585	2.870	8300
3	750 MCM	2.820	8980	2.875	9390	3.155	10180
3	1000 MCM	3.150	11710	3.205	12125	3.485	13000
4	14	0.490	140	0.545	235	0.665	305
4	12	0.565	200	0.620	315	0.740	390
4	10	0.620	265	0.675	385	0.795	470
4	8	0.745	395	0.800	530	0.960	660
4	7	0.785	470	0.840	615	1.000	750
4	6	0.875	590	0.930	745	1.090	895
4	5	0.930	705	0.985	870	1.145	1030
4	4	0.990	850	1.045	1020	1.205	1190
4	3	1.060	1020	1.115	1205	1.275	1385
4	2	1.135	1240	1.190	1435	1.350	1625
4	1	1.280	1545	1.335	1760	1.495	1970
4	1/0	1.380	1880	1.435	2110	1.595	2335
4	2/0	1.490	2300	1.545	2565	1.765	2905
4	3/0	1.615	2820	1.670	3105	1.890	3470
4	4/0	1.815	3580	1.870	3890	2.090	4295
4	250 MCM	1.970	4195	2.025	4530	2.245	4970
4	300 MCM	2.105	4940	2.160	5290	2.380	5755
4	350 MCM	2.230	5700	2.325	6075	2.545	6575
4	400 MCM	2.345	6440	2.400	6830	2.620	7345
4	500 MCM	2.545	7900	2.600	8325	2.880	9040

Table 8-17—Dimensions and weights; single-, two-, three-, and four-conductor 600 V; type T/N distribution cables

		Unarmored		Armored		Armored and sheathed	
Number of conductors	AWG/ MCM size	Approximate Nom. Dia. (in)	Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Weight (lb/1000 ft)
1	14	0.21	32	0.26	44	0.35	71
1	12	0.23	45	0.28	57	0.37	86
1	10	0.26	61	0.31	75	0.40	105
1	8	0.31	92	0.36	109	0.45	145
1	6	0.36	130	0.41	149	0.50	189
1	4	0.43	201	0.48	223	0.61	287
1	2	0.49	243	0.54	318	0.67	389
1	1	0.58	386	0.63	416	0.76	447
1	1/0	0.62	467	0.67	499	0.80	585
1	2/0	0.66	571	0.71	605	0.88	729
1	3/0	0.71	698	0.76	734	0.93	866
1	4/0	0.78	858	0.83	898	1.00	1041
1	250 MCM	0.88	1051	0.93	1095	1.10	1254
1	300 MCM	0.94	1226	0.99	1273	1.16	1441
1	350 MCM	0.99	1393	1.04	1443	1.21	1619
1	400 MCM	1.03	1603	1.08	1655	1.25	1837
1	500 MCM	1.12	1931	1.17	1987	1.34	2184
1	600 MCM	1.23	2288	1.28	2350	1.45	2564
1	750 MCM	1.34	2818	1.39	2885	1.56	3110
1	1000 MCM	1.49	3677	1.54	3752	1.77	4110
2	14	0.33	66	0.38	84	0.47	121
2	12	0.37	88	0.42	108	0.51	149
2	10	0.43	133	0.48	155	0.61	219
2	8	0.58	216	0.63	246	0.76	329
2	6	0.65	311	0.70	344	0.83	434
2	4	0.80	479	0.85	520	1.02	666
2	2	0.97	727	1.02	776	1.19	949
2	1	1.00	933	1.05	983	1.22	1161
2	1/0	1.18	1110	1.23	1170	1.40	1376
2	2/0	1.27	1323	1.32	1385	1.49	1605
2	3/0	1.38	1602	1.43	1671	1.60	1908
2	4/0	1.56	2122	1.61	2200	1.84	2574
2	250 MCM	1.62	2337	1.67	2418	1.90	2804
2	300 MCM	1.80	2851	1.85	2941	2.08	3367
2	350 MCM	1.90	3303	1.95	3348	2.18	3795
2	400 MCM	2.08	3662	2.13	3765	2.36	4267
2	500 MCM	2.17	4497	2.22	4605	2.45	5111
2	600 MCM	2.36	4401	2.41	5018	2.64	5565
2	750 MCM	2.57	6404	2.62	6531	2.91	7240
3	14	0.35	86	0.40	104	0.49	143
3	12	0.39	120	0.44	140	0.57	199
3	10	0.46	171	0.51	195	0.66	262

Table 8-17—Dimensions and weights; single-, two-, three-, and four-conductor 600 V; type T/N distribution cables (*Continued*)

		Unarmored		Armored		Armored and sheathed	
		Approximate		Approximate		Approximate	
Number of conductors	AWG/ MCM size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
3	8	0.61	301	0.66	332	0.79	417
3	6	0.69	406	0.74	441	0.91	572
3	4	0.84	664	0.94	709	1.11	872
3	2	1.02	980	1.07	1031	1.24	1214
3	1	1.16	1228	1.21	1286	1.38	1497
3	1/0	1.24	1557	1.29	1619	1.46	1837
3	2/0	1.36	1828	1.41	1896	1.58	2133
3	3/0	1.45	2244	1.50	2316	1.73	2666
3	4/0	1.59	2773	1.64	2852	1.88	3232
3	250 MCM	1.80	3360	1.85	3450	2.08	3876
3	300 MCM	1.91	3920	1.96	4015	2.19	4464
3	350 MCM	2.05	4550	2.10	4652	2.32	5132
3	400 MCM	2.22	5133	2.27	5243	2.50	5711
3	500 MCM	2.45	6472	2.50	6594	2.79	7360
3	600 MCM	2.52	7375	2.57	7500	2.86	8245
3	750 MCM	2.83	9200	2.88	9340	3.17	10170
4	14	0.39	151	0.44	129	0.57	188
4	12	0.43	225	0.48	171	0.61	235
4	10	0.51	366	0.56	247	0.69	320
4	8	0.66	536	0.71	392	0.88	516
4	6	0.77	878	0.82	570	0.99	712
4	4	0.99	1268	1.04	917	1.21	1093
4	2	1.13	1598	1.18	1318	1.35	1516
4	1	1.27	1924	1.32	1655	1.49	1875
4	1/0	1.38	2374	1.43	1988	1.60	2225
4	2/0	1.49	2569	1.54	2443	1.77	2801
4	3/0	1.61	2850	1.66	2960	1.89	3344
4	4/0	1.82	3650	1.87	3741	2.07	4112
4	250 MCM	1.98	4319	2.03	4417	2.26	4877
4	300 MCM	2.11	5051	2.16	5156	2.39	5649
4	350 MCM	2.34	5866	2.29	5982	2.52	6503
4	400 MCM	2.46	6623	2.51	6755	2.80	7484
4	500 MCM	2.56	8086	2.61	8213	2.90	8969
4	600 MCM	2.87	9657	2.92	9799	3.21	10640
4	750 MCM	3.11	11949	3.16	12103	3.45	13010

Table 8-18—Dimensions and weights; single conductor 2000 V; type P distribution cables

Conductor size in circular mil and AWG	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
8	–	–	0.306	118	0.430	162
6	–	–	0.355	162	0.479	212
5	–	–	0.405	212	0.533	270
4	–	–	0.425	244	0.553	304
2	–	–	0.485	317	0.613	384
1	–	–	0.570	443	0.698	521
1/0	–	–	0.620	517	0.748	600
2/0	–	–	0.665	599	0.793	688
3/0	–	–	0.735	783	0.903	915
4/0	0.808	852	0.875	996	1.043	1148
262 MCM	0.850	962	0.917	1132	1.085	1290
313 MCM	0.912	1131	0.985	1319	1.153	1488
373 MCM	0.931	1354	1.035	1528	1.203	1710
444 MCM	1.050	1607	1.115	1784	1.283	1974
535 MCM	1.173	1994	1.235	2226	1.443	2489
646 MCM	1.268	2303	1.350	2590	1.558	2875
777 MCM	1.335	2734	1.415	2967	1.643	3297
1111 MCM	1.563	3743	1.635	4069	1.863	4446

Table 8-19—Dimensions and weights; two ,three, four and five conductor 600 V; type P distribution cables

		Unarmored		Armored		Armored and sheathed	
Number of conductors	AWG/MCM size	Approximate Nom. Dia. (in)	Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Weight (lb/1000 ft)
2	8	0.590	217	0.645	323	0.733	411
2	6	0.688	316	0.743	433	0.911	568
2	5	0.784	409	0.843	540	1.011	687
2	4	0.868	506	0.923	664	1.091	828
2	3	0.918	583	0.973	748	1.141	921
2	2	0.988	682	1.043	805	1.211	988
2	1	1.158	923	1.213	1126	1.421	1392
2	1/0	1.258	1087	1.313	1312	1.521	1598
2	2/0	1.348	1271	1.403	1514	1.631	1850
2	3/0	1.560	1860	1.620	2765	1.870	2586
2	4/0	1.695	2193	1.753	2468	2.011	2932
2	262 MCM	1.792	2420	1.857	2774	2.105	3269
3	8	0.625	275	0.681	390	0.849	511
3	6	0.730	403	0.787	539	0.955	677
3	5	0.865	572	0.929	753	1.097	913
3	4	0.899	666	0.976	853	1.144	1021
3	3	0.974	761	1.029	949	1.197	1125
3	2	1.060	891	1.107	1006	1.275	1194
3	1	1.243	1270	1.290	1495	1.498	1769
3	1/0	1.318	1479	1.397	1857	1.625	2183
3	2/0	1.455	1795	1.532	2141	1.760	2586
3	3/0	1.647	2385	1.706	2741	1.964	3189
3	4/0	1.810	2901	1.865	3282	2.123	3769
3	262 MCM	1.943	3393	1.998	3824	2.256	4452
3	313 MCM	2.090	3968	2.145	4385	2.433	5010
3	373 MCM	2.193	4633	2.248	5081	2.536	5734
3	444 MCM	2.400	5552	2.450	6050	2.738	6758
3	535 MCM	2.706	6824	2.710	7410	2.998	8190
3	646 MCM	2.900	8016	2.955	8486	3.243	9353
3	777 MCM	3.040	9382	3.095	9883	3.383	10789
4	8	0.685	356	0.736	468	0.904	598
4	6	0.803	524	0.854	659	1.022	804
4	5	0.949	748	1.018	941	1.186	1115
4	4	0.987	863	1.063	1070	1.231	1252
4	3	1.072	982	1.127	1206	1.295	1398
4	2	1.168	1153	1.211	1397	1.419	1656
4	1	1.373	1650	1.416	1954	1.644	2284
4	1/0	1.457	1950	1.537	2272	1.765	2628
4	2/0	1.626	2372	1.705	2740	1.963	3188
4	3/0	1.849	3216	1.904	3599	2.162	4096
4	4/0	1.997	3815	2.044	4262	2.332	4860
4	262 MCM	2.143	4435	2.198	4798	2.486	5570

Table 8-19—Dimensions and weights; two ,three, four and five conductor 600 V; type P distribution cables (*Continued*)

Number of conductors	AWG/ MCM size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
4	313 MCM	2.340	5292	2.392	5793	2.680	6485
4	373 MCM	2.457	6276	2.512	6672	2.800	7417
4	444 MCM	2.650	7390	2.705	7825	2.993	8622
4	535 MCM	2.939	9159	2.994	9649	3.282	10484
4	646 MCM	3.216	10654	3.290	11260	3.600	12290
5	8	0.748	410	0.803	572	0.971	713
5	6	0.924	675	0.979	843	1.147	1011
5	4	1.086	1055	1.168	1307	1.336	1505
5	2	1.275	1412	1.330	1702	1.538	1984
5	1	1.545	2168	1.600	2427	1.828	2806
5	1/0	1.700	2514	1.755	2794	2.013	3266
5	2/0	1.834	3005	1.876	3342	2.164	3898
5	3/0	2.040	4046	2.095	4386	2.383	5013
5	4/0	2.202	4682	2.257	5227	2.545	5899

Table 8-20—Dimensions and weights; 3 conductor 5000 V type E and X; distribution cables

AWG/MCM size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
8	1.135	700	1.190	885	1.350	1075
7	1.160	770	1.215	960	1.375	1150
6	1.203	855	1.260	1050	1.420	1250
5	1.265	890	1.320	1095	1.480	1305
4	1.325	1085	1.380	1300	1.540	1515
3	1.385	1240	1.440	1460	1.600	1685
2	1.450	1425	1.505	1650	1.725	1980
1	1.535	1660	1.590	1925	1.815	2275
1/0	1.625	1945	1.680	2226	1.900	2590
2/0	1.780	2390	1.840	2690	2.060	3085
3/0	1.895	2820	1.950	3135	2.170	3560
4/0	2.020	3360	2.075	3695	2.295	4140
250 MCM	2.115	3825	2.170	4170	2.390	4635
300 MCM	2.240	4425	2.295	4790	2.515	5282
350 MCM	2.345	5015	2.400	5400	2.625	5916
400 MCM	2.450	5605	2.505	6000	2.785	6690
500 MCM	2.675	6840	2.730	7265	3.010	8015

Table 8-21—Dimensions and weights; 1 conductor 5000 V type E and X; distribution cables

	Unarmored Approximate		Armored Approximate		Armored and sheathed Approximate	
AWG/MCM size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
8	0.570	225	0.625	335	0.745	415
7	0.585	245	0.640	350	0.760	430
6	0.605	270	0.660	380	0.780	460
5	0.630	300	0.685	415	0.805	500
4	0.655	340	0.710	455	0.870	575
3	0.685	390	0.740	510	0.900	635
2	0.715	445	0.770	570	0.930	700
1	0.755	515	0.810	645	0.970	780
1/0	0.795	600	0.850	735	1.010	875
2/0	0.880	740	0.935	885	1.095	1040
3/0	0.930	870	0.990	1025	1.150	1185
4/0	0.990	1035	1.045	1200	1.205	1370
250 MCM	1.035	1180	1.090	1350	1.250	1525
300 MCM	1.095	1360	1.150	1540	1.310	1725
350 MCM	1.145	1540	1.200	1730	1.360	1925
400 MCM	1.190	1720	1.245	1915	1.405	2115
500 MCM	1.295	2095	1.350	2305	1.510	2520
600 MCM	1.375	2445	1.430	2665	1.590	2890
750 MCM	1.480	2965	1.535	3200	1.755	3540
1000 MCM	1.635	3815	1.690	4095	1.910	4465

Table 8-22—Dimensions and weights; multiconductor control 600 V; types T,E,X,S,LSE, and LSX cables

Number of conductors	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
2	18	0.315	47	0.370	99	0.460	134
3	18	0.330	56	0.385	108	0.475	144
4	18	0.360	68	0.415	126	0.505	165
7	18	0.425	99	0.480	177	0.600	237
10	18	0.565	153	0.620	259	0.740	335
14	18	0.610	195	0.665	305	0.785	386
19	18	0.670	250	0.725	369	0.885	489
24	18	0.780	308	0.835	440	0.995	577
30	18	0.825	370	0.880	509	1.040	652
37	18	0.930	480	0.985	635	1.145	793
44	18	1.030	547	1.085	716	1.245	890
61	18	1.100	696	1.155	875	1.315	1059
2	16	0.340	57	0.395	129	0.485	166
3	16	0.360	71	0.415	149	0.505	188
4	16	0.390	87	0.445	168	0.565	225
7	16	0.460	129	0.515	222	0.635	286
10	16	0.615	197	0.670	316	0.790	398
14	16	0.665	255	0.720	381	0.880	501
19	16	0.735	328	0.790	464	0.950	594
24	16	0.900	444	0.955	601	1.115	756
30	16	0.950	529	1.005	694	1.165	856
37	16	1.020	631	1.075	806	1.235	978
44	16	1.155	748	1.210	945	1.370	1137
61	16	1.275	980	1.330	1195	1.490	1405
2	14	0.370	72	0.425	132	0.515	172
3	14	0.390	92	0.445	152	0.565	209
4	14	0.425	114	0.480	192	0.600	253
7	14	0.505	173	0.560	264	0.680	333
10	14	0.675	261	0.730	380	0.890	501
14	14	0.730	342	0.785	468	0.945	697
19	14	0.810	444	0.865	583	1.025	724
24	14	0.990	593	1.045	757	1.205	925
30	14	1.050	714	1.105	885	1.265	1062
37	14	1.130	856	1.185	1041	1.345	1230
44	14	1.270	1010	1.325	1215	1.485	1425
61	14	1.395	1350	1.450	1573	1.610	1801

NOTE—Weights given are for cables with Type E and X insulated conductors. Cables with Type T ,LSE, and LSX insulated conductors will vary slightly from those shown.

Table 8-23—Dimensions and weights; multiconductor control 600 V; type T/N cables

Number of conductors	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
2	18	0.28	35	0.33	50	0.42	83
3	18	0.29	44	0.34	60	0.43	94
4	18	0.31	53	0.36	70	0.45	106
7	18	0.36	86	0.41	105	0.50	145
10	18	0.45	117	0.50	140	0.63	206
14	18	0.49	150	0.54	175	0.67	246
19	18	0.57	211	0.62	240	0.75	320
24	18	0.65	262	0.70	295	0.83	385
30	18	0.69	310	0.74	345	0.91	474
37	18	0.74	372	0.79	410	0.96	547
44	18	0.86	471	0.91	515	1.08	671
61	18	0.95	612	1.00	660	1.17	830
2	16	0.30	49	0.35	65	0.44	100
3	16	0.31	53	0.36	70	0.45	104
4	16	0.34	72	0.39	90	0.48	128
7	16	0.39	114	0.45	135	0.58	195
10	16	0.50	159	0.55	185	0.68	257
14	16	0.56	226	0.61	255	0.74	334
19	16	0.62	288	0.67	320	0.80	406
24	16	0.72	358	0.77	395	0.94	529
30	16	0.77	431	0.82	470	0.99	612
37	16	0.87	556	0.92	600	1.09	751
44	16	0.96	652	1.01	700	1.18	871
61	16	1.07	816	1.12	870	1.29	1059
2	14	0.33	62	0.38	80	0.47	117
3	14	0.35	81	0.40	100	0.49	137
4	14	0.37	101	0.42	120	0.51	161
7	14	0.44	157	0.49	180	0.62	245
10	14	0.58	240	0.63	270	0.76	354
14	14	0.63	308	0.68	340	0.81	430
19	14	0.71	399	0.76	435	0.93	567
24	14	0.81	494	0.86	535	1.03	682
30	14	0.90	639	0.95	685	1.12	847
37	14	0.96	762	1.01	810	1.18	981
44	14	1.08	901	1.13	955	1.30	1145
61	14	1.14	1210	1.24	1270	1.41	1478

Table 8-24—Dimensions and weights; multiconductor control 600 V; type P cables

Number of conductors	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
2	18	0.338	58	0.393	122	0.523	177
3	18	0.354	70	0.409	135	0.533	190
7	18	0.449	129	0.504	206	0.632	276
44	18	1.024	667	1.079	843	1.247	1026
45	18	1.025	685	1.096	863	1.264	1055
91	18	1.405	1345	1.400	1490	1.628	1816
2	16	0.352	63	0.407	126	0.535	183
3	16	0.369	77	0.424	147	0.552	206
4	16	0.401	101	0.456	175	0.584	239
6	16	0.466	135	0.521	213	0.645	283
8	16	0.550	174	0.605	272	0.733	352
10	16	0.584	200	0.639	359	0.767	443
14	16	0.631	267	0.686	378	0.814	471
16	16	0.664	300	0.719	411	0.887	540
18	16	0.698	333	0.753	450	0.921	593
20	16	0.744	364	0.799	496	0.967	639
22	16	0.769	393	0.824	523	0.992	674
24	16	0.812	430	0.867	565	1.035	720
37	16	0.966	637	1.021	798	1.189	973
44	16	1.080	776	1.135	958	1.303	1156
60	16	1.194	958	1.249	1215	1.457	1481
91	16	1.462	1538	1.519	1783	1.747	2145
2	14	0.378	78	0.433	145	0.557	203
3	14	0.398	98	0.453	172	0.580	234
4	14	0.431	123	0.485	207	0.613	273
5	14	0.471	144	0.526	229	0.650	298
6	14	0.505	174	0.560	256	0.688	331
7	14	0.505	192	0.560	279	0.688	356
10	14	0.636	269	0.691	380	0.819	474
12	14	0.656	309	0.710	423	0.879	552
14	14	0.688	352	0.743	468	0.911	601
19	14	0.763	455	0.818	585	0.986	732
20	14	0.802	487	0.857	621	1.025	774
24	14	0.930	611	0.985	773	1.153	947
30	14	0.982	732	1.038	893	1.206	1077
37	14	1.057	839	1.112	1095	1.280	1284
44	14	1.184	1016	1.239	1262	1.447	1525
60	14	1.311	1375	1.366	1592	1.574	1889
91	14	1.625	2144	1.682	2385	1.940	2839

Table 8-24—Dimensions and weights; multiconductor control 600 V; type P cables (*Continued*)

Number of conductors	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
2	12	0.416	100	0.471	174	0.599	238
3	12	0.439	128	0.493	207	0.621	274
4	12	0.477	162	0.531	250	0.659	321
5	12	0.518	202	0.573	288	0.701	367
6	12	0.566	239	0.621	335	0.749	420
10	12	0.712	356	0.767	487	0.935	621
20	12	0.949	681	1.004	870	1.172	1042
37	12	1.190	1215	1.245	1420	1.453	1685
60	12	1.522	1955	1.577	2245	1.805	2619
2	10	0.490	146	0.545	235	0.673	308
3	10	0.519	194	0.572	289	0.700	365
4	10	0.566	249	0.620	322	0.748	404
5	10	0.618	303	0.673	418	0.841	538
7	10	0.673	405	0.728	520	0.892	648
9	10	0.900	583	0.955	729	1.123	889

Table 8-25—Dimensions and weights; twisted-pair signal cable, 300 V; type T

		Pairs shielded				Pairs unshielded			
No of pairs	No. of con-ductors	Nominal diameter (in)			Approximate weight (lb/1000 ft)	Nominal diameter (in)			Approximate weight (lb/1000 ft)
	AWG#	16	18	20	16	16	18	20	16
1	2	0.42	0.40	0.38	125	0.42	0.40	0.37	125
2	4	0.68	0.64	0.57	260	0.56	0.53	0.49	195
3	6	0.72	0.67	0.63	295	0.65	0.57	0.53	245
4	8	0.78	0.72	0.67	345	0.73	0.68	0.64	295
5	10	0.85	0.79	0.73	405	0.75	0.70	0.65	345
6	12	0.96	0.86	0.79	505	0.78	0.72	0.67	370
7	14	0.96	0.86	0.79	500	0.78	0.73	0.67	385
8	16	1.04	0.96	0.85	560	0.86	0.80	0.74	440
9	18	1.10	1.03	0.95	630	0.98	0.86	0.81	540
10	20	1.19	1.09	1.01	690	1.01	0.88	0.82	560
11	22	1.19	1.09	1.01	720	1.03	0.95	0.84	590
12	24	1.22	1.13	1.05	755	1.05	0.97	0.86	625
13	26	1.25	1.15	1.06	800	1.08	1.00	0.88	660
14	28	1.28	1.18	1.09	835	1.12	1.04	0.96	710
15	30	1.33	1.22	1.12	890	1.16	1.06	0.99	740
16	32	1.35	1.24	1.15	920	1.16	1.07	0.99	770
17	34	1.41	1.29	1.19	985	1.17	1.08	1.00	800
18	36	1.43	1.31	1.21	1030	1.21	1.11	1.03	830
19	38	1.43	1.31	1.21	1020	1.23	1.13	1.05	865
20	40	1.47	1.36	1.24	1070	1.25	1.16	1.06	895
21	42	1.49	1.38	1.26	1110	1.28	1.18	1.08	930
22	44	1.55	1.43	1.31	1160	1.30	1.20	1.10	960

Table 8-26—Dimensions and weights; multiconductor shielded signal cable 600 V; type P cables

Number of conductors	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
Overall Aluminum/Polyester Tape Shield							
3	20	0.338	65	0.393	122	0.525	185
4	20	0.362	74	0.417	139	0.545	197
5	20	0.391	89	0.450	158	0.578	218
6	20	0.420	103	0.475	171	0.603	237
3	18	0.356	75	0.411	150	0.551	207
4	18	0.385	93	0.440	162	0.568	222
6	18	0.447	126	0.502	200	0.630	269
25	18	0.792	402	0.927	535	1.095	750
3	16	0.371	89	0.426	156	0.554	213
4	16	0.401	107	0.456	177	0.584	239
12	16	0.687	295	0.742	411	0.910	545
6	14	0.507	182	0.562	267	0.690	345
4	10	0.581	265	0.622	370	0.750	459
Overall Tinned Copper Braid Shield							
4	20	0.386	94	0.441	159	0.569	221
3	18	0.385	91	0.440	156	0.568	218
4	18	0.412	109	0.467	180	0.595	245
7	18	0.480	158	0.535	237	0.683	331
12	18	0.599	246	0.654	345	0.782	446
20	18	0.735	376	0.790	498	0.954	630
15	16	0.695	341	0.750	460	0.918	594
2	14	0.404	101	0.459	170	0.587	232
3	14	0.423	122	0.478	195	0.606	261
5	14	0.498	185	0.553	266	0.681	341
7	14	0.536	224	0.591	313	0.719	394
14	14	0.723	402	0.778	524	0.946	662
19	14	0.798	509	0.853	642	1.021	793
30	14	1.017	797	1.072	970	1.240	1156
44	14	1.219	1113	1.274	1313	1.482	1591
60	14	1.346	1452	1.441	1731	1.669	2070
91	14	1.660	2191	1.715	2466	1.973	2921

Table 8-27—Dimensions and weights; paired shielded signal cable 600 V; type P cables

Number of pairs	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
Overall Aluminum/Polyester Tape Shield							
12	22	0.809	297	0.843	341	1.011	494
3	20	0.493	119	0.570	222	0.694	298
4	20	0.522	135	0.620	252	0.748	332
5	16	0.659	221	0.773	359	0.941	496
8	16	0.976	449	1.030	620	1.199	799
Overall Tinned Copper Braid Shield							
1	18	0.364	76	0.419	139	0.547	198
2	18	0.507	140	0.562	227	0.690	304
4	18	0.583	199	0.638	299	0.766	385
7	18	0.691	286	0.746	403	0.874	530
9	18	0.907	418	0.962	572	1.130	740
10	18	0.907	456	0.962	606	1.130	755
14	18	0.979	542	1.034	714	1.162	887
15	18	1.030	585	1.085	759	1.253	946
Individual Aluminum/Polyester Tape Shield							
2	22	0.464	92	0.534	189	0.662	261
3	22	0.489	111	0.544	194	0.672	266
12	22	0.866	342	0.921	490	1.089	651
17	22	1.008	456	1.063	631	1.231	812
19	22	1.008	483	1.063	656	1.231	843
1	20	0.322	53	0.377	112	0.505	165
2	20	0.488	112	0.560	208	0.688	285
3	20	0.515	124	0.570	223	0.698	300
4	20	0.563	161	0.622	258	0.750	341
19	20	1.078	612	1.133	790	1.301	985
25	20	1.287	813	1.342	1031	1.550	1319
1	18	0.340	62	0.395	127	0.523	182
2	18	0.546	139	0.600	230	0.728	311
3	18	0.555	163	0.610	251	0.738	334
4	18	0.608	204	0.663	293	0.791	383
5	18	0.666	242	0.720	360	0.888	487
6	18	0.725	278	0.780	399	0.948	537
7	18	0.725	302	0.780	423	0.948	563
8	18	0.904	410	0.959	563	1.127	730
10	18	0.964	450	1.019	641	1.187	816
12	18	0.995	514	1.050	681	1.218	863
14	18	1.046	609	1.101	776	1.269	969
20	18	1.239	837	1.294	1038	1.502	1315
24	18	1.402	1031	1.457	1262	1.685	1604
1	16	0.354	76	0.409	134	0.537	192

Table 8-27—Dimensions and weights; paired shielded signal cable 600 V; type P cables (*Continued*)

		Unarmored		Armored		Armored and sheathed	
		Approximate		Approximate		Approximate	
Number of pairs	AWG size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
2	16	0.550	145	0.605	229	0.733	309
3	16	0.582	185	0.637	300	0.765	384
4	16	0.637	215	0.732	375	0.860	471
5	16	0.698	275	0.753	398	0.921	532
6	16	0.761	326	0.800	452	0.984	593
7	16	0.761	352	0.800	481	0.984	623
8	16	0.930	458	0.985	619	1.153	788
10	16	1.012	541	1.067	710	1.235	892
12	16	1.044	629	1.099	798	1.267	987
15	16	1.160	781	1.215	925	1.423	1122
20	16	1.287	971	1.351	1196	1.559	1484
22	16	1.411	1126	1.466	1316	1.704	1625
2	14	0.598	181	0.653	286	0.781	372
4	14	0.696	303	0.751	421	0.919	555
10	12	1.244	1023	1.299	1233	1.507	1512
Individual and Overall Aluminum/Polyester Tape Shields							
2	20	0.554	146	0.609	237	0.737	319
2	18	0.612	182	0.667	286	0.795	376
3	18	0.641	225	0.696	324	0.864	454
4	18	0.694	254	0.749	372	0.917	508
7	18	0.811	364	0.866	501	1.034	656
8	18	0.980	474	1.035	639	1.203	814
10	18	1.040	535	1.095	705	1.263	897
12	18	1.071	617	1.126	801	1.294	998
14	18	1.122	675	1.177	865	1.345	1070
16	18	1.179	767	1.234	924	1.442	1194
24	18	1.438	1089	1.493	1333	1.721	1688
2	16	0.616	196	0.671	300	0.799	389
3	16	0.668	243	0.723	356	0.891	487
4	16	0.703	279	0.758	396	0.926	533
8	16	1.006	543	1.061	708	1.229	892

Table 8-28—Dimensions and weights; triad shielded signal cable 600 V; type P cables

Number of triads	AWG size	Unarmored Approximate Nom. Dia. (in)	Unarmored Approximate Weight (lb/1000 ft)	Armored Approximate Nom. Dia. (in)	Armored Approximate Weight (lb/1000 ft)	Armored and sheathed Approximate Nom. Dia. (in)	Armored and sheathed Approximate Weight (lb/1000 ft)
Overall Aluminum/Polyester Tape Shield							
3	18	0.635	205	0.690	314	0.858	439
5	18	0.765	304	0.820	441	0.988	586
7	18	0.876	423	0.931	576	1.099	739
1	16	0.371	127	0.426	152	0.554	213
3	16	0.668	241	0.723	353	0.891	483
4	16	0.733	300	0.788	422	0.956	565
5	16	0.806	355	0.861	497	1.029	649
6	16	0.921	424	0.976	588	1.144	756
8	16	1.097	597	1.152	782	1.320	983
12	16	1.209	813	1.264	1007	1.472	1284
16	16	1.348	1068	1.403	1262	1.631	1652
Individual and Overall Aluminum/Polyester Tape Shields							
6	16	0.997	547	1.052	728	1.220	913

Table 8-29—Dimensions and weights; twisted-pair signal cable 300 V; type T/N cables, unshielded pairs

		Unarmored		Armored		Armored and sheathed	
Number		Approximate		Approximate		Approximate	
of pairs	AWG size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
1	20	0.231	28.6	0.286	41.9	0.380	71.1
2	20	0.370	61.0	0.425	80.5	0.551	137.9
3	20	0.382	63.8	0.437	83.9	0.563	142.7
4	20	0.417	78.3	0.472	100.1	0.598	163.0
5	20	0.435	92.3	0.490	114.9	0.616	179.9
6	20	0.443	103.5	0.498	126.6	0.624	192.5
7	20	0.491	120.6	0.546	146.0	0.672	217.6
8	20	0.558	152.0	0.613	180.7	0.739	260.2
9	20	0.584	166.9	0.639	196.9	0.765	279.4
10	20	0.609	181.3	0.664	212.5	0.790	298.0
11	20	0.631	195.5	0.686	227.8	0.812	315.8
12	20	0.653	207.0	0.708	240.4	0.876	364.5
13	20	0.676	221.2	0.731	255.7	0.899	383.4
14	20	0.695	237.7	0.750	273.1	0.918	403.8
15	20	0.715	251.5	0.770	287.9	0.938	421.8
16	20	0.735	265.8	0.790	303.2	0.958	440.2
17	20	0.753	279.4	0.808	317.7	0.976	457.5
18	20	0.771	293.2	0.826	332.4	0.994	475.0
19	20	0.788	306.7	0.843	346.7	1.011	492.0
20	20	0.805	319.9	0.860	360.7	1.028	508.7
21	20	0.864	366.4	0.919	410.1	1.087	567.3
22	20	0.880	380.9	0.935	425.4	1.103	585.1
1	18	0.244	33.8	0.299	47.1	0.393	77.4
2	18	0.336	57.9	0.391	75.7	0.485	114.1
3	18	0.410	79.7	0.465	101.2	0.591	163.3
4	18	0.446	98.6	0.501	121.8	0.627	188.1
5	18	0.470	116.4	0.525	140.8	0.651	209.9
6	18	0.477	132.6	0.532	157.3	0.658	227.2
7	18	0.564	169.5	0.619	198.5	0.745	278.7
8	18	0.600	189.6	0.655	220.4	0.781	304.8
9	18	0.629	208.4	0.684	240.6	0.810	328.4
10	18	0.656	227.6	0.711	261.1	0.879	385.7
11	18	0.681	245.7	0.736	280.4	0.904	408.9
12	18	0.705	264.3	0.760	300.2	0.928	432.5
13	18	0.730	282.9	0.785	320.0	0.953	456.2
14	18	0.751	301.3	0.806	339.5	0.974	479.0
15	18	0.773	319.1	0.828	358.4	0.996	501.3
16	18	0.794	338.2	0.849	378.5	1.017	524.7
17	18	0.815	355.3	0.870	396.6	1.038	546.1
18	18	0.877	406.9	0.932	451.3	1.100	610.5
19	18	0.895	425.8	0.950	471.0	1.118	633.1
20	18	0.914	444.0	0.969	490.2	1.137	655.2
21	18	0.933	462.3	0.988	509.4	1.156	677.4
22	18	0.950	480.9	1.005	528.8	1.173	699.5

Table 8-29—Dimensions and weights; twisted-pair signal cable 300 V; type T/N cables, unshielded pairs (*Continued*)

		Unarmored		Armored		Armored and sheathed	
Number of pairs	AWG size	Approximate Nom. Dia. (in)	Approximate Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Approximate Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Approximate Weight (lb/1000 ft)
1	16	0.264	42.7	0.319	57.0	0.413	89.1
2	16	0.369	75.3	0.424	94.7	0.550	129.8
3	16	0.453	105.3	0.508	128.9	0.634	196.0
4	16	0.497	132.7	0.552	158.4	0.678	230.7
5	16	0.553	174.2	0.608	202.7	0.734	281.6
6	16	0.562	197.6	0.617	226.5	0.743	306.4
7	16	0.624	228.2	0.679	260.2	0.805	347.4
8	16	0.665	255.7	0.720	290.0	0.888	416.0
9	16	0.698	282.6	0.753	318.2	0.921	449.4
10	16	0.729	309.1	0.784	346.2	0.952	482.2
11	16	0.757	335.0	0.812	373.5	0.980	513.9
12	16	0.785	361.2	0.840	401.0	1.008	545.8
13	16	0.813	387.1	0.868	428.3	1.036	577.5
14	16	0.879	447.3	0.934	491.8	1.102	651.4
15	16	0.904	473.6	0.959	519.3	1.127	682.8
16	16	0.928	500.6	0.983	547.5	1.151	714.7
17	16	0.951	526.9	1.006	574.9	1.174	745.7
18	16	0.974	553.6	1.029	602.7	1.197	777.1
19	16	0.996	579.1	1.051	629.5	1.219	807.4
20	16	1.017	605.4	1.072	656.6	1.240	837.8
21	16	1.038	631.7	1.093	684.0	1.261	868.5
22	16	1.058	657.2	1.113	710.4	1.281	898.0

Table 8-30—Dimensions and weights; twisted-pair signal cable 300 V; type T/N cables, shielded pairs

		Unarmored		Armored		Armored and sheathed	
Number of pairs	AWG size	Approximate Nom. Dia. (in)	Approximate Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Approximate Weight (lb/1000 ft)	Approximate Nom. Dia. (in)	Approximate Weight (lb/1000 ft)
1	20	0.229	32.8	0.284	45.4	0.378	74.4
2	20	0.370	61.0	0.425	80.5	0.551	137.9
3	20	0.390	80.0	0.445	100.5	0.571	160.2
4	20	0.425	98.6	0.480	120.8	0.606	184.6
5	20	0.465	117.6	0.520	141.8	0.646	210.3
6	20	0.505	137.2	0.560	163.4	0.686	236.6
7	20	0.505	153.0	0.560	179.1	0.686	252.3
8	20	0.555	186.2	0.610	214.9	0.736	249.0
9	20	0.621	210.9	0.676	242.8	0.802	329.7
10	20	0.666	228.9	0.721	262.9	0.889	389.1
11	20	0.666	245.0	0.721	279.0	0.889	405.2
12	20	0.692	267.1	0.747	302.4	0.915	432.6
13	20	0.727	287.1	0.782	324.1	0.950	459.8
14	20	0.727	302.5	0.782	339.5	0.950	475.2
15	20	0.767	322.9	0.822	361.9	0.990	503.9
16	20	0.767	339.0	0.822	378.0	0.990	520.0
17	20	0.807	359.6	0.862	400.5	1.030	548.8
18	20	0.807	375.4	0.862	416.3	1.030	564.6
19	20	0.807	391.2	0.862	432.1	1.030	580.4
20	20	0.891	447.1	0.946	492.1	1.114	653.5
21	20	0.891	462.9	0.946	507.9	1.114	669.3
22	20	0.933	485.1	0.988	532.2	1.156	700.2
1	18	0.248	39.7	0.303	53.2	0.397	83.9
2	18	0.403	74.3	0.458	95.4	0.584	156.6
3	18	0.418	97.3	0.473	119.1	0.599	182.1
4	18	0.457	121.8	0.512	145.6	0.638	213.2
5	18	0.500	146.8	0.555	172.7	0.681	245.3
6	18	0.576	189.2	0.631	218.8	0.757	300.4
7	18	0.576	210.5	0.631	240.1	0.757	321.7
8	18	0.622	236.6	0.677	268.5	0.803	355.5
9	18	0.668	263.3	0.723	297.4	0.891	423.9
10	18	0.724	291.3	0.779	328.2	0.947	463.5
11	18	0.724	312.4	0.779	349.3	0.947	484.6
12	18	0.746	336.1	0.801	374.0	0.969	512.7
13	18	0.785	361.4	0.840	401.2	1.008	546.0
14	18	0.785	382.7	0.840	422.5	1.008	567.3
15	18	0.870	442.5	0.925	486.5	1.093	644.6
16	18	0.870	463.9	0.925	507.9	1.093	666.0
17	18	0.914	491.8	0.969	538.0	1.137	703.0
18	18	0.914	512.9	0.969	559.1	1.137	724.1
19	18	0.914	533.9	0.969	580.1	1.137	745.1
20	18	0.960	562.4	1.015	610.8	1.183	783.1
21	18	0.960	583.5	1.015	631.9	1.183	804.2
22	18	1.006	612.6	1.061	663.3	1.229	842.8

Table 8-30—Dimensions and weights; twisted-pair signal cable 300 V; type T/N cables, shielded pairs (*Continued*)

		Unarmored		Armored		Armored and sheathed	
		Approximate		Approximate		Approximate	
Number of pairs	AWG size	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)	Nom. Dia. (in)	Weight (lb/1000 ft)
1	16	0.268	48.7	0.323	63.2	0.417	95.7
2	16	0.436	57.5	0.491	80.2	0.617	145.3
3	16	0.461	123.7	0.516	147.7	0.642	215.8
4	16	0.505	155.2	0.560	181.3	0.686	254.5
5	16	0.586	205.3	0.640	235.4	0.767	318.8
6	16	0.636	239.5	0.691	272.0	0.859	393.5
7	16	0.636	267.7	0.691	300.2	0.859	421.7
8	16	0.688	299.7	0.743	344.8	0.911	474.4
9	16	0.740	337.1	0.795	374.7	0.963	512.5
10	16	0.804	372.8	0.859	413.6	1.027	561.4
11	16	0.804	401.1	0.859	441.9	1.027	589.7
12	16	0.866	465.5	0.921	509.3	1.089	666.8
13	16	0.915	501.4	0.970	547.6	1.138	712.8
14	16	0.915	529.7	0.970	575.9	1.138	741.1
15	16	0.964	565.6	1.019	616.9	1.187	789.8
16	16	0.964	594.2	1.019	645.5	1.187	818.5
17	16	1.014	630.4	1.069	681.5	1.237	862.2
18	16	1.014	659.2	1.069	710.3	1.237	891.0
19	16	1.014	687.4	1.069	738.5	1.237	919.2
20	16	1.066	723.9	1.121	777.5	1.289	966.4
21	16	1.066	752.1	1.121	805.7	1.289	994.6
22	16	1.118	788.7	1.173	844.9	1.341	1041.9

Table 8-31—Color code, control, and signal cable

Conductor number	Base color	Tracer color	Tracer color	Conductor number	Base color	Tracer color	Tracer color
1	Black			45	White	Black	Blue
2	White			46	Red	White	Blue
3	Red			47	Green	Orange	Red
4	Green			48	Orange	Red	Blue
5	Orange			49	Blue	Red	Orange
6	Blue			50	Black	Orange	Red
7	White	Black		51	White	Black	Orange
8	Red	Black		52	Red	Orange	Black
9	Green	Black		53	Green	Red	Blue
10	Orange	Black		54	Orange	Black	Blue
11	Blue	Black		55	Blue	Black	Orange
12	Black	White		56	Black	Orange	Green
13	Red	White		57	White	Orange	Green
14	Green	White		58	Red	Orange	Green
15	Blue	White		59	Green	Black	Blue
16	Black	Red		60	Orange	Green	Blue
17	White	Red		61	Blue	Green	Orange
18	Orange	Red		62	Black	Red	Blue
19	Blue	Red		63	White	Orange	Blue
20	Red	Green		64	Red	Black	Blue
21	Orange	Green		65	Green	Orange	Blue
22	Black	White	Red	66	Orange	White	Red
23	White	Black	Red	67	Blue	White	Red
24	Red	Black	White	68	Black	Green	Blue
25	Green	Black	White	69	White	Green	Blue
26	Orange	Black	White	70	Red	Green	Blue
27	Blue	Black	White	71	Green	White	Red
28	Black	Red	Green	72	Orange	Red	Black
29	White	Red	Green	73	Blue	Red	Black
30	Red	Black	Green	74	Black	Orange	Blue
31	Green	Black	Orange	75	Red	Orange	Blue
32	Orange	Black	Green	76	Green	Red	Black
33	Blue	White	Orange	77	Orange	White	Green
34	Black	White	Orange	78	Blue	White	Green
35	White	Red	Orange	79	Red	White	Orange
36	Orange	White	Blue	80	Green	White	Orange
37	White	Red	Blue	81	Blue	Black	Green
38	Black	White	Green	82	Orange	White	
39	White	Black	Green	83	Green	Red	
40	Red	White	Green	84	Black	Green	
41	Green	White	Blue	85	White	Green	
42	Orange	Red	Green	86	Blue	Green	
43	Blue	Red	Green	87	Black	Orange	
44	Black	White	Blue	88	White	Orange	

Table 8-31—Color code, control, and signal cable (*Continued*)

Conductor number	Base color	Tracer color	Tracer color
89	Red	Orange	
90	Green	Orange	
91	Blue	Orange	
92	Black	Blue	
93	White	Blue	
94	Red	Blue	
95	Green	Blue	
96	Orange	Blue	
97	Yellow		
98	Yellow	Black	
99	Yellow	White	
100	Yellow	Red	
101	Yellow	Green	
102	Yellow	Orange	
103	Yellow	Blue	
104	Black	Yellow	
105	White	Yellow	
106	Red	Yellow	
107	Green	Yellow	
108	Orange	Yellow	
109	Blue	Yellow	
110	Black	Yellow	Red
111	White	Yellow	Red
112	Green	Yellow	Red
113	Orange	Yellow	Red
114	Blue	Yellow	Red
115	Black	Yellow	White
116	Red	Yellow	White
117	Green	Yellow	White
118	Orange	Yellow	White
119	Blue	Yellow	White
120	Black	Yellow	Green
121	White	Yellow	Green
122	Red	Yellow	Green
123	Orange	Yellow	Green
124	Blue	Yellow	Green
125	Black	Yellow	Blue
126	White	Yellow	Blue
127	Red	Yellow	Blue

Table 8-32—Color code for twisted-pair cables

Pair number	First conductor	Second conductor base color	Tracer color	Tracer color	Pair number	First conductor	Second conductor base color	Tracer color	Tracer color
1	White	Black			46	White	Red	White	Blue
2	White	White[a]			47	White	Green	Orange	Red
3	White	Red			48	White	Orange	Red	Blue
4	White	Green			49	White	Blue	Red	Orange
5	White	Orange			50	White	Black	Orange	Red
6	White	Blue			51	White	White	Black	Orange
7	White	White	Black		52	White	Red	Orange	Black
8	White	Red	Black		53	White	Green	Red	Blue
9	White	Green	Black		54	White	Orange	Black	Blue
10	White	Orange	Black		55	White	Blue	Black	Orange
11	White	Blue	Black		56	White	Black	Orange	Green
12	White	Black	White		57	White	White	Orange	Green
13	White	Red	White		58	White	Red	Orange	Green
14	White	Green	White		59	White	Green	Black	Blue
15	White	Blue	White		60	White	Orange	Green	Blue
16	White	Black	Red						
17	White	White	Red						
18	White	Orange	Red						
19	White	Blue	Red						
20	White	Red	Green						
21	White	Orange	Green						
22	White	Black	White	Red					
23	White	White	Black	Red					
24	White	Red	Black	White					
25	White	Green	Black	White					
26	White	Orange	Black	White					
27	White	Blue	Black	White					
28	White	Black	Red	Green					
29	White	White	Red	Green					
30	White	Red	Black	Green					
31	White	Green	Black	Orange					
32	White	Orange	Black	Green					
33	White	Blue	White	Orange					
34	White	Black	White	Orange					
35	White	White	Red	Orange					
36	White	Orange	White	Blue					
37	White	White	Red	Blue					
38	White	Black	White	Green					
39	White	White	Black	Green					
40	White	Red	White	Green					
41	White	Green	White	Blue					
42	White	Orange	Red	Green					
43	White	Blue	Red	Green					
44	White	Black	White	Blue					
45	White	White	Black	Blue					

[a]with black dashmark.

Table 8-33—Cable designations

Cable type		Group shielding		Insulation type		Jacket and/or sheath type		Armor	
S	Single-conductor distribution	(None)	Unshielded	E	Ethylene Propylene Rubber	T	Thermoplastic polyvinyl chloride	(None)	Unarmored
				EV[a]	VW-1 rated E				
D	Two-conductor distribution	(OS)	Overall shield	X	Cross-linked Polyethylene	CP	Thermosetting chlorosulfonated polyethylene (hypalon)	A	Aluminum
				XV[a]	VW-1 rated X				
T	Three-conductor distribution	(IS)	Individually shielded	T	Polyvinyl Chloride	N	Thermosetting polychloroprene (neoprene)	B	Bronze
				TV[a]	VW-1 rated T			T	Tin-coated copper
				T/N	Polyvinyl Chloride/ Nylon				
F	Four-conductor distribution	(IS-OS)	Individually shielded and overall shield	T/NV[a]	VW-1 rated T/N	L	Cross-linked polyolefin (low-smoke)	S[b]	Armor with sheath
Q	Five-conductor distribution	(OBS)	Overall tinned copper braid shield	S	Silicone Rubber	TPO	Thermoplastic polyolefin (low-smoke)		
				SV[a]	VW-1 rated S				
C	Control	(IS-OBS)	Individually shielded and overall tinned copper braid shield	P	Cross-linked polyolefin				
TP	Twisted pair			LSX	Low-smoke cross-linked polyolefin				
TT	Twisted triad			LSE	Low-smoke ethylene propylene rubber				

[a]For insulation types E, X, T. T/N, and S where the VW-1 requirement is the option, the letter "V" is added after the insulation type to indicate compliance with this optional requirement.
[b]Add the type of armor, A, B, or T, before the S.

9. Cable application

9.1 General

The cable constructions listed in Clause 8 are specifically designed for installation and use in a marine environment for the services defined in this clause. A variety of constructions are detailed, permitting a selection of conductor insulation, jacket types, and ampacities for the general usage distribution type cables. Cable constructions intended for other specific applications and different voltages are also included. The application of each respective type is defined below.

These cables are designed particularly to meet the recognized special environmental conditions, installation methods, and reliability requirements of marine service addressed in this standard. The design and characteristics of any cables used other than those defined in Clause 8 should be carefully evaluated to ensure a total cable equivalency with respect to flame retardance, conductor material and temperature rise, insulation characteristics and life expectancy, jacket flexibility, mechanical strength, and compatibility with marine installation methods and adverse service conditions.

Each control, communication, or signal system cable 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.

The maximum continuous load carried by a cable should not exceed its continuous current rating. Cable should be selected to ensure that the maximum rated conductor temperature for normal operation of the insulation is not exceeded when connected to the terminals of the circuit protective device. 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.

9.2 Distribution cables (600 V)

These cables should be used for the distribution of power up to their voltage rating throughout the system, and may be used in lighting, communication, control, and electronic circuits as desired. (See 8.14.1–8.14.4, 8.14.8, 8.14.9, and 8.14.18.)

9.3 Distribution cables (medium voltage, 2000 V, 5000 V)

These cables should be used for the distribution of power up to their voltage rating. (See 8.14.5–8.14.7,and 8.14.17.)

9.4 Control cables (600 V)

These cables should be used for control, indicating, communication, electronic, and similar circuits where multiple parallel conductor cables are required. Conductor size selection should be made with particular attention to voltage drop considerations. (See 8.14.10–8.14.12, and 8.14.19)

9.5 Signal cables (300 V, 600 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 tape and drain (ground) wire or a tinned copper braid, or a combination of both to prevent electrostatic and/or electromagnetic interference. (See 8.14.13–8.14.16, 8.14.20–8.14.23).

9.6 Special service requirements

Cables, cords, and wires required for applications not otherwise defined should be in accordance with the following subclauses.

9.6.1 Portable cords, jacketed, two-, three-, or four-conductor

These cords 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 UL 62-1991, types SJ, SJE, SJO, SJEO, SJT, SJTO, or SJTOO and, for hard service, types S, SO, or ST. Portable cords and cables may also be used, as specified by MIL-C-24643. Ampacities of cords and cables should be as defined by ANSI/NFPA 70-1996 or MIL-HDBK-299 as applicable.

9.6.2 Coaxial cables

These cables should be selected in accordance with MIL-C-17. The fire propagation resistant constructions in accordance with MIL-C-17/180-200 should be used wherever possible.

9.6.3 Switchboard wiring

See 7.2 for recommendations concerning switchboard wiring.

9.6.4 Wires

Component insulated wiring should be selected from a recognized commercial standard or military specification MIL-W-16878 or MIL-W-22759, with particular attention to the effects of vibration, moisture, ambient temperature, and other adverse conditions such as contaminants and oils that may be present.

9.6.5 Special applications

Flexible cables used for special applications such as elevators and cranes should meet an appropriate recognized commercial standard (e.g. ANSI/UL 1581-1991), Military Specification (e.g., MIL-C-24643), NEMA WC 7-1988, or NEMA WC 8-1988. Flame-retardant versions of these cables should be used wherever possible.

9.7 AC applications

In general, multiple conductor cable should be used for all ac lighting and power circuits. The conductors of all phases of any circuit should be contained in a single cable to neutralize induction except as noted below.

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

Where the use of multiple conductor cable will involve 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.

9.8 Ampacities

The current-carrying capacities (ampacities) of the various cable types are tabulated in Table 9-1.

Current-carrying capacities should be adjusted as noted to suit the ambient temperature in which the cable is installed if it differs from 45 °C (113 °F). Cable ampacities in Table 9-1 are for single banked installations. Double banked cables should be derated in accordance with Note 6 of Table 9-1.

Conductors should be sized to limit conductor operating temperatures at the termination device to those designated for the termination devices involved. For listed devices, unless marked with higher temperature limits, the terminals of devices rated 100 A or less typically are limited to operating temperatures of 60 °C (140 °F), and devices rated in excess of 100 A typically are limited to 75 °C (167 °F). In selecting circuit conductors, the designer shall assure that the actual conductor temperature does not exceed the temperature rating of the terminal device. The derating required for motor circuits and continuous loads on devices such as circuit breakers, which limits the actual current allowed in circuit wiring, can be considered when determining conductor operating temperature. Other factors such as ambient temperature within enclosures and the single conductor configuration of most terminations also can be taken into account when determining the actual conductor temperatures attainable.

Other segments of the cable run where different thermal conditions exist from those at the termination point will require separating derating considerations. The lowest ampacity calculated for any 3 m (10 ft) section in the cable run will determine the cable size.

9.9 Ambient temperatures

The use of the various conductor insulation types should be restricted to the following maximum ambient temperatures in shipboard spaces (see 1.5.1):

— T 50 °C (122 °F)
— T/N 50 °C (122° F)
— E 60 °C (140 °F)
— X 60 °C (140 °F)
— LSE 60 °C (140 °F)
— LSX 60 °C (140 °F)
— S 70 °C (158 °F)
— P 70 °C (158 °F)

9.10 Armor

Cables may be used without armor unless specifically recommended in this standard (e.g., hazardous locations and propulsion systems). On armored cable, a sheath may be added over the armor for corrosion protection when cables are installed on decks, through cargo holds, in pump rooms, keel ducts, and similar wet or corrosive spaces.

Table 9-1—Distribution, control, and signal cables—single banked, maximum current-carrying capacity (types T, T/N, E, X, S, LSE, LSX and P @ 45 °C ambient)

			Single Conductor Cable			Two-Conductor			Three-Conductor Cable		
MCM/ AWG	mm^2	Circular mil	T 75°C	LSE LSX T/N E,X 90°C	S,P 100°C	T 75°C	LSE LSX T/N E,X 90°C	S,P 100°C	T 75°C	LSE LSX T/N E,X 90°C	S,P 100°C
20	0.6	1022	9	11	12	8	9	10	6	8	9
18	1.0	1624	13	15	16	11	13	14	9	11	12
16	1.2	2583	18	21	23	15	18	19	13	15	16
14	2.1	4110	28	34	37	24	29	31	20	24	25
12	3.3	6530	35	43	45	31	36	40	24	29	31
10	5.3	10 400	45	54	58	38	46	49	32	38	41
8	8.4	16 500	56	68	72	49	60	64	41	48	52
7	10.6	20 800	65	77	84	59	72	78	48	59	63
6	13.3	26 300	73	88	96	66	79	85	54	65	70
5	16.8	33 100	84	100	109	78	92	101	64	75	82
4	21.1	41 700	97	118	128	84	101	110	70	83	92
3	26.7	52 600	112	134	146	102	121	132	83	99	108
2	33.6	66 400	129	156	169	115	137	149	93	111	122
1	42.4	83 700	150	180	194	134	161	174	110	131	143
1/0	53.5	106 000	174	207	227	153	183	199	126	150	164
2/0	67.4	133 000	202	240	262	187	233	242	145	173	188
3/0	85.0	168 000	231	278	300	205	245	265	168	201	218
4/0	107.2	212 000	271	324	351	237	284	307	194	232	252
250 MCM	127	250 000	300	359	389	264	316	344	217	259	282
262 MCM	133.1	262 600		378	407		333	358		273	294
300 MCM	152	300 000	345	412	449	296	354	385	242	290	316
313 MCM	158.7	313 100		423	455		363	391		298	321
350 MCM	177	350 000	372	446	485	324	387	421	265	317	344
373 MCM	189.4	373 700		474	516		406	442		332	361
400 MCM	203	400 000	410	489	533	351	419	455	286	342	371
444 MCM	225.2	444 400		546	588		468	504		382	411
500 MCM	253	500 000	469	560	609	401	479	520	329	393	428
535 MCM	271.3	535 000	485	615	662	415	526	566	340	432	465
600 MCM	304	600 000	521	623	678	450	539	585	368	440	478
646 MCM	327.6	646 000		671	731		581	632		474	516
750 MCM	380	750 000	605	723	786	503	602	656	413	494	537
777 MCM	394.2	777 000		755	822		629	684		516	562
1000 MCM	507	1 000 000	723	867	939						
1111 MCM	563.1	1 111 000		942	1025		784	854		644	701
1250 MCM	633	1 250 000	824	990	1072						
1500 MCM	706	1 500 000	917	1100	1195						
2000 MCM	1013	2 000 000	1076	1292	1400						

Table 9-1—Distribution, control, and signal cables—single banked, maximum current-carrying capacity (types T, T/N, E, X, S, LSE, LSX and P @ 45 °C ambient) (*Continued*)

Ampacity adjustment factors for more than 3 conductors in a cable with no load diversity:

Number of conductors	Percent of values in Table 9-1 for three-conductor cable as adjusted for ambient temperature, if necessary
4 through 6	80
7 through 9	70
10 through 20	50
21 through 30	45
31 through 40	40
41 through 60	35

NOTE 1—Current ratings are for ac or dc.
NOTE 2—For service voltage in the 601 V to 5000 V range, Type T, T/N, LSE, and LSX should not be used.
NOTE 3—Current-carrying capacity 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 listed in Table 9-1.
NOTE 4—The above values are based on an ambient temperature of 45 °C and maximum conductor temperature not exceeding 75 °C for type T insulated cables, 90 °C for type T/N, X, E, LSE, and LSX insulated cables, and 100 °C for type S and P insulated cables.
NOTE 5—If ambient temperatures differ from 45 °C, the values shown above should be multiplied by the following factors:

Ambient temperature	40 °C	50 °C	60 °C	70 °C
Type T insulated cables	1.08	0.91	—	—
Type T/N, X, E, LSE, LSX insulated cables	1.05	0.94	0.82	—
Type S and P insulated cables	1.04	0.95	0.85	0.74

NOTE 6—The above current-carrying capacities are for marine installations with cables arranged in a single bank per hanger and are 85% of the ICEA calculated values [see Note 7]. Double banking of distribution-type cables should be avoided. For those instances where cable must be double banked, the current-carrying capacities in the above table should be multiplied by 0.8.
NOTE 7—The ICEA calculated current capacities of these cables are based on cables installed in free air; that is at least one cable diameter spacing between adjacent cables. See IEEE Std 835-1994.
NOTE 8—For cables with maintained spacing of at least 1 cable diameter apart, the values above may be divided by 0.85.

10. Cable installation

10.1 Single-conductor ac cables

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, and no magnetic material permitted between cables of different phases of a circuit.
b) Single-conductor ac cables should not be located closer than 76 mm (3 in) from parallel magnetic material.
c) Single conductor ac cable should be supported on insulators. Armor, if used, should be grounded only at approximately the midpoint of the cable run.
d) Where single-conductor ac cables penetrate the bulkhead, conductors of each phase of the same circuit should pass through a common nonferrous bulkhead plate to prevent heating of the bulkhead.
e) Single-conductor cables in groups should be arranged to minimize their inductive effect. This may be accomplished by the transposition of cables in groups of three (one each phase) to give the effect of triplexed cable. 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).

10.2 Cable continuity and grounding

All cable should be continuous between terminations, however, splicing is permitted under certain conditions (see 10.11). For cable provided with armor, 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.

10.3 Cable locations

Cable installation should avoid spaces where excessive heat and gases may be encountered such as galleys, boiler rooms and pump rooms, and spaces where cables may be exposed to damage such as cargo spaces and 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 might include submerged cargo pumps and associated control devices, cargo monitoring instrumentation, and underwater navigation systems. For cables associated with hazardous locations, see Clause 33.

Unless unavoidable, cables should not be located behind or embedded in structural heat 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.

Cables should not be located in bilges.

10.4 Cable protection

Cables should be adequately protected where exposed to mechanical damage. Cables should be secured against chafing or displacement due to vibration. Cables in bunkers, and where particularly liable to damage, such as locations in way of cargo ports, hatches, tank tops, and where passing through decks, should be protected by removable metal coverings, angle irons, or other equivalent means.

Where cables pass through insulation, they should be protected by a continuous pipe. For wiring entering refrigerated compartments, the pipe should be of heat-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 pipe.

Where cables are installed in pipes, 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 pipe) shall not be greater than 0.41, except for two cables, where the space factor shall not exceed 0.31. Pipes shall be so arranged or designed to prevent the accumulation of internal condensation.

10.5 Cable support and retention

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. Distribution cables grouped in a single hanger should be limited to single banking, except under the limitations in Table 9-1, Note 6 or 8. 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. Metallic band strapping used for cable support should be secured by metal buckles or other suitable methods. Metallic band strapping used for cable support should be steel and corrosion treated if not a corrosion-resistant material. The support for all cables should be such as to 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 that the cables remain tight without damage to the cable.

Metal supports should be designed to secure cables without damage to armor or insulation and should be so arranged that the cable will be supported for a length of at least 13 mm (0.5 in).

Cable retention devices should be installed not less than every 610 mm (24 in) on vertical runs, and not less than every 2.5 m (8 ft) on horizontal runs. At turns of horizontal runs, cable-retention devices should be spaced not more than 610 mm (24 in) apart. Nylon or plastic retaining devices may be used in horizontal runs where cables will not fall if the retention devices fail. When nylon or plastic cable retaining devices are employed on exterior cable runs, they should be of a type resistant to ultraviolet light (sunlight).

10.6 Cables—radius of bends

Armored cables should not be bent to a radius of less than eight times the cable’s diameter. Unarmored cables may not be bent to a radius of less than six times the cable’s diameter.

10.7 Cables through bulkheads, decks, beams, etc.

Where cables pass through watertight decks or bulkheads, watertight penetrators or watertight stuffing tubes that are capable of taking packing should be employed.

Multicable penetrators (see 3.2.2) may be used for the passage of cables through watertight bulkheads and decks.

Where cables pass through nonwatertight 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 (0.25 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 bulkhead is not impaired. Nonmetallic stuffing tubes should not be used in fire boundaries.

10.8 Cable pulling-in force

Care should be taken to prevent damage to insulation or distortion of cable during installation.

Straight pulling forces should not exceed 0.008 times the tensile strength of the copper cross-sectional area when pulling on the conductors utilizing pulling eyes and bolts. When pulling with a basket-weave grip, maximum pulling tension (per grip) should not exceed 460 kg (1000 lb), or the value calculated above, whichever is greater.

The sidewall pressure should not exceed 450 kg/m (300 lb/ft) of the inside radius of the bend.

Cables should not be pulled in freezing conditions. If it is necessary to pull in these conditions, cables should be stored at a temperature above 10 ºC (50 ºF) for 24 h prior to installation, if the cable has been previously stored in an area under 0 ºC (32 ºF).

Additional consideration should be given when installing low-smoke cables due to their possible lower tear strength and coefficient of friction.

For more guidance concerning this subject, refer to IEEE Std 576-1989.

10.9 Cable ratproofing

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

10.10 Holes for cables

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.

10.11 Cable splicing (600 V or less)

10.11.1 Conditions

A cable for 600 V or less 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 cables, cables for repeated flexing service, and cables in hazardous locations (see Clause 33) should not be spliced.

10.11.2 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. Splicing should be performed as follows:

a) Conductors should be joined using a compression-type butt connector that meets ANSI/UL 486-1991. A one-cycle compression tool and proper dies should be used. A long-barrel butt connector with wire stops should be used for wire sizes 10 AWG or larger.
   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.
b) 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.
c) For shielded cables, replacement shielding should be provided. 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 (0.5 in) overlap between replacement shielding material and the permanent shielding.
d) 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.
e) 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.

10.12 Propulsion cables

The effects of electromagnetic interference, impedance, system harmonics, short-circuit bracing, and, for voltages above 3.3 kV, corona, should be taken into considration 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 3.3 kV or greater should be terminated with a stress cone or other stress-terminating device, where necessary. A propulsion cable should not be spliced. Single-conductor propulsion cables should be adequately secured to prevent displacement by short-circuit conditions.

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.

11. Distribution

11.1 General

In general, the method of electric power distribution is as follows:

From the distribution section of the ship service or emergency generator switchboard to

a) A feeder circuit for an individual controller and motor, or an appliance.
b) A motor control center or power distribution panel, then to a branch circuit for an individual controller and motor, or an appliance.
c) A lighting load center or lighting distribution panel, then to a lighting branch circuit.
d) A power load center or distribution panel, then to a branch circuit supplying other panels, and individual loads, or both.
e) Another switchboard, then by any individual or combination of the above, as required.
f) A power transformer, and then by any individual or combinations of the above, as required.
g) An automatic bus transfer switch (ABT), and then to vital equipment or distribution panels supplied from two sources of power.

Except in the case of small vessels and small electric plants, it is recommended that the lighting distribution system, the power distribution system, the interior communications power distribution system, and the electronics power distribution system be maintained as separate distribution systems fed from the ship service generator and emergency generator switchboards (see Figure 7-1 through Figure 7-4).

11.2 Location and type of equipment

All distribution panels should be located so that they are readily accessible at all times to qualified personnel. They should not be located in bunkers, cargo holds, and similar spaces. Distribution panels located on weather decks or other spaces exposed to the weather or other severe moisture conditions should be waterproof; elsewhere, they may be dripproof. Power load centers of the switchboard type, unless installed in machinery spaces or in compartments assigned exclusively to electric equipment and accessible only to authorized personnel, should be completely enclosed or otherwise protected against accidental contact and unauthorized operation.

11.3 Circuit elements

All normal current-carrying elements of electrical power supply circuits should be specifically intended for that purpose only. Ship structure should not be used as a normal current-carrying conductor for the electrical power supply distribution systems.

11.4 Shore power feeder

If a shore power connection is provided, a connection box (see 13.7) should be installed in a location convenient for the reception of the cables from the shore. Cables from the connection box to the ship service switchboard should be permanently installed. A phase sequence or phase rotation device should be provided at the shore power connection box. Shore power circuit breaker(s) and power available indicating light(s) should be included. One of the switchboard voltmeters should have the capability to indicate the shore power voltage.

11.5 Demand factor and voltage drop for lighting, communications, and electronics circuits

Conductors for lighting, communications, and electronics circuits should be sized for the total connected load, including not less than 50 W for each receptacle (100 W per duplex). The connected load should include 50% of the rating of spare circuits on switchboards or load centers and the average active circuit load for the spare circuits on distribution panels. Loads for circuits supplying electric discharge type lamps should be computed on the basis of ballast input current. Feeders for circuits including cargo flood lighting receptacles should be calculated on the basis of expected load, but not less than 300 W per receptacle.

Power for normal lighting should be distributed from the ship service switchboard. Power for emergency lighting, interior communications, and electronics systems feeders should be distributed from the lighting buses of the emergency switchboard. Vital interior communications and electronics feeders should be fed via an ABT switch from the ship service and emergency switchboards. For a remote distribution switchboard, the bus feeder from the ship service switchboard may supply both lighting and power loads. For distribution circuits, the combined maximum voltage drop from the ship service switchboard to any point in the system should not exceed 6%.

11.6 Demand factor and voltage drop for searchlight circuits

Conductors for searchlight circuits should be sized for the rated current of the lamp or ballast, if provided. For arc searchlights, where a resistance is permanently connected in the circuit, the voltage drop need not be limited except that where motor control is employed, the drop should be limited to a value that will permit satisfactory operation of the motor and lamp at all times.

11.7 Demand factor and voltage drop for air heater circuits

Conductors for air heater circuits should be sized for the rated current of the air heater. The voltage drop should not exceed 6% from the switchboard to the most remote air heater. The total current rating of heaters connected to the same circuit should not exceed 15 A.

11.8 Demand factor and voltage drop for galley circuits

Conductors for galley equipment should be sized on the basis of 100% demand factor for the first 50 kW of connected load, and 65% of the connected load in excess of 50 kW. Based on rated load as calculated above, the voltage drop should not exceed 6% from the switchboard to the most remote piece of equipment.

11.9 Demand factor and voltage drop for individual and multiple motor circuits

Except as recommended below and in 11.20, conductors supplying an individual motor should have a continuous current-carrying capacity equal to 125% of the motor nameplate rating. Conductors supplying more than one motor should have a continuous current-carrying capacity equal to 125% of the largest motor plus the sum of the nameplate ratings of all other motors supplied, including 50% of the rating of spare switches on the distribution unit.

Conductors less than No. 14 AWG (2.1 mm^2) should not be used in any branch circuit. The voltage drop from the ship service switchboard to the most remote motor should not exceed 6%.

Conductors supplying a group of three or more workshop tool motors should have a continuous current-carrying capacity equal to 125% of the nameplate rating of the largest motor plus 50% of the sum of the nameplate ratings of all other motors of this group.

Conductors supplying two or more motors driving deck cargo winches or cargo elevators should have a continuous current-carrying capacity equal to 125% of the largest motor plus 50% of the sum of the nameplate ratings of all other motors.

Conductors supplying two or more motors driving cargo cranes should have a continuous current-carrying capacity equal to 125% of the largest motor plus 50% of the sum of the nameplate rating of all other motors. Where the conductor supplies two or more motors associated with a single crane, the current-carrying capacity should be equal to 125% of the largest motor plus 45% of the sum of the nameplate rating of the other motors.

11.10 Demand factor and voltage drop for generator and bus-tie circuits

The conductors from each generator to the switchboard should be sized for not less than 115% of the generator rating for continuous rated machines and 115% above the overload rating for machines with specified overload ratings.

Conductors between separate ship service switchboards having connected generators (ship service generator switchboards) should be sized on the basis of 75% of the switchboard having the greatest generating capacity. The drop in voltage from each generator to its switchboard should not exceed 1%, and the drop in voltage between switchboards should not exceed 2%.

Conductors between ships service switchboards and the emergency switchboard should be sized on the basis of the maximum operating load of the emergency switchboard or 125% of the emergency generator capacity, whichever is larger.

Conductors from storage batteries to the point of distribution should be sized for the maximum charge or discharge rate, whichever is greater. The drop in voltage from the storage batteries to the point of distribution should not exceed 1%. Battery conductors for heavy duty applications, such as diesel starting, should be sized for 125% of maximum rated battery discharge.

Conductors from the ship service switchboard to the shore power connection box should be sized for the maximum operational load requirement when on shore power. The drop in voltage from the connection box to the switchboard should not exceed 2%.

11.11 Two-wire device connections

In grounded systems, the shell of all lampholders should be connected to the grounded conductor, and all single-pole switches should be in the ungrounded conductor. In two-wire ungrounded systems, the color of conductors connected to single-pole switches should be uniform throughout the system.

11.12 Feeder and branch circuit continuity

Except as permitted below and in 11.14, each feeder and branch circuit supplying a single energy consuming appliance should be continuous and uniform in size throughout its length. In instances of feeders of large size and exceptional length, feeder boxes or splices may be used for ease of installation. When authorized by the appropriate regulatory agency, splices or feeder boxes may be permitted to repair damaged cable (see 10.11).

11.13 Feeder connections

Where a feeder supplies more than one distribution panel, it may be continuous from the switchboard to the farthest panel or it may be interrupted at any intermediate panel. If the bus bars of any distribution panel carry “through” load, the size of the buses should be suitable for the total current. The size of feeder conductors will ordinarily be uniform for the total length but may be reduced at any intermediate distribution panel provided that the smallest section of the feeder is protected by the overload device at the distribution switchboard.

11.14 Distribution for lights controlled from the navigating bridge

A separate feeder should be provided for all lights supplied from the emergency switchboard and located in or controlled from the navigating bridge. On passenger vessels, two feeders may be provided: one from the temporary emergency (storage battery) bus and one from the final emergency bus. For the feeder supplying navigation lights (from the temporary emergency bus, if provided) the rating of the cable and of the fuse or circuit breaker on the emergency switchboard should be not less than 20 A or not less than 125% of connected load including allowance for spare circuits, whichever is greater.

One or more distribution panels may be served by the feeders described above. Through feed, without switch or overcurrent protection, should be provided for the navigation light panel. For all other lights, including any navigation or signal lights not supplied by the navigation light panel, branch circuits, each with a fused-switch or circuit breaker, should be provided.

Floodlights for lifeboat launching should be supplied by branch circuits from the navigating bridge emergency panel, or may be supplied directly from the emergency system through local lighting contactors controlled from the navigating bridge.

One four-conductor, or two two-conductor branch circuit cables should be provided from the navigation light indicator panel for each two-lamp navigation light fixture. Each four-conductor branch circuit cable from the indicator panel should terminate in a waterproof two-circuit, two-gang receptacle located adjacent to the running light. If two two-conductor branch circuit cables are provided, each cable should terminate in a single-gang waterproof receptacle. The receptacles should be of the grounding type. Two three-conductor portable cables should be provided for each two-lamp fixture, and each should be fitted with a three-pole plug.

11.15 Distribution for machinery space lighting

Separate lighting feeders should be installed for each main and auxiliary machinery space. These feeders should not supply fixtures outside the machinery spaces, other than storerooms opening into these spaces. The number and size of the feeders and distribution panels should be determined by the number of fixtures and the extent of the spaces covered. It is recommended that alternate groups of fixtures within these spaces be so arranged that the failure of any one circuit will not leave these spaces in darkness.

11.16 Distribution for cargo space lighting

Separate feeders should be installed for all cargo lighting. The distribution panels should be located outside the cargo spaces. Receptacles in cargo spaces should not be connected to feeders that are used for lighting or for other circuits required for the underway operation of the vessel.

11.17 Distribution for lighting accommodation spaces

For vessels provided with structural fire boundary bulkheads forming fire zones, it is recommended that at least two separate feeders be provided exclusively for each vertical zone between two fire boundary bulkheads. These feeders may serve all decks within the zone. One of these may be the emergency lighting feeder. The supply of lights in all passageways and public spaces and in any berthing compartment accommodating more than 25 persons should be divided between two feeders so that if either fails, there will be sufficient light to prevent panic and to permit people to find their way to the open deck. The two feeders serving one compartment should be separated as widely as practicable to minimize the possibility of damage to both from a fire or other casualty.

Electric service to each stateroom should be supplied by at least two separate branch circuits connected to the general lighting system. The lighting should be so divided that, in the event of failure of one branch circuit, there will be sufficient light to permit use of the space.

11.18 Distribution for power equipment

In general, power feeders for cargo elevators, cargo cranes, and cargo winches that should be disconnected when the vessel is underway, should not be used to supply ventilation fans, heaters, drainage pump motors, or any apparatus required for the ship's operation.

Separate feeders from switchboards should be run for main and auxiliary machinery space loads, motors for cargo-handling gear, steering gear, navigation and electronics loads, searchlights, and for ventilation and air conditioning loads. Cargo ventilation fans, machinery space ventilation fans, and fans for ventilation of accommodations should not be supplied from the same feeder.

The steering gear motors should be supplied from two different circuits, and, where practical, from two different switchboards or switchboard bus sections. These circuits should be widely separated so as to minimize failure of both feeders due to collision, fire, or other casualty. Both feeders may be connected to the ship service switchboard or, where required by the regulatory agencies, one feeder may be connected to the ship service switchboard and one to the emergency switchboard. Each circuit should have a continuous current-carrying capacity of not less than 125% of the rating of the motor or motors simultaneously operated.

In order to prevent the spread of fire, arrangements should be made to permit stopping all ventilation fans, fuel oil pumps, and lube oil transfer pumps from a central point. For further details, see 18.9.

11.19 Distribution for heating and cooking equipment

Separate feeders and distribution panels should be provided for air heaters when they are used extensively. Separate feeders and distribution panels should be provided for galleys equipped with electric ranges, ovens, and other electric apparatus.

11.20 Branch circuits—general

The branch circuit conductors should not be less than No. 14 AWG (2.1 mm^2). Cable types and sizes (refer to Clauses 8 and 9) should be selected for compatibility with all local environmental conditions throughout the length and voltage drop limitations of this clause. Each branch circuit should be provided with overcurrent protection in accordance with 11.31 except as otherwise indicated. The maximum connected load should neither exceed the rated current-carrying capacity of the cable nor 80 % of the overcurrent protective device setting or rating.

11.21 Branch circuits for heating and cooking equipment

Generally, a separate branch circuit should be provided for each electric heater. An individual heater or a group of heaters may be supplied from a lighting or power distribution panel, depending on the required voltage.

For ranges, bake ovens, and similar galley units in which self-contained or locally mounted protective devices are provided for each individually controlled heating element, only one branch circuit need be provided for each assembled unit.

11.22 Branch circuits for motors

A separate branch circuit should be provided for each fixed motor having a full-load current rating of 6 A or more and the conductors should have a carrying capacity of not less than 125% of the motor full-load current rating. Any branch circuit conductor should not be less than No. 14 AWG (2.1 mm^2).

11.23 Branch circuits for fixed appliances

Fixed appliances may be supplied by branch circuits from galley, lighting, or power distribution panels according to availability. However, no lighting or receptacle outlets should be served by the same branch circuits serving fixed appliances. Indicating lights in or on any appliance may be considered as being protected by the branch circuit fuse or circuit breaker.

11.24 Branch circuits for receptacles

Receptacles installed on a 15 A branch circuit protective device, except 15 A circuits containing more than one receptacle, may use lower rated receptacles; 20 A circuits containing more than one receptacle may use 15 A rated receptacles. Circuits of 30 A or higher and containing more than one receptacle should use receptacles rated at no less than the circuit rating. Receptacles should not supply a total load of portable and stationary equipment in excess of 80% of the branch circuit protective device rating.

Receptacle outlets in passages and public spaces for vacuum cleaners, in galleys for motor driven scrubbers, in laundries for pressing irons, in shops for special portable motor-driven tools, or for any similar special application should be of the heavy-duty type and on separate branch circuits, with no other outlets connected. Receptacle outlets in machinery spaces should be on separate branch circuits supplied from lighting distribution panels. In auxiliary machinery compartments where there are not more than two receptacles, the receptacles may be connected to a lighting distribution circuit.

11.25 Motors larger than 750 W (1 hp)

In general, motors larger than 190 W (0.25 hp) should not be connected to lighting circuits.

11.26 Receptacles for portable equipment

Where portable motors that operate on other than the ships normal lighting voltage are used, the receptacles for their use should be permanently marked indicating the voltage. They should also be of a type that will not permit attaching equipment for which the voltage is unsuitable.

11.27 Lighting branch circuits—connected load

Lighting branch circuits should be single-phase circuits supplied from panelboards and provided with two-pole overcurrent protection devices rated at 15 A, 20 A, 25 A, or 30 A.

Three-phase lighting branch circuits may be used for special purposes such as clusters of floodlights and large multilamp lighting fixtures. Switches for such circuits should open all conductors of the circuit.

AC general-use snap switches should have a minimum rating equal to the load controlled. AC-DC general-use snap switches for use with tungsten filament lamp loads should have a minimum rating equal to the load controlled and the inrush current. Lighting fixtures for use on 25 A and 30 A circuits should be heavy-duty type rated not less than 750 W. The total single-phase branch circuit load should be balanced as far as practicable at the connection point to the three-phase system. Any imbalance should not exceed 15%.

11.28 System protection—general

Careful consideration must be given to short-circuit protection and to the selection of the various protective devices to ensure proper interrupting capacity and coordination regardless of their location in the vessel.

Protective devices should be provided on the switchboard for each electric generating unit and each connected circuit.

Feeder and branch circuits for lighting, heating, and ship service power distribution should have each ungrounded conductor protected by a circuit breaker or fuse of suitable interrupting capacity.

The selection, arrangement, and performance characteristics of the various overcurrent protective devices should be as recommended herein, and should provide continuity of service under fault conditions through the selective operation of the various protective devices, that is, the isolation of a fault with the least interruption of vital services. See 3.10.21 for the definition of vital services.

The overcurrent protective devices should also provide high-speed clearance of low-impedance faults for ac systems and low resistance faults for dc systems in order that fault currents of large magnitude will cause minimum damage to the system and equipment and minimize hazards. The overcurrent protective devices should also protect electric apparatus and circuits from damage under fault conditions through the coordination of the electrical and thermal characteristics of the circuit or apparatus and the tripping characteristics of the protective devices.

In order to achieve these basic objectives, each protective device should have an interrupting rating not less than the maximum short-circuit current available at the point at which the device is installed. Selective tripping should be provided between generator, bus tie, bus feeder, and feeder protective devices. In circuits supplying vital services, selective tripping should also be provided between feeder and branch circuit protective devices. A short-circuit on a circuit that is vital to the propulsion, control, or safety of the vessel should be cleared only by the protective device that is closest to the point of the short-circuit. A short-circuit on a circuit that is not vital to the propulsion, control, or safety of the vessel should not trip equipment that is vital.

Protective devices should be applied so that single-phase operation of any three-phase connected ac motor will be precluded. Protective devices should not be used beyond their interrupting capacity.

11.28.1 AC systems

The maximum available short-circuit current should be determined from the aggregate contribution of all generators that can be simultaneously operated in parallel and the maximum number of motors that will be in operation. The maximum short-circuit current is calculated assuming a three-phase fault on the load terminals of the protective device. If the system is grounded and the zero sequence impedance is lower than the positive sequence impedance, a line-to-ground fault should be calculated in place of the three-phase fault. The protective device selected should have withstand and interrupting capabilities, including peak current capability, that exceed these calculated. Circuit breakers rated on a symmetrical basis should be applied on the basis of the symmetrical rms fault current. The system power factor at point of application should be greater than the power factor used in establishing the circuit breaker symmetrical rating. If it is not, consideration needs to be given to the circuit breaker's capability to withstand the asymmetrical value. The asymmetrical rms values of current can be obtained by applying the K_1 and K_2 factors of Figure 11-1 to the symmetrical values. The X/R ratio of Figure 11-1 is determined from the inductive reactance (X) and the resistance (R) of the circuit under consideration.

The short-circuit currents should be determined on the following basis:

a) *Maximum asymmetrical rms current:* Generator contribution based on circuit impedance including direct-axis subtransient reactance of generators. Motor contribution based on four times the rated current of induction motors.
b) *Average asymmetrical rms current:* Generator contribution based on circuit impedances including direct-axis subtransient reactance of generators. Motor contribution based on 3.5 times the rated current of motors.
c) *Estimated short-circuit currents:* For a preliminary estimate of short-circuit currents, pending the availability of generator reactances, the following may be used for estimating the generator contribution:
   1) Maximum asymmetrical rms current: 10 times generator full-load current.
   2) Average asymmetrical rms current: 8.5 times generator full-load current.

   NOTE—These values for estimating generator contribution should not be used where unusually stringent transient voltage dip limitations have been specified for the generator.

d) *Minimum short-circuit current:* The minimum available short-circuit current should also be determined to ensure that selectivity and fault clearing will be obtained under these conditions. The minimum short-circuit current is based on the least number of generators in operation and no motor load for a phase-to-phase fault at the load end of the cable connected to the protective device on an ungrounded system.

11.28.2 DC systems

When calculating the maximum short-circuit current, it should be assumed that each generator that can be simultaneously operated in parallel will, if limited only by internal resistance, contribute 10 times its normal rated current and that all motors that may be in operation simultaneously will, limited by internal resistance, contribute six times their combined normal ratings.

11.28.3 Fault-current calculations and overcurrent protective devices

In addition to the calculation of available short-circuit currents for three-phase faults specified in 11.28.1, calculations should be made of available short-circuit currents for line-to-ground faults on a grounded system. The recommendations of 11.29 and 7.8 should also be considered in regard to the provision of overcurrent protective devices for each ungrounded conductor.

11.29 Overcurrent protection of conductors

Except as otherwise recommended in 7.8 and 18.3, overcurrent protection by fuses or circuit breakers should be provided for all ungrounded conductors. Fuses should not, and circuit breaker overcurrent trips need not, be provided for the neutral conductor of a three-wire grounded system, but provision should be made for feeder disconnect including the neutral.

The purpose of overcurrent protection for conductors is to open the electric circuit if the current reaches a value that will cause an excessive or dangerous temperature in the conductor or conductor insulation. A grounded conductor is protected from overcurrent if a protective device of a suitable rating or setting is in each ungrounded conductor of the same circuit. For ac systems over 600 V, fuses should not be used for overcurrent protection.

11.30 Overcurrent protection of fixture wires and cords

Each lighting branch circuit should be protected by an overcurrent device rated at 20 A or less. Each lighting branch circuit cable should have a continuous current rating equal to or greater than the overcurrent device setting. Fixtures connected to circuits of 15 A or less should have fixture wire or flexible cord of No. 18 AWG (0.82 mm^2)

or larger. Fixtures connected to 20 A circuits should have fixture wire or flexible cord of No. 14 AWG (2.1 mm^2) or larger.

11.31 Overcurrent protection—motor branch circuits

For motor branch circuits, overcurrent protection can be provided by fuses or circuit breakers. Refer to 17.1 and 18.3 for recommended overload protection of motors. For a circuit breaker protecting an ac motor branch circuit, the recommended rating (or setting, if adjustable) of the long time-delay trip element is from 115% to 125% of full-load motor current unless the inertia of the load, the characteristics of the motor, the tripping characteristic of the circuit breaker itself, or other factors necessitate a higher rating. The minimum rating should be 115% of full-load motor current. Refer to Table 11-1. Motors having a power rating exceeding 0.5 kW should be individually protected against overload. See17.1 and 18.3.

The protective devices should be designed to allow current to pass during the normal accelerating period of motors according to the conditions corresponding to normal use. When the time-current characteristics of the overload-protective device of a motor are not adequate for the starting period of the motor, the overload-protective device may be rendered inoperative during the accelerating period provided that the protection against short-circuit remains operative and that the suppression of the overload protection is only temporary.

For continuous duty motors, protective devices should have time-delay characteristics that ensure reliable thermal protection of the motors for overload conditions.

For intermittent duty motors, the current setting and the time-delay characteristics for protective devices should be chosen after considering the actual service conditions.

When fuses are used to protect polyphase motor circuits, means should be provided for protection against single-phasing.

The setting of instantaneous trips provided for short-circuit protection only and that are responsive to transient inrush should be the standard value nearest to, but not less than, 10 times full-load motor current.

In motor control centers, a motor branch circuit may be considered to be protected against short-circuit and overcurrent by an instantaneous trip circuit breaker set to trip at a value not exceeding 1300% of the motor full-load current, used in conjunction with the motor controller overcurrent relay, in lieu of circuit breakers with long time-delay trip and magnetic instantaneous trip elements.

For a circuit breaker protecting a dc motor branch circuit, the maximum rating (or setting, if adjustable) of the time-delay trip element should be the standard rating or setting equal to or (if not in exact agreement) next above 1.5 times the full-load rating of the motor served.

11.32 Overcurrent protection—ac motors more than 750 W (1 hp)

Continuous-duty motors rated more 750 W (1 hp) should have running overcurrent protection of approximately 115% of the full-load current rating of the motor. This value may be modified as permitted by 11.38. Calculated values for overcurrent protection calculated for common motor ratings are shown in Table 11-1.

11.33 Overcurrent protection—ac motors 750 W (1 hp) or less, manually started

Motors of 750 W (1 hp) or less that are manually started and that are in a location within sight of the operator may be considered as protected against overcurrent by the overcurrent device protecting the conductors of the branch circuit. This overcurrent device should not be larger than that recommended in Table 11-34. Any such motor that is in location out of sight of the operator should be protected as recommended in 11.34 for automatically started motors.

11.34 Overcurrent protection—ac motors 750 W (1 hp) or less, automatically started

Motors 750 W (1 hp) or less that are started automatically may be considered protected against overcurrent if provided with running overcurrent protection as recommended in 11.33 and11.35. They will also be considered protected if they are provided with a thermal protector integral with the motor that will prevent dangerous overheating by opening the motor circuit through contacts integral with the protector, or if part of an approved assembly that does not normally subject the motor to overloads, which is also equipped with other safety controls that protect the motor against damage due to stalled rotor current. Finally, motors may be considered protected against overcurrent if the characteristics of the motor are such that overheating due to failure to start cannot occur and the motor is protected as recommended in 11.33.

11.35 Protective device size selection—ac motors

Where the values recommended for motor-running overcurrent protection do not correspond to standard sizes or ratings of fuses, nonadjustable circuit breakers, thermal cutouts, thermal relays, heating elements of thermal-trip motor switches, or possible setting of adjustable circuit breakers adequate to carry the load, the next higher size, rating, or setting may be used, but should not be more than approximately 125% of the motor full-load current. If the protective device is not shunted out during the starting period as permitted by 11.36, it should have sufficient time-delay to permit the motor to accelerate.

11.36 Shunting overcurrent protection starting period—ac motors

Motor-running overcurrent protection relays may be shunted or cutout of the circuit during the starting period of a motor, provided the device by which the overcurrent protection is shunted or cutout is not left in the starting position. The motor may be considered as protected against overcurrent during the starting period if fuses or time-delay circuit breakers are so located in the circuit as to be operative during the starting period of the motor.

11.37 Location of overcurrent devices in circuit—ac motors

Motor-running overcurrent devices should be located only in ungrounded conductors. Protective devices (fuse or circuit breaker pole) should be in each ungrounded conductor for single-phase motors and in all three ungrounded conductors for three-phase motors. The protective device should not be in a grounded neutral. All ungrounded conductors should be opened simultaneously to prevent single-phasing.

11.38 Rating or setting of distribution circuit protection devices

Except as otherwise recommended for lighting branch circuits in 11.27, motor branch circuits in 11.31, and steering gear circuits in 18.3, the rating of fuses or of trip elements in long time-delay circuit breakers should not exceed the rated capacity of the conductors. If the standard ratings and settings of overcurrent devices do not correspond with the rating and setting allowed for conductors, the next higher standard rating and setting may be used, but should not exceed 150 % of the allowable current-carrying capacity of the conductor. Where an instantaneous or short time-delay circuit breaker trip is used for short-circuit protection in addition to a long time-delay trip for overload protection, or where it is provided for short-circuit protection only, it should be set below the value of the minimum available short-circuit current determined in accordance with 11.28.

An overcurrent-interrupting device must not be connected in parallel with another overcurrent-interrupting device.

11.39 Grounding electrical systems and equipment

11.39.1 System grounding—general

Low-voltage (600 V or less) distribution systems should be insulated (ungrounded) to the maximum extent possible to ensure continuity of service under all operating conditions. Ungrounded distribution systems should have all current-carrying conductors, including source of power and all connected loads, completely insulated from ground throughout the system. The ungrounded system should have provisions for continuous ground fault monitoring.

When a solidly grounded distribution system is used, the neutral conductor should be full-sized to preclude overheating due to harmonic distortion from non-linear loads. (See Clause 33 for restrictions in hazardous locations.)

Medium-voltage systems may be grounded through resistance or reactance. For further guidance on these systems, refer to the regulatory agencies and the classification societies.

The secondary winding of each instrument and control transformer should be grounded at the enclosure.

11.39.1.1 Grounding points

For each separately derived system or part of a system that is desired to be operated as a grounded system, a system ground connection should be provided. Separate grounded and ungrounded systems may be provided in a ship if the two parts are isolated by motor-generator sets or transformers with independent primary and secondary windings. For 115 V single-phase circuits feeding isolated convenience receptacles, the transformer secondary supplying the 115 V circuit may be solidly grounded and GFCI interrupters installed for the convenience receptacles.

The system grounding point should be selected on the following basis:

a) *Three-phase system:* At the neutral.
b) *Single-phase, three-wire system:* At the phase midpoint.
c) *Single-phase, two-wire system:* At either power conductor.

The grounding connection to the system or parts of a system should be made as close to the source of power as possible rather than at the load ends of the system. There should be only one point of connection to ground on any grounded system, regardless of the number of power sources operating in parallel in the system.

11.39.1.2 Grounding arrangements

Grounded low-voltage systems (600 Vac or less) should be solidly grounded. However, an external grounding impedance may be used where the maximum resulting fault current of a line-to-ground fault is sufficiently higher than a maximum three-phase fault to necessitate the use of circuit breakers with increased short-circuit interrupting capabilities, or would exceed the magnitude of current for which the generator windings are braced. If an impedance in the ground connection is required, a value of impedance should be selected that will result in the line-to-ground fault current being equal to or less than the three-phase fault current.

The connection to the hull should be made to a suitable structural frame or longitudinal girder. In the case of large-capacity systems, the connection should be made to both a frame and girder. Grounding devices should have an insulation class suitable for the line-to-line voltage rating of the system. The thermal capabilities of any external impedance should be coordinated with the characteristics of the overcurrent protective device for the power source to ensure that ground-fault currents will be interrupted before the thermal limit of the grounding device is exceeded.

A disconnect feature should be provided for each generator ground connection to permit checking the insulation resistance of the generator-to-ground, before the generator is connected to the bus.

11.39.1.3 Hull return

A vessel's hull must not carry current as a conductor, except as part of impressed current cathodic protection systems, or limited and locally grounded systems. Examples of limited or locally grounded systems are a battery system for engine starting that has a one-wire system and the ground lead connected to the engine, insulation level monitoring devices where the circulation current does not exceed 30 mA under the most unfavorable conditions, and welding systems using hull return.

11.39.1.4 Neutral grounding

Each propulsion, power, lighting, or distribution system having a neutral bus or conductor shall have the neutral grounded at a single point. The neutral of a dual-voltage system (i.e., three-phase four-wire ac, three-wire dc, or single-phase three-wire, ac) should be solidly grounded at or directly adjacent to the generator switchboard. Where the grounded system includes a power source, such as a transformer, the single-point ground connection should be made at or directly adjacent to the switchboard or distribution panel for the power source.

11.39.1.5 Generation and distribution system grounding

The neutral of each grounded generation and distribution system should be grounded at the generator switchboard, except the neutral of an emergency power generation system should be grounded with no direct ground connection at the emergency switchboard. The emergency switchboard neutral bus should be permanently connected to the neutral bus on the ship service switchboard and no switch, circuit breaker, or fuse should be in the neutral conductor of the bus-tie feeder connecting the emergency switchboard to the main switchboard.

The ground connection should be accessible for checking the insulation resistance of the generator to ground before the generator is connected to the bus.

Fuses should not, and circuit breakers need not be provided for the neutral of a circuit. The grounded conductor of a circuit should not be disconnected by a switch or circuit breaker unless the ungrounded conductors are simultaneously disconnected.

Medium-voltage transformer primary neutrals should not be grounded except when all generators are disconnected and power is being supplied from shore.

11.39.1.6 Tank vessel grounded distribution systems

Distribution systems on tank vessels of less than 1000 V, line-to-line, should not be grounded. If the voltage of the distribution system on a tank vessel is 1000 V or more, line-to-line, and the distribution system is grounded, any resulting current should not flow through hazardous locations.

11.39.1.7 Grounding three-wire, dual-voltage dc systems

The neutral connection of three-wire 230/115 Vdc systems should be solidly grounded at the generator switchboard with a center zero ammeter in the ground connections. The center zero ammeter should be equipped with a shunt, having a full-scale reading of 150% of the neutral current rating of the largest generator and marked "plus" and "minus" to indicate the polarity of grounds.

The ground connection should be made in such a manner that it will not prevent checking the insulation of the generator to ground before the generator is connected to the bus.

No direct ground connection should be provided at the emergency switchboard but the neutral bus or buses of the emergency switchboard should be solidly and permanently connected to the neutral bus of the main generator switchboard. The capacity of this neutral conductor should be the same as that of the positive and negative conductors or No. 8 AWG, whichever is larger. An interrupting device should not be provided in the neutral conductor of the bus tie feeder connecting the two switchboards.

11.39.1.8 Sizing of neutral grounding conductors

In an ac system, the conductor that connects the system neutral to the single-point ground should be equal in capacity to the largest generator conductor supplying the system or equivalent for paralleled generators.

A conductor that serves as the neutral grounding conductor on a dc system should be equal in capacity to the current-carrying conductor, or No. 8 AWG (8 mm^2 or 16 500 cmil), whichever is larger.

11.39.2 Ground detection

Means to continuously monitor and indicate the state of the insulation-to-ground should be provided for electric propulsion systems and integrated electric plants; ship service and emergency power systems; lighting systems; and power or lighting distribution systems that are isolated from the ship service or emergency power and lighting system by transformers, motor-generators, or other devices.

For insulated (ungrounded) distribution systems, a device or devices should be installed that continuously monitor and display the insulation level and give audible and visual alarms in case of abnormal conditions. These devices should be in addition to ground detection lights.

When a ship is designed for operation with an unattended machinery space, ground detection alarms should be connected to the machinery control monitoring and alarm system.

Ground indicators should be located at the ship service switchboard for the normal power, normal lighting, and emergency lighting systems; at the emergency switchboard for emergency power and lighting, and at the main power switchboard for integrated propulsion systems. All ground indicators should be readily accessible.

11.39.2.1 Ground detection lamps on ungrounded systems

Ground detection for each ungrounded system should have a monitoring and display system which has a lamp for each phase that is connected between the phase and ground. This lamp should operate at more than 5 W and less than 24 W when at one-half voltage in the absence of a ground. The monitoring and display system should also have a normally closed, spring return-to-normal switch between the lamps and the ground connection.

11.39.2.2 Ground detection on grounded neutral ac systems

Ground detection for each ac system which has a grounded neutral should have an ammeter and ammeter switch that can withstand the maximum available fault current without damage. The ammeter should indicate the current in the ground connection and should have a scale that accurately, and with clear definition, indicates current in the 0 to 10 A range. The ammeter switch should be the spring return-to-on type.

The ammeter and current transformer should both be of such a design that they are not damaged by ground-fault currents. Where the ammeter is located in a remote enclosure from the current transformer, a suitable protective device should be provided to prevent high voltage in the event of an open circuit. A short-circuiting switch should be connected in parallel with the protective device for manually short-circuiting the remote part of the current transformer.

11.39.2.3 Ground detection on dual-voltage dc systems

Ground detection for each dual-voltage dc system should have a zero-center ammeter that is in the ground connection. The zero-center ammeter should have a full-scale range of 150% of the neutral current rating and the polarity of the ground marked.

11.39.3 Equipment grounding

Exposed non-current-carrying metal parts of fixed equipment that may become energized because of any condition for which the arrangement and method of installation does not ensure positive grounding, should be permanently grounded through separate conductors or grounding straps, securely attached, and protected against damage.

The metal case of each instrument, relay, meter, and instrument transformer should be grounded.

Instrument and control transformer enclosures should be grounded to the ship structure.

Each receptacle outlet that operates at 55 V or more should have a grounding pole. However, this requirement does not apply to lamp bases, shades, reflectors, or guards supported on lampholders or lighting fittings constructed of or shrouded in nonconducting material. Grounding poles are also not required on portable appliances that have double insulation, or portable appliances that are protected by isolating transformers. Grounding poles are not required on bearing housings that are insulated in order to prevent the circulation of current in the bearings. Grounding poles are not required on apparatus supplied at not more than 55 V.

11.39.3.1 Equipment grounding methods

All non-current-carrying metallic parts of electrical equipment should be effectively grounded by the following methods. Metal frames or enclosures of apparatus should be fixed to, and be in metallic contact with, the ship’s structure, provided that the surfaces in contact are clean and free from rust, scale, or paint when installed and are firmly bolted together. Alternatively, they should be connected to the hull either directly by ground strap or, for portable equipment, via the grounding terminal of a receptacle outlet. A reading of 0.1 S (dc resistance) or less should be achieved between an equipment enclosure and an adjacent structural ground potential point.

Metallic cable sheaths or armor should not be solely relied upon for achieving equipment grounding. The metallic sheaths and armor should be grounded by means of stuffing tubes, connectors, or cable glands intended for that purpose and designed to ensure an effective ground connection. The stuffing tube should be firmly attached to, and be in effective electrical contact with, a grounded metal structure. Conduits should be grounded by being screwed into a grounded metallic enclosure, or by nuts on both sides of the wall of a grounded metallic enclosure where contact surfaces are clean and free from rust, scale, or paint.

As an alternative to the methods described in the above paragraph, armor and conduit may be grounded by means of clamps or clips of corrosion-resistant metal, making effective contact with the sheath or armor and grounded metal. All joints in metallic conduits and ducts and in metallic sheaths of cables that are used for ground continuity should be solidly made and protected against corrosion.

Every grounding conductor should be of copper or other corrosion-resistant material and should be securely installed and where necessary, protected against damage and electrolytic corrosion.

On wood and composite ships, a continuous-ground conductor should be installed to facilitate the grounding of non-current-carrying exposed metal parts. The ground conductor should terminate at a copper plate of area not less than 0.2 m^2 (2 ft^2) fixed to the keel below the light waterline in a location that is fully immersed under all conditions of heel.

Every ground connection to the ship structure, or on wood and composite ships to the continuous ground conductor, should be made in an accessible position and should be secured by a screw or connector of brass or other corrosion-resistant material used solely for that purpose.

All armor or other metal coverings of cable should be electrically continuous throughout the entire length and should be effectively grounded to the hull of the ship at both ends, except for branch circuits (final subcircuits), which may be grounded at the supply end only. The metallic braid or sheath should be terminated at the stuffing tube or connector where the cable enters the enclosure and should be in good electrical contact with the enclosure.

Methods of securing aluminum superstructures to the steel hull of a ship often include insulation to prevent galvanic corrosion between these materials. In such cases, a separate bonding connection should be provided between the superstructure and the hull. The connection should be made in a manner that minimizes galvanic corrosion and permits periodic inspection.

11.39.3.2 Grounding of portable equipment

Portable electrical equipment energized from the ship's electrical system should have all exposed metal parts grounded. This should be accomplished by an additional conductor (green) in the portable cable and a grounding device in the attachment plug and receptacle. Further safety can be provided by the use of an isolating transformer. Double insulated portable electrical equipment need not have exposed metal parts grounded.

11.39.3.3 Lightning protection

Lightning protection should be provided for each mast on wooden and composite vessels and for each wooden or composite mast on steel vessels. Where the height of an antenna exceeds that of the mast and the antenna is equipped with lightning protective devices, separate mast lightning protection need not be provided.

Lightning protection should consist of continuous tape or wire having a section of not less than 100 mm^2 (212 000 cmil) attached by copper rivets or clamps to a copper spike not less than 13 mm (0.5 in) in diameter, projecting at least 150 mm (6 in) above the top of the mast. The copper tape or wire should be run to a copper plate having an area not less than 0.2 m^2 (2 ft^2), fixed to the keel below the light water line in a location that is fully immersed under all conditions of heel. No grounding conductor should be attached to the lightning conductor plate. The copper plate should be separate from and in addition to the copper plate for terminating the grounding conductor.

Table 11-1—Overcurrent protection for motors and motor branch circuits

Motor full-load current rating	For motor running protection (Note 1)		Recommended setting of branch circuit breaker long-time delay trip element (Note 2)	
	Recommended rating of fuses	Recommended setting of controller inverse-time protection device	Single-phase and three-phase squirrel-cage and synchronous motors (Autotransformer, full-voltage reactor and resistor starting)	DC and wound-rotor ac motors
Amperes	Amperes	Amperes	Amperes	Amperes
1	2	1.15	15	15
2	3	2.3	15	15
3	4	3.45	15	15
4	6	4.6	15	15
5	6	5.75	15	15
6	8	6.9	15	15
7	10	8.05	15	15
8	10	9.2	15	15
9	12	10.35	15	15
10	12	11.5	15	15
11	15	12.65	15	20
12	15	13.8	15	20
13	15	14.95	20	20
14	20	16.1	20	25
15	20	17.25	20	25
16	20	18.4	20	25
17	20	19.55	25	30
18	25	20.7	25	30
19	25	21.8	25	30
20	25	23.0	25	30
22	30	25.3	30	35
24	30	27.6	30	40
26	30	29.9	35	40
28	35	32.2	35	45
30	35	34.5	40	45
32	40	36.8	40	50
34	40	39.1	45	60
36	45	41.4	45	60
38	45	43.7	50	60
40	50	46.0	50	60
42	50	48.3	60	70
44	60	50.6	60	70
46	60	52.9	60	70
48	60	55.2	60	80
50	60	57.5	70	80
52	60	59.8	70	80

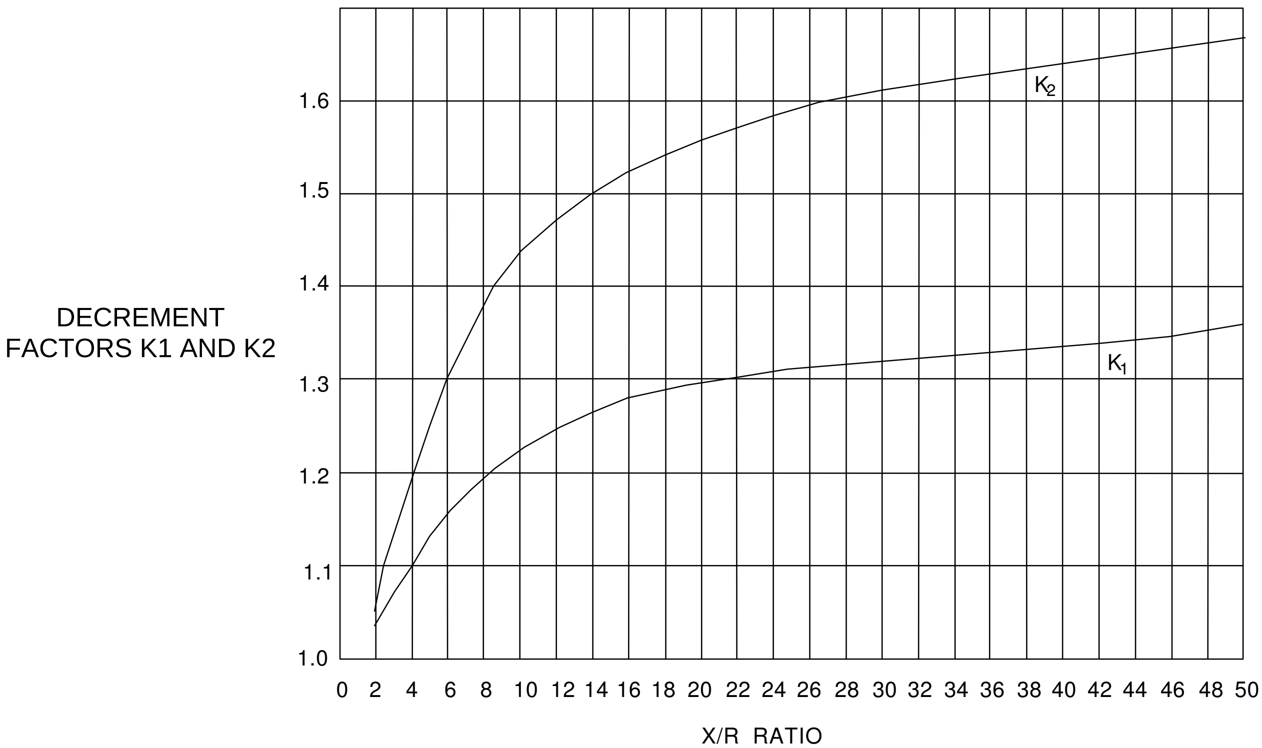
Table 11-1—Overcurrent protection for motors and motor branch circuits *(Continued)*

Motor full-load current rating	For motor running protection (Note 1)		Recommended setting of branch circuit beaker long time-delay trip element (Note 2)	
	Recommended rating of fuses	Recommended setting of controller inverse-time protection device	Single-phase and three-phase squirrel-cage and synchronous motors (Autotransformer, full-voltage reactor and resistor starting)	DC and wound-rotor ac motors
Amperes	Amperes	Amperes	Amperes	Amperes
54	70	62.1	70	90
56	70	64.4	70	90
58	70	66.7	80	90
60	70	69.0	80	90
62	80	71.3	80	100
64	80	73.6	80	100
66	80	75.9	90	100
68	80	78.2	90	110
70	90	80.5	90	110
72	90	82.8	90	110
74	90	85.1	100	125
76	90	87.4	100	125
78	90	89.7	100	125
80	100	92.0	100	125
82	100	94.3	110	125
84	100	96.6	110	150
86	100	98.9	110	150
88	110	101.2	110	150
90	110	103.5	125	150
92	110	105.8	125	150
94	110	108.1	125	150
96	125	110.4	125	150
98	125	112.7	125	150
100	125	115	125	150
105	125	120.75	150	175
110	150	126.5	150	175
115	150	132.25	150	175
120	150	138	150	200
125	150	143.75	175	200
130	150	149.5	175	200
135	175	155.25	175	
140	175	161	175	
145	175	166.75	200	
150	175	172.5	200	
155	200	178.25	200	
160	200	184	200	

Table 11-1—Overcurrent protection for motors and motor branch circuits *(Continued)*

	For motor running protection (Note 1)		Recommended settings of branch circuit breaker long time-delay trip element	
Motor full-load current rating	Recommended rating of fuses	Recommended setting of controller inverse-time protection device	Single-phase and three-phase squirrel-cage and synchronous motors (Autotransformer, full-voltage reactor and resistor starting)	DC and wound-rotor ac motors
Amperes	Amperes	Amperes	Amperes	Amperes
165	200	189.75	225	
170	200	195.5	225	
175		201.25	225	
180		207	225	
185		212.75	250	
190		218.5	250	
195		224.25	250	
200		230	250	
210		241.5	300	
220		253	300	
230		264.5	300	
240		276	300	
250		287.5	350	
260		299	350	
270		310.5	350	
280		322	350	
290		333.5	400	
300		345	400	
320		368	400	
340		391	450	
360		414	450	
380		437	500	
400		460	500	
420		483	600	
440		506	600	

NOTE 1—Refer to 17.1.
NOTE 2—Refer to 11.32, 11.33, 11.34, and 11.35.



K_1 Ratio of the average asymmetrical rms current in the three phases at one-half cycle to the rms value of the symmetrical current.

K_2 Ratio of the maximum rms asymmetrical current in one phase at one-half cycle to the rms value of the symmetrical current.

Figure 11-1—Fault-current decrement conversion factors

12. Circuits in the vicinity of magnetic compass

12.1 General

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

In the binnacle, there should be only a single pair of conductors, twisted for their full length, and used for the binnacle light. For other wiring and equipment, the minimum distance from the magnetic compass should be approximately as follows:

a) *Single-conductor wiring:* None should be installed on or in the vicinity of the bridge.
b) *Direct-current wiring:*
   1) Parallel laid twin conductors
      a) 0 to 1 A .... 0.6 m (2 ft)
      b) 1 to 10 A .... 1.5 m (5 ft)
      c) Over 10 A.. 2.5 m (8 ft)
   2) Twisted conductors
      a) 1 to 10 A .... 1.0 m (3 ft)
      b) Over 10 A.. 1.5 m (5 ft)
   3) Motors (except windshield wipers) .... 3.7 to 4.3 m (12 to 14 ft)
   4) Telephone transmitters and receivers:
      a) Battery powered.. 1.5 m (5 ft)
      b) Sound powered .... 2.1 m (7 ft)
   5) Loudspeakers.. 3.7 m (12 ft)
   6) Searchlight projectors, except when made of nonmagnetic material (see 25.1)...................................... 3.7 m (12 ft)
   7) Magnetically operated relays, indicators, etc. .... 2.5 m (8 ft)
   8) Telegraphs, electric .... 1.2 m (4 ft)
   9) Windshield wipers.. 1.2 m (4 ft)

Multiple-conductor cables carrying alternating current will 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.

13. Distribution equipment

13.1 Distribution panels

Distribution panel components, such as enclosing cases, cabinets, latches, and locks, etc., should be constructed of corrosion-resistant materials. However, current-carrying components may be of corrodible material provided an acceptable corrosion-resistant finish has been applied.

Electrical creepage and clearances should be in accordance with a nationally recognized standard.

All parts of distribution panel interior fittings should be renewable without removing the distribution panel's insulating base. Circuit breaker elements of unit type construction may be used to build up a distribution panel unit.

Each outgoing circuit should have a suitable nameplate. Where there is insufficient space adjacent to the branch circuit breaker for a nameplate, then each circuit should be numbered and a directory list attached to the inside of the door.

Distribution panels for motor, appliance, lighting (including emergency), and other branch circuits should utilize multipole circuit breakers. These circuit breakers should provide overload protection for each ungrounded conductor in each branch circuit. Circuit breakers in grounded neutral distribution panels should include a pole or switch for the neutral. The number of branch circuits controlled by a single distribution panel should not exceed 18 for three-phase ac branches and 26 for single-phase ac or two-wire dc branches. The wiring space within each enclosure should be of sufficient size to avoid conductor overcrowding and to ensure adequate ventilation. All circuit breakers for motor starting and stopping should have horsepower ratings that meet a nationally recognized standard.

For three-phase distribution panels, buses and primary connections should be arranged such that the phase sequence is A, B, C. For dc distribution panels, the polarities are positive, neutral, negative front to back, top to bottom, and left to right as viewed from the front of the panel. A distribution panel cabinet or enclosing case that is accessible to passengers should be provided with a lock. Dead-front type distribution panels should be used.

Distribution panels should have a degree of enclosure appropriate for the installation location.

Watertight distribution panel cabinets should be cast or welded construction with external mounting lugs and externally operable switches. Terminal tubes should be provided for all cables for watertight distribution panels and for cables entering the top of dripproof distributions panels, which may allow condensation or other moisture to drip into the enclosing case or cabinet. Suitable bushings or clamps should be used when cables enter the bottom and sides of dripproof enclosures.

Large load center power distribution panels should conform to all applicable requirements of Clause 7.

13.2 Circuit breakers

Circuit breakers should meet other national or international requirements and be tested or certified by a nationally recognized independent testing laboratory as suitable for shipboard applications.

13.3 Wire lugs and connectors

All lugs should be of the solderless type and should provide adequate contact area and pressure to provide good contact, low-voltage drop, low-temperature rise, and mechanical strength to resist pullout and withstand shipboard vibration.

All pressure type connectors and lugs should conform to ANSI/UL 486A-1991, or another nationally recognized standard.

If soldering lugs are used, they should have a solder contact length a minimum of 1.5 times the diameter of the conductor.

Tongues should be suitable for the intended application with the contact surface having a suitable finish and adequate area. If the location of soldering lugs is such that any misalignment could result in a short-circuit or ground fault, then the lug should have two screw holes or otherwise be adequately secured against turning.

If soldering lugs are attached to studs, bus bars, etc., that have silver-plated contact areas, the contact area of the lug should also be silver-plated.

13.4 Feeder box fittings

Feeder box fittings may be of two types. One type of feeder box fitting does not require severing the feeder. The other type of feeder box fitting utilizes terminal blocks, which are arranged to attach the branch circuit and the two sections of the severed feeder by lugs conforming to the requirements of 13.3.

13.5 Branch box fittings

Branch box fittings should be provided with bases constructed of flame-retarding and moisture-resistant insulating material. Connections should be provided with spring washers to retain the wires, or connection plates should be provided with upturned lugs or confining walls to retain the wires. Screw holes for securing fittings should not penetrate the enclosure of waterproof boxes.

13.6 Connection box fittings

Connection box fittings should be provided with insulating bases that are designed for connecting wire lugs or terminals conforming to the requirements of 13.3. When providing connections for different voltages in one connection box, the connections for each voltage group should be separated by a barrier and the voltage of each group of terminals should be indicated on the connection box.

13.7 Shore connection boxes

Shore connection boxes should comply with the following:

a) Connection boxes should have portable cable connection capability utilizing watertight multipole power receptacles or protected terminals.
b) The terminals should be properly sized and shaped to facilitate satisfactory connections.
c) There should be phase sequence marking for the terminals for three-phase ac system portable cables.
d) Terminals should be polarity marked for dc system portable cables.
e) There should be an instruction plate, or sheet, providing essential information on the ship's electrical supply system and connection requirements.
f) Connection boxes should be of watertight construction.

g) Connection boxes should have provisions for bottom entrance of portable cables.
h) Connection boxes should be designed to prevent moisture or water entrance via the top or sides of the enclosure.
i) Connection boxes should have phase sequence and phase rotation indicators for three-phase ac systems.

13.8 Feeder, branch, and connection boxes

13.8.1 General

Feeder, branch, and connection boxes should generally be constructed of the following materials:

a) Cast brass,
b) Bronze,
c) Malleable iron,
d) Welded iron,
e) Welded sheet steel with corrosive-resistant finish,
f) Pressed sheet brass, or
g) Molded composition.

13.8.1.1 Boxes exposed to weather

Boxes mounted in locations exposed to the weather should be constructed of the following materials:

a) Brass,
b) Bronze,
c) Molded composition, or
d) Other suitable corrosion-resistant materials.

13.8.1.2 Molded composition boxes

Molded composition boxes should be made of flame-retardant material in accordance with ASTM D229-96. This material should also be impervious to oil, moisture, and ultraviolet radiation. The boxes should have mechanical performance characteristics similar to comparable metallic enclosures.

13.8.2 Minimum box wall thickness

Feeder, branch, and connection boxes should be constructed with minimum box wall thickness as follows:

a) For brass and bronze boxes: 2.4 mm (0.09 in)
b) For malleable iron and molded composition boxes: 3.2 mm (0.125 in)
c) For welded iron and welded sheet steel: 1.6 mm (0.062 in)
d) For pressed sheet brass: 1.98 mm (0.078 in)

13.8.3 Tolerances between box and fittings

Metallic boxes should provide an air gap as follows between live fittings and the box or cover, unless an insulating barrier is used:

a) For 125 V or less: 12.7 mm (0.5 in) creepage and 6.35 mm (0.25 in)
b) For 126 V to 600 V inclusive: 6.35 mm (0.25 in) air gap

13.8.4 Stuffing tube bosses/pads

The minimum thickness for stuffing tube bosses or pads should be as follows, excluding wall thickness of the box:

a) For molded composition and cast boxes: 6.35 mm (0.25 in)
b) For sheet boxes: 3.17 mm (0.125 in)

Where nonmetallic cable hubs or seals are fitted in molded composition boxes, no bosses or pads need be provided.

13.8.5 Box covers

Box covers should have a minimum cover thickness as follows:

a) For cast and molded composition boxes: 3.17 mm (0.125 in) thick
b) For all other boxes: 1.6 mm (0.062 in) thick.

Box covers should be secured with screws of corrosion-resistant material as follows:

a) For screw cap covers: Screws should have U.S. Standard threads, 12 per inch or metric equivalent.
b) For covers other than screw cap covers: Screws should be at a minimum No. 10 gauge, 24 threads per inch or metric equivalent.

Covers for watertight boxes should be fitted with gaskets that are thick enough for the application and secured such that a continuous seating and uniform compression of the gasket is ensured.

13.8.6 Watertight boxes

Watertight boxes should be provided with external mounting feet. No mounting holes should penetrate the enclosure.

13.8.7 Box locations

Nonwatertight feeder, branch, and connection boxes may be used in the following locations:

a) Chart room
b) Navigating bridge
c) Radio room
d) Gyro room
e) Accommodation spaces
f) Pantries
g) Passageways adjacent to accommodation spaces
h) Public washrooms and toilets not equipped with baths or showers

Nonwatertight feeder, branch, and connection boxes should not be installed within 3 m (10 ft) of weather deck doors or access openings to the weather where the openings are not protected by an overhead deck that extends the full width of the weather deck to which the doors or openings lead. These boxes may be installed within 3 m (10 ft) of weather deck doors or access openings, if the boxes are concealed in fire-resisting joiner panels. In all other spaces, feeder, branch, and connection boxes should be watertight as required by the location. The integrity of these enclosures should be as defined in 3.7.

13.9 Receptacles, plugs, and switches—nonwatertight

13.9.1 General

Nonwatertight receptacles, plugs, and switches should meet to the following standards:

a) Nonwatertight receptacles, plugs, and switches should be of rugged construction.
b) They should be capable of withstanding rough treatment and usage.

Nonwatertight receptacle, plug, and switch enclosures should conform to all applicable requirements of 13.8.

Receptacles and switches should have sufficient contact surface and meet all tests and requirements set by a nationally recognized independent testing laboratory.

13.9.2 Receptacles

All receptacles should meet the following grounding requirements:

a) Provide an extra pole or contact grounded to the enclosure.
b) Allow extension of safety circuit or ground connection through supplementary contact in the plug to portable equipment casing.

The receptacle body supporting current-carrying contacts and terminals should be constructed of flame-resisting and moisture-resistant insulating material. There should be a barrier separating current-carrying parts.

NOTE—Porcelain is not recommended as a barrier for current-carrying components.

All current-carrying components should meet requirements set by a nationally recognized independent testing laboratory.

Receptacles and plugs of different electrical ratings should not be interchangeable, as stated in standards promulgated by a nationally recognized independent testing laboratory.

13.9.3 Plugs

Plugs should meet the following recommendations:

a) They should conform to all applicable receptacle requirements.
b) Plug connections should be made in such a manner that no strain is transmitted to terminals and contacts.
c) Plugs should be designed such that when in place, they are held in positive contact regardless of vibration level.
d) All portable equipment plugs should be a type that grips the cord except for the following equipment:

    1) Desk, table, and floor lamps
    2) Bracket fans used in staterooms and living quarters

13.9.4 Switches

Switches should meet the following requirements:

a) Switches should be reciprocating or toggle-type switches
b) They should be of the quick make-and-break action type
c) They should have a self-evident position indication

13.9.5 Connections

Connections for all plugs, receptacles, and switches should be as follows:

a) *For more than 30 A:* Provided with lugs for connecting conductors.
b) *For 30 A or less:* Conductors may be held by a binding screw and provided with means for confining the wire.

When receptacles are incorporated as part of a fixture, the receptacle should be a type that has a nationally recognized independent testing laboratory approval, with no restrictions, for the use of any nationally recognized independent testing laboratory approved attachment plug. However, when the receptacle does not have a nationally recognized independent testing laboratory approval rating, then the receptacle should be mounted on a nonconducting surface, or an insulating shield, to effect an insulated area large enough to permit the use of any nationally recognized independent testing laboratory approved attachment plug.

13.9.6 Locations

Nonwatertight receptacles, plugs, and switches may be used in the following locations:

a) Chart room
b) Navigating bridge
c) Radio room
d) Gyro room
e) Accommodation spaces
f) Pantries
g) Passageways adjacent to accommodation spaces
h) Public washrooms and toilets not equipped with baths or showers

Nonwatertight receptacles, plugs, and switches should not be installed within 3 m (10 ft) of weather deck doors or access openings to the weather where the openings are not protected by an overhead deck that extends the full width of the weather deck to which the doors or openings lead unless the junction boxes for this equipment are concealed in fire-resisting joiner work panels.

13.10 Receptacles, plugs, and switches other than nonwatertight

13.10.1 General

Enclosures for other than nonwatertight receptacles, plugs, and switches should be watertight, submersible, or explosionproof depending on location and as defined in 3.7. The enclosures should conform to all applicable requirements of 13.8. Additionally, receptacle enclosures should be designed so that with plugs removed, they can be made to meet the requirements for degree of enclosure.

13.10.2 Connections

All devices should conform to all applicable requirements of 13.9. All receptacles should be a polarized type and designed not to accommodate existing nongrounded plugs. All receptacle plugs should be designed such that, when in place, they are held in positive contact and establish and maintain the required degree of enclosure.

Where threaded caps are used to seal off receptacle openings, they should be mechanically fastened to the cover, or enclosure, by a strong link or hinged strap. Bead chains should not be used for this purpose.

13.10.3 Location

Watertight receptacles, plugs, and switches should be used in all spaces where nonwatertight units are not applicable, except where either explosionproof or submersible units are required. Watertight units may be used in any location where nonwatertight units are permitted.

For areas where explosionproof enclosures are recommended see Clause 33. Explosionproof receptacles should have interlocked explosionproof switches or should be otherwise arranged to avoid an explosion hazard when the plug is inserted or withdrawn. Explosion-proof switches should have poles that are arranged to break all current-carrying legs of the circuit. The installation of switches or receptacles in areas subject to explosion hazard should be avoided when possible.

Submersible units may be required in certain applications due to special or unusual locations.

13.11 Terminal and stuffing tubes

Terminal tubes should consist of nonferrous material. Where terminal tubes are installed in contact with dissimilar metals except steel, precautions should be taken to prevent electrolytic action. Terminal tubes should be machined with a standard pipe thread and designed to receive a flanged nut or gland nut. The flange nut and gland nut, when screwed into the tube body, should force a loose collar or gland ring against suitable watertight packing and provide a watertight joint.

Bulkhead tubes should conform to the recommendations listed above except that the body may be constructed of steel. In addition, the tube body or bulkhead tube should have a nipple of sufficient length to pass through the bulkhead with room for a gasket and lock nut to secure a watertight joint through the bulkhead. If the nipple is constructed of steel and designed accordingly, it may be welded to the bulkhead to secure the watertight joint.

Deck-stuffing tubes should be provided with a nut on each side or should be designed specially for welding to the deck.

13.12 Multicable penetrators

The surrounding frame of a multicable penetrator should consist of metal compatible with the metal of the bulkhead, deck, or equipment enclosure to which it is attached. Materials that compose the fitting and seal should not induce electrolysis or cause deterioration of the cable, armor, or cable sheath in any way.

13.13 Bolts, taps, etc.

All bolts, taps, and threads used in the construction and installation should be of U.S. Standard size threads or a recognized standard of special thread.

13.14 Power factor correction capacitors

Power factor correction capacitors may be used in limited shipboard applications to improve system power factor. This reduces the kilovoltamperes required to supply a given kilowatt load. Power factor correction capacitors may be directly connected to the circuit or connected by means of contactors.

Installation of power factor correction capacitors should not raise the system power factor at the minimum generator load condition above 0.9 lagging. Generator regulator instability may occur at power factors above this level. The installation of power factor correction capacitors causes increased harmonic currents, often requiring increases in cable size, circuit breaker, and contactor rating. In general, cables and circuit breakers should be sized for at least 135% of the rated capacitor load.

Excessive capacitor current will flow when capacitors are connected to solid-state motor controllers, because of silicon control rectifier (SCR) line notching, so power factor correction capacitors should not be installed without isolation transformers. Undesirable ground current will flow if the capacitors are directly connected to ungrounded power systems.

13.15 Spare parts

Spare parts should be provided as recommended by the applicable classification societies.

14. Motors

14.1 General

All motors should be compatible with the voltage, phase, and frequency of the supply system. The construction and type of winding should be determined by the conditions under which the motor will operate. Motors may be of the wound-rotor induction, squirrel-cage induction, synchronous, or suitable commutator type. Motors should be constructed so that their operation is not impaired by vibration and shock likely to arise under normal service conditions. Windings and current-carrying parts should be copper, and fasteners securing the current-carrying parts should be provided with means to prevent loosening due to vibration. Motors used with variable speed drives should be specifically designed to operate successfully on the nonsinusoidal input power from the drive. Squirrel-cage induction motors should be used wherever suitable.

Where water cooling is used, the cooler should be arranged to prevent water entry into the machine from heat exchanger leakage or condensation.

Motors in damp spaces or in the weather, especially motors left idle for appreciable periods, should be provided with an effective means (e.g., internal heaters) to prevent the accumulation of condensation.

Measures should be taken, where necessary, to prevent the circulation of current between the shaft and the bearings.

In the interest of achieving a favorable power factor, motors should be selected that closely meet the actual load requirements. Oversize motors should be avoided.

14.2 Installation and location

Motors exposed to the weather or located where they would be exposed to seas, splashing or other severe moisture conditions should be watertight or protected by watertight enclosures. Such enclosures should be designed to prevent internal temperatures in excess of motor ratings. Motors should be located so they cannot be damaged by bilge water. Where such a location is unavoidable, they should be either submersible or provided with a watertight coaming to form a well around the base of the equipment and a means for removing water. Where explosionproof, dripproof, watertight, and dusttight equipment is required, the enclosure should comply with the appropriate recognized standard.

Fan-cooled motors should not be installed in locations subject to ice formation.

For motors in hazardous locations, see Clause 33.

Horizontal motors should be installed, as far as practicable, with the rotor or armature shafts in the fore and aft direction of the vessel. If motors must be mounted in a vertical or an athwartship position, the motors should have bearings appropriate for the intended installation.

14.3 Accessibility

Motors (except for submersible motors, sealed motors, or motors for hazardous locations) should be designed to permit ready removal of the rotor, stator components, and bearings, and to facilitate bearing maintenance. All wound-rotor ac motors, synchronous motors, and commutating motors of the enclosed type, except fractional horsepower motors, should have viewing ports or readily removable covers at the slip ring or commutator end for inspection of the rings, commutator and brushes while in operation.

Eyebolts or equivalent should be provided for lifting motors.

14.4 Insulation of windings

Insulating materials and insulated windings should be resistant to moisture, sea air, and oil vapor. All form-wound coils for ac motors and assembled armatures, and the armature coil for open-slot dc construction, should utilize vacuum pressure impregnated solventless epoxy insulating systems.

For ac motors, all random-wound stators and rotors having insulated windings should utilize vacuum pressure impregnated solventless epoxy Class F or H insulation systems, with Class B rise, or be of the encapsulated type.

All field coils for dc motors should be treated with varnish or other insulating compound while being wound, or should be impregnated. The finished winding should be water- and oil-resistant.

Abnormal brush wear and commutator maintenance may occur in motors containing silicon materials. Special consideration should be given to these problems if silicon is used in any form that can release vapor in motor interiors.

14.5 Lubrication

Motors should operate successfully for continuous periods when permanently inclined at an angle of 5° fore and aft, and 15° athwartship; and should operate successfully and not spill oil when the vessel rolls 22.5° either side of the vertical or pitches 7.5°. Motors should have efficient and continuous lubrication at all running speeds and all normal working bearing temperatures.

Means should be provided to prevent lubricant from creeping along the shaft or otherwise contacting the insulation or any live part. Each oil-lubricated bearing should be provided with an overflow. Where ring lubrication is employed, the rings should be constrained so that they cannot leave the shaft. Each self-lubricated sleeve bearing on a machine 100 kVA ac/100 kW dc or greater should be fitted with an oil gauge or an inspection cover for visual indication of oil level.

14.6 Terminal arrangements

All motors should be provided with terminal boxes appropriate to their type of enclosure. Terminal boxes should be of sufficient size to accommodate wiring without crowding and each box should be of adequate mechanical strength and rigidity to protect the contents and to prevent distortion under all normal conditions of service. Cables of differing voltage should not be included in the same terminal box unless each voltage is clearly and permanently identified and effective barriers provided within the enclosure to separate each voltage. Motors should have the terminal leads suitably secured to the motor frame. The end of these leads should be fitted with approved connectors suitable for use with terminal lugs on incoming cables in accordance with 13.3. All connections to the interior of motors as well as those to the power supply should be provided with efficient locking devices.

The leads of watertight motors should be brought into watertight junction boxes through watertight seals. The leads of explosionproof motors should be terminated to maintain the explosionproof integrity of the motor.

Special consideration should be given to terminal enclosures of multispeed ac motors to ensure adequate space for connecting and insulating multiple cables.

14.7 Corrosion-resistant parts

All motor screens, interior bolts, nuts, pins, screws, terminals, brushholder studs, springs, handhole cover bolts, nuts, and such other small parts that would be seriously damaged and rendered ineffective by corrosion should be corrosion-resistant. Steel springs should be treated to resist moisture in such a manner as not to impair their spring quality.

Motors should be painted with a corrosion resistant finish or otherwise protected against corrosion.

14.8 Nameplates

All motors should be fitted with nameplates of corrosion-resistant material marked with the following information:

14.8.1 Induction motors, single or polyphase

a) Name of manufacturer
b) Manufacturer's type and frame designation
c) Manufacturer's serial number
d) Mechanical output, kW or horsepower
e) Time rating
f) Temperature rise at rated load and design ambient temperature
g) Speed at rated load
h) Voltage
i) Amperes at full load
j) Frequency
k) Number of phases
l) Nominal efficiency

14.8.2 Wound-rotor induction motors, single or polyphase

Items a) to l) in 14.8.1, plus

m) Secondary amperes at full load
n) Secondary voltage

14.8.3 Synchronous motors, single or polyphase

Items a) to n) in 14.8.1 and 14.8.2, plus

o) Power factor
p) Excitation voltage
q) Excitation current and rating

14.8.4 DC motors

Same as induction motor items a) to i) in 14.8.1, plus

r) Type of winding: shunt, series, compound, stabilized shunt.

14.9 Ambient temperature

Motors for main and auxiliary machinery spaces containing significant heat sources such as prime movers and boilers, except machine tools, should be selected on the basis of a 50 °C (122 °F) ambient temperature. Motors for machine tools and other locations where the ambient temperature will not exceed 40 °C (104 °F) may be selected on the basis of 40 °C (104 °F) ambient temperature.

Motors which must be installed where the temperature normally will exceed 50 °C (122 °F) should be considered as special and should be designed for 65 °C (149 °F) or the actual expected ambient temperature. Consideration should be given to ensuring satisfactory lubrication at high temperatures.

If a machine is to be utilized in a space in which the machine’s rated ambient temperature is below the assumed ambient temperature of the space, it should be used at a derated load. The assumed ambient temperature of the space plus the machine’s actual temperature rise at its derated load should not exceed the machine’s total rated temperature (machine’s rated ambient temperature plus its rated temperature rise).

14.10 Limits of temperature rise

The temperature rise of each of the various parts of ac motors and dc motors when tested in accordance with the full-load rating should not exceed values given in Table 14-1 and Table 5-1, respectively.

Where provision is made for ensuring an ambient temperature being maintained at 40 °C (104 °F) or less, as by air cooling or by location outside of the boiler and engine rooms, the temperature rises of the windings may be 10 °C (50 °F) higher. Deck-winch and direct-acting capstan motors should be rated on a full-load run of at least 1/2 h; direct-acting windlass motors should be rated on a full-load run of at least 1/2 h; and those operating through hydraulic transmission should be rated for 30 min idle pump operation, followed by full load for 1/4 h; steering-gear motors should be rated on a full-load run of 1 h if direct acting; or if indirect drive, for continuous operation at 15% of rated load followed by full load for 1 h. Steering-gear control motors should be rated on a full-load run of 1 h.

14.11 Insulation tests

Insulation tests should be made in accordance with the recommendations in IEEE Std 43-1974 with the machine windings in a clean, dry condition. The results obtained from the tests depend not only on the characteristics of the insulation materials and the way they are applied, but also on the test conditions. It is recommended that the data recorded during the tests include ambient conditions, particularly those concerning the ambient temperature and the degree of humidity at the time of the test. The Polarization Index (ratio of 10 min to 1 min insulation resistance value) for the machine windings should be evaluated. The recommended Polarization Index minimum value for ac and dc rotating machines is 2.0.

14.12 Insulation resistance

The resistance should be measured with all circuits of equal voltage above ground connected together; circuits or groups of circuits of different voltages above ground should be tested separately. This test should be made at a dc voltage of 500 V for a minimum of 1 min. The recommended minimum insulation resistance Rm for ac and dc machine armature windings and for field windings of ac and dc machines can be determined as follows:

$$Rm = \mathrm{kV} + 1$$

where

Rm = recommended minimum insulation resistance in MΩ at 40 °C (104 °F) of the entire machine winding
kV = rated machine terminal to terminal potential, in rms kilovolts

The actual winding insulation resistance to be used for comparison with the recommended minimum value *Rm* is the observed insulation resistance, corrected to 40 °C, obtained by applying direct potential to the entire winding for
1 min to obtain the initial value and for 10 min to obtain the value for the polarization index.

The minimum insulation resistance of the field windings of machines separately excited, with voltage less than the rated voltage of the machine, should be not less than one MΩ.

14.13 Tests

Prior to delivery, tests should be performed to ensure that the machine is in accordance with these recommendations and operates at its specified rating. When a machine is a duplicate of one already tested, only such check tests need be made as may be necessary to demonstrate that the machine operates successfully. Spare parts should be given a regular insulation resistance test, but need not be given any running test. Tests should be conducted in accordance with the following:

a) For single-phase motors, ANSI/NEMA MG-1-1993
b) For polyphase induction motors, IEEE Std 112-1996
c) For synchronous motors, IEEE Std 115-1995
d) For dc motors, ANSI/NEMA MG-1-1993

The tests that should be performed are

a) Temperature-rise
b) Insulation resistance
c) High potential
d) Overload
e) Commutation test

14.14 Temperature-rise test

After the machines have been run continuously under full load and steady-state temperatures have been reached, the temperature rises should not exceed those given in Table 14-1 or Table 5.1.

14.15 Insulation resistance test

The insulation resistance test of motor windings should be carried out with the machine at operating temperature and values should be not less than the values in 14.12.

14.16 High-potential test

The dielectric strength of the insulation should be tested by the continuous application for 1 min of an alternating voltage whose value is 1000 V plus twice the rated voltage of the circuit to which the machine is to be connected. The test voltage should be applied between all circuits and ground, between shunt and other field windings, and between brush rings of opposite polarity.

When synchronous motors are to be started with alternating current, the fields should be tested in accordance with the following, depending upon the field starting arrangements:

a) *Field short-circuited.* The field windings should be tested with 10 times the exciter voltage but not less than 2500 V nor more than 5000 V.
b) *Field open-circuited and sectionalized.* The field windings should be tested with 1.5 times the maximum rms voltage that can occur between the terminals of any section under the specified starting conditions, but not less than 2500 V or 10 times the rated excitation voltage per section, whichever is greater.
c) *Field open-circuited and connected all in series.* The field windings should be tested with 1.5 times the maximum rms voltage that can occur between the field terminals under the specified starting conditions, but not less than 2500 V or 10 times the rated excitation voltage, whichever is greater.
d) *Resistor in series with field.* The field windings should be tested with a voltage equal to twice the rms value of the IR drop across the resistor but not less than 2500 V. The IR drop should be taken as the product of the resistance and the current that would circulate in the field winding if short-circuited on itself at the specified starting voltage.

Phase-wound rotors of induction motors should be tested with twice their normal induced voltage plus 1000 V. When induction motors with phase-wound rotors are to be reversed while running at approximately normal speed by reversing the primary connections, the test should be four times the normal induced voltage plus 1000 V.

For fractional horsepower motors (250 V or less) rated 0.37 kW (0.5 hp) and less, the dielectric strength of the insulation should be tested by the application of alternating voltage whose effective value is 1000 V for 1 min for ac motor tests and 900 V for 1 min for dc motor tests. When fractional horsepower motors are produced in quantities, the high-potential test may be modified to consist of the application of a 20% higher voltage than recommended above applied for 1 s.

14.17 Overload test

The overload test for motors should be performed at rated speed, or in the case of a motor with a range of speeds, at the highest and lowest speeds. The test should be made with a gradual increase of torque and the appropriate excess torque given below. Synchronous motors and synchronous induction motors should withstand the excess torque without falling out of synchronism and without adjustment of excitation circuit preset at the value corresponding to rated load.

— DC motors	50% for 15 s
— Polyphase ac synchronous motors	50% for 15 s
— Polyphase ac synchronous induction motors	35% for 15 s
— Polyphase ac induction motors	60% for 15 s
— Single-phase ac motors	33% for 15 s

14.18 Commutation test

The commutation test on dc motors should consist of the application of a momentary torque of 50% in excess of that corresponding to its rating, for 15 s with fixed brush setting. There should be no severe sparking or damage to the commutator or brushes. The commutation of ac commutator motors should be essentially sparkless over the specified range of load and speed.

14.19 Spare parts

Spare parts should be provided as recommended by the classification societies. One complete set of bearings for each size and type of motor is recommended for ocean-going vessels.

14.20 Spare parts storage

Spare parts should be stowed in accordance with 5.22.

Table 14-1—Limits of observable temperature rise for ac motors

			Ambient							
			50 °C (122 °F)				65 °C (149 °F)			
			Class of insulation							
Item	Machine part	Method of temperature determination	A	B	F	H	A	B	F	H
1	Windings									
	a) All except b) and c)	Resistance	50	70	95	115	34	60	80	105
	b) Totally enclosed nonventilated enclosures only	Resistance	55	75	100	125	40	65	85	110
	c) Encapsulated only	Resistance	55	75	100		40	65	85	
2	d) 1500 hp and less	Embedded detector	60	80	105	130	40	65	90	115
	e) Over 1500 hp	Embedded detector	55	75	100	125	40	65	85	110
	Field winding of synchronous motors									
	a) Salient pole	Resistance	50	70	95	115	35	60	80	105
	b) Cylindrical rotor	Resistance		75	95	115		65	85	105

15. Motor application

15.1 General

Motors should be selected for the particular application. Motors should be rated for continuous duty unless used in an application that imposes an intermittent or varying duty.

Generally, motors should be of the dripproof and guarded type, unless an equipment enclosure provides an equivalent degree of protection. Motors subjected to excessive dripping of water or oil should be totally enclosed, or watertight. Motors on the open deck should be watertight unless enclosed in watertight housings.

15.1.1 AC motors

Since most applications do not require speed control of the driven load, single-speed squirrel-cage induction motors should be used whenever possible. If speed control is required, consideration should be given to solid-state variable speed drive controllers or multispeed squirrel-cage induction motors. The windings may be grouped for series or parallel operation to provide a two-to-one ratio of speeds, or two or more independent windings may be used to provide other ratios of synchronous speeds. A wound-rotor induction motor may also be used with suitable control equipment.

15.1.2 DC motors

For most applications, shunt or stabilized shunt-wound motors should be used. Since shunt field control will readily provide for at least a 10% increase in speed, it is recommended for applications requiring small speed adjustment. If greater speed control is required, armature voltage control, shunt field control, or a combination of both should be utilized.

15.2 Machinery space auxiliaries

Since machinery space air can contain oil vapor, consideration should be given to using totally enclosed fan-cooled motors or to piping the ventilating air to enclosed self-ventilated motors to prevent oil accumulation on the windings.

Care should be taken to locate dripproof motors to avoid bilge water. In general, motors should not be located below the level of the floor plates unless they are watertight. However, where located in openings in the floor plates where they are not subjected to splashing bilge water and are readily visible and serviceable, dripproof motors may be used.

15.3 Ventilating fan and blower motors

Motors that drive axial flow fans and draw air from, or discharge air to, the open deck should be waterproof.

15.3.1 AC motors

If two-speed motors are used, full and two-third speeds are recommended. One-half speed motors usually provide insufficient air flow with a centrifugal type fan.

15.3.2 DC motors

Motors for operating ventilating fans and blowers should be of the shunt type. In cases where the motor speed exceeds 600 r/min, a stabilized shunt motor should be used. Speed control, if provided, should be as described in 15.1.2.

15.4 Pump motors

Motors for operating close-coupled pumps should be totally enclosed. Alternatively, motors may be dripproof, with the driving end totally enclosed or designed to prevent liquid from entering the motor.

15.5 Refrigerated spaces

In general, motors should not be installed in refrigerated spaces. If installed, such as for recirculating fans, special consideration should be given to the effects of condensation.

15.6 Galley, laundry, workshop, printshop, and similar spaces

Motors for installation in these spaces should be totally enclosed or totally enclosed fan-cooled. Where the enclosing case of the appliance provides equivalent protection, open or dripproof motors may be used.

15.7 Applications in hazardous locations

See Clause 33 for additional recommendations.

15.8 Motor-generators

Squirrel-cage or synchronous motors may have the same duty rating as the driven generator.

15.9 Deck machinery motors

Motors should be waterproof unless located in deckhouses, below deck, or otherwise suitably protected.

15.9.1 AC motors

Single or multispeed constant-torque squirrel-cage motors generally provide sufficient speed points for a windlass, winch, or capstan drive. Variable speed drive controllers or wound-rotor motors with several types of impedance control may be used if additional speed control is required.

15.9.2 DC motors

Motors may be stabilized shunt, compound, or series wound. With a warping head, a stabilized shunt or compound-wound motor should be used. Speed control with special operating characteristics is usually required.

15.9.3 Duty rating

The duty rating required depends upon the mechanical configuration of the drive. For indirect drives, such as dc adjustable-voltage drives or electrohydraulic drives, consideration should be given to the fact that the motor driving the motor-generator set or pump will be operating continuously at light load with superimposed intermittent loading.

The minimum duty ratings recommended for windlass, capstan, and winches are as follows:

	Windlass	Capstan	Cargo winch	Topping and vang winch
Direct gear	30 min	30 min	30 min	15 min
Direct gear with warping head	30 min var[a]	30 min var[a]	30 min var[a]	—
Indirect (motor driving m-g set or pump)	30 min var[a]	30 min var[a]	30 min var[a]	—

[a]Varying duty comprises continuous operation at light load followed by full load for the specified time period. Boat winches and watertight door operators should have a minimum duty rating of full load for 5 min.

15.10 Steering gear motors

15.10.1 AC motors

For direct-drive steering gears, a wound-rotor motor with a breakdown torque of at least twice the full-load torque or a continuously rated squirrel-cage motor with reversible, variable speed drive is recommended.

For an indirect-drive steering gear with a dc adjustable voltage drive or an electrohydraulic drive, the squirrel-cage motor should be rated for continuous operation at 15% of rated load, followed by full load for 60 min.

15.10.2 DC motors

For direct-drive steering gears, a compound-wound motor with a 60 min intermittent duty is recommended. For an indirect-drive steering gear, the motor driving the motor-generator set or pump should be shunt or stabilized shunt wound and have the same 60 min varying duty rating as the ac motor above.

16. Watertight and fire door equipment

16.1 General

The control system for watertight door equipment should include a central control panel, motor operating units, motor control panels, local control stations, and visible and audible alarm system, as necessary for complete system control. Fire door controls include a central control panel, hold-back magnets, and local control switches.

Enclosures for electric components at the watertight door position or below the bulkhead deck should be waterproof. At other locations, dripproof enclosures may be used.

16.2 Watertight door systems

16.2.1 Watertight door central control panel

The panel should be constructed of corrosion-resistant material and have a visible permanent diagram showing the location of each watertight door by deck. It should provide a two-position master switch. The switch should have a position to close all watertight doors simultaneously (doors may be opened locally, but will automatically reclose). The other position provides for full local door control. Indicator lights showing the open (red) and closed (green) door positions should be provided. Both lights should be on when the door is in an intermediate position. Where a very large number of watertight doors are to be operated, the central control system may provide for operation of doors sequentially, with preference to closing doors on the lowest decks of the vessel first.

16.2.2 Motor unit

Each watertight door should have a motor operating unit of ample capacity, with self-contained gearing and limit switches, arranged to start without load and automatically clutch to the door mechanism. The motor-operating door unit should be designed to automatically disconnect all hand gear when electrically operated. Hand gear should always be engaged when not electrically operated. The method of control should ensure protection of the motor in the event of a jammed door.

16.2.3 Motor control panel

Each motor-driven unit should have a suitable control panel, line disconnect switch, reversing contactors, relays, and resistors.

16.2.4 Local control station

A local control station should be provided at each watertight door, operable from either side of the bulkhead. When the corresponding control switch on the navigating bridge central control panel is in the closed position, the door may be opened by the local control station, but should reclose automatically when the local control handle is released.

16.2.5 Electrohydraulic doors

The power supply for each hydraulically operated watertight door system that uses a hydraulic system common to more than one watertight door should be an accumulator tank with enough capacity to close all doors twice, and open all doors once. The accumulator tank should be supplied by one or more motor-driven hydraulic pumps that can operate from the emergency power system. Motor-driven hydraulic pumps should automatically maintain the accumulator tank pressure within the design limits. Pumps should be located above, and controlled from, the uppermost continuous deck. Accumulator tank capacity should be available when the accumulator tank pressure is at the automatic pump "cut-in" pressure.

Power for each hydraulically operated watertight door that has an independent hydraulic system for the door operator should be from the emergency power system.

16.2.6 Alarm and indicating equipment

An audible signal should be installed adjacent to each power-operated watertight door that operates prior to the movement of the door in either direction and continues until the door has reached its limit of travel. A visible signal should be provided at each remote manual operating station to show the open and closed positions of the door.

16.2.7 Electric power supply

The watertight door system should be connected to the emergency switchboard. Each distribution panelboard for a watertight door system should be above the uppermost continuous deck and should have means for locking. Each individual watertight door operating system should have a separate branch circuit.

16.2.8 Fault protection

The watertight door system should be protected against overcurrent such that failure in one door circuit will not be the cause of failure in any other door circuit. A short circuit or other fault in the alarm and indicator circuit should not result in loss of power for door operation. The overcurrent devices should be arranged to isolate a fault with as little disruption of the system as possible. The instantaneous setting of each feeder overcurrent device should be not less the 200% of its maximum load and the instantaneous setting of a branch circuit overcurrent device should be not more than 25% of that of the feeder overcurrent device.

The system connections should be such that leakage of water into the local controller will not establish a circuit that will cause the door to open.

16.3 Fire door holding and release systems

16.3.1 Equipment

Certain self-closing fire doors are required by regulatory agencies to be released from a central control station by opening an electric circuit. Arrangements should be provided for fire doors to be held in the open position by means of energized electromagnets controlled from a central control point. Doors should also be capable of being released locally. Door release systems should be arranged to be "fail-safe," i.e., they should cause the door to close in the event of their failure.

Each fire door should have a holding magnet, a self-aligning armature plate on the door to be held by the magnet when the fire door is fully open, and a local control station. Each holding magnet should be operable from a central control station. Each fire door holding circuit should be arranged so that loss of potential releases the doors, except that a momentary interruption of the circuit that results from the operation of an automatic bus-transfer device in connection with the emergency lighting and power system should not release the doors.

16.3.2 Central control station

The central control station should be an enclosed switch, circuit breaker, or magnetic contactor of a rating large enough to interrupt the connected load. The switching unit should be an externally operable, maintaining type. On a large vessel where the simultaneous closing of all fire doors could interfere with firefighting operations or with the evacuation of passengers, the fire door release system should be subdivided into two or more circuits. The circuits should be arranged so that it is possible to isolate any compartment in which a fire is reported by enough closed fire doors to stop drafts to the fire area. The following doors would be closed:

a) Each fire door in the area between the main vertical zone bulkheads immediately forward and aft of the fire area;
b) Each fire door in the main vertical zone bulkheads immediately forward and aft of the area; and
c) Each fire door in the adjacent main vertical zones forward and aft of the fire area.

An indication system that shows the "door open" and "door closed" condition should be provided. The device giving "door closed" indication should only operate on the final movement of closing.

The source of power for the fire door holding and release system should be the emergency power source.

16.3.3 Local control station

The local control station should be an enclosed, externally operable, fused switch or circuit breaker having a rating of not less than 10 A and 125 V, and should be of the maintained contact type. A single fire door holding magnet should be connected to the load end of this local control station, except that if several doors are near each other, a single local control station switch of ample rating may be used to release the doors simultaneously. A switch on each side of the door is preferred; but if only one switch is provided at each local door switching position, it should be easily accessible and conspicuous to anyone passing through the door opening.

16.3.4 Fire door holding magnet

Each fire door holding magnet should be designed to hold with a minimum force of 90 kg (200 lb), and should be capable of exerting a pull that equates to at least half the weight of the door, plus the force required to overcome any self-closing mechanism so that the door can be held open under a rolling condition of up to at least 15½° either way. Other retaining devices, e.g., solenoid controlled latches, should be capable of exerting a restraint equivalent to the above. When de-energized, the residual magnetism shall not impede the door from closing at inclinations of 3½° in any axis. If the arrangement of the electrical supply involves transfer relays to transfer the supply from a normal to a temporary source, a fire door holding magnet must be designed so that, with a pull on the armature of 50 kg (110 lb), the armature is held in the sealed position for at least ¼ s after the circuit to the magnet is opened. The fire door holding magnet should be designed for continuous duty in an ambient temperature of 40 °C with a temperature rise by thermometer measurement of not more than 55 °C for Class A insulation, and not more than 80 °C for Class B insulation. The electromagnetic coil should be vacuum-pressure impregnated, and the magnet enclosure should be either dripproof or watertight.

17. Control apparatus

17.1 General

Control circuits that extend outside the controller enclosure to remote devices should operate at 120 V or less, and conductors should be protected against damage from short circuits. Conductors wired in series with current-limiting devices, such as coils and resistors, that are located within the enclosure are considered to be adequately protected. Conductors not protected by current limiting parts within the enclosure should be fused.

Except for steering gear, overload protection should be provided for all motors, either by overload device or by motor-winding temperature sensing devices. This recommendation may be disregarded where controllers are equipped with an overload, jamming, or stepback relay of the instantaneous trip type, which arranges to insert resistance into the rotor circuit when the load exceeds approximately 200% of rated-load, and thereby limits the locked-rotor current to approximately 125% of rated current. For typical motor full-load and overload protection current values, see Table 11-1.

The design of control apparatus should incorporate all possible steps to eliminate more than one source of potential in an enclosure. Where the control functions, such as interlocking, indicating light circuits, heater circuits, etc., make it impracticable to connect the circuits to the load side of the controller contacts, but require a separate source of potential for successful operation, one of the following alternative precautions should be observed:

a) Limit the voltage of the circuit to not more than 55 V.
b) Provide a disconnecting device actuated by the panel door enclosure. The device and its connections should be designed so that there are no exposed electrically uninsulated surfaces.
c) A permanent instruction plate should be mounted on the external surface of the panel door enclosure stating that two or more sources of potential supply the equipment.

Controllers should have an internally mounted wiring diagram showing the complete circuitry, including external connections.

Where the ship arrangement conditions justify the application, it is recommended that consideration be given to arranging the controllers in groups in motor control centers, or on common panels.

Terminal studs or connection points equipped with compression lugs designed and tested for stranded conductors in accordance with ANSI/UL 486A-1991, for wire connectors and lugs should be provided for all outgoing cables.

Controller enclosures, the metal cases of instruments, and the secondaries of all instrument transformers should be grounded to hull ground potential. All wearing parts of controllers should be readily accessible for inspection and renewal.

17.2 Installation and location

Control apparatus should be located and arranged to provide access to all parts and to facilitate operation, inspection, and maintenance. The apparatus should be in a dry area, away from fluid system piping, and in a location least liable to exposure to mechanical damage and excessive heat. No wood or similar flammable material should be used in the installation of control apparatus.

Resistors should be located to ensure adequate circulation of cooling air, and to prevent transmission of heat to adjacent equipment items.

Where a number of motor loads are located in close proximity, individual motor controllers may be group-mounted in motor control centers. Control apparatus recommendations apply when individual controllers are group-mounted, since switchboard recommendations are not appropriate. Motor control centers should have dripproof enclosures, and drip shields should be provided over the entire assembly if not otherwise protected by a false ceiling in the compartment in which they are installed.

Pushbuttons, switches, and similar control devices, except the actuating control elements such as a thermal bulb or thermocouple initiating the operation, should not be installed in refrigerated spaces unless such location is essential to the purpose for which it is provided. Control device enclosures should provide an appropriate degree of protection, consistant with their installed location in the ship.

A service nameplate should be provided on all motor controllers and control devices, designating the application, rating, and circuit number.

17.3 Types

Control and starting apparatus is generally of the manual, magnetic, or solid-state type. A controller should contain a switching device to control the application of power to the load, and an overload device to provide load overheating protection.

For dc installations, the manual type usually consists of a line switch for fractional horsepower motors, or for larger motors, a panel type containing flat segments with a sliding contact or a drum type consisting of a rotatable cylinder fitted with projections or cams that close the contacts. These manually operated contacts carry the full motor current.

For ac motors, the control and starting apparatus may consist of a line switch, an across-the-line magnetic starter equipped with overcurrent protection, or a self-protected starter that combines circuit breaker, contactor, and overload relay providing coordinated motor circuit protection.

In the case of the magnetic type, the contacts that carry the motor current are operated by electromagnets designed to automatically accelerate the motor to a preset speed. Either time-limit or current-limit acceleration may be used. In order to start the operation of automatic acceleration or to stop the motor, two types of manually operated master switches are in general use. One type consists of a start-stop pushbutton station, and the other is a small drum-type master controller. These master switches conduct only the current levels necessary to operate the electromagnet coils.

Magnetic controllers are often configured for fully automatic operation by the application of a remote temperature, pressure, humidity, float, proximity, or optically operated device that starts and stops the motor within predetermined system limits.

In determining the proper type of starter for squirrel-cage ac motor applications, particular attention should be given to the capacity of the generating plant and the effects of the motor starting currents on the power system characteristics indicated in Table 4-1.

Reduced voltage ac starters should have starting and running overload protection, be of the manual or magnetic type, and should have self-contained autotransformers or resistors.

Solid-state type starters should inherently limit motor inrush current values.

Low-voltage protection should be provided except in those cases where low-voltage release is required by the regulatory authorities. Manually operated ac starters that are not of the across-the-line type should be equipped with low-voltage protection to prevent across-the-line starting upon return of voltage after an interruption. These starters should be provided with quick-make-and-break type switches and should be arranged so that it will be impossible to switch to the running position without having first gone through the starting position.

17.4 Protecting cases

All control apparatus, except when installed in switchboards, motor control centers, or in compartments assigned primarily to electrical equipment, should be protected by enclosures provided with hasps or the equivalent. In addition, where necessary to prevent unauthorized operation, means for locking should be provided.

Enclosures having hinged doors exceeding a height of 1145 mm (45 in) or a width of 610 mm (24 in) that, when open, expose live parts, should be provided with door positioners.

The types of enclosures for control apparatus should be determined by the location, and, unless otherwise recommended, the following should apply:

a) Watertight enclosures should be used for deck machinery unless the apparatus is mounted in deck houses or below deck.
b) Splashproof or dripproof enclosures should be used when the apparatus is mounted in main or auxiliary machinery spaces, or similar spaces adjacent to a weather deck access, where the equipment may be subject to splashing, mechanical damage, or dripping fluids.
c) Dripproof enclosures should be used in all interior locations where the apparatus may be exposed to dripping fluids or condensation.
d) Provisions should be made for maintaining adequate ventilation of the apparatus components in all types of enclosures.

Enclosures should be of substantial metallic construction and should protect the control devices from damage due to liquids or solid matter falling from any angle up to 15 degrees from the vertical. Enclosures should be made of corrosion-resistant material or have corrosion-resistant coatings applied both inside and out.

Cable entrance plates should be provided on splashproof or dripproof enclosures having a volume exceeding 3300 cm^3 (200 in^3). Top cable entrance plates should be fitted with gaskets, and should be at least 3.2 mm (1/8 in) thick to permit tapping for terminal tubes. For splashproof enclosures, the bottom cable entrance plate should be similar to the top plate. For dripproof enclosures, when cables enter through the bottom entrance plate, standard clamps or bushings may be installed instead of terminal tubes.

17.5 Disconnecting means

For every motor controller, an integral means of disconnecting both the motor and the controller from all supply conductors should be provided. A manually operated motor controller for motors rated not more than 1.5 kW (2 hp) and not more than 250 V may use a single device to serve as both controller and motor disconnecting means provided it has an ampere rating not less than twice the rated current of the motor.

For portable or semiportable motors supplied from a receptacle outlet, the plug and receptacle may serve as the disconnecting means.

Except as otherwise stated above, for motors up to and including a 37 kW (50 hp) rating, the disconnect means should be a switch with a horsepower rating not less than the motor rating or a circuit breaker with an ampere rating at least 115% of the motor rating. For larger motors, the disconnect may be a switch or circuit breaker with an ampere rating 115% of the motor rating. Ampere rated switches should be provided with a label plate warning against opening the circuit under load, except in an emergency.

The disconnect device may be in the same enclosure as the controller, or may be in a separate enclosure adjacent to the controller, and should be externally operated. The disconnect device should indicate by position of the handle, or otherwise, whether it is open or closed. If located in the same enclosure as the controller, the line side parts of the disconnect device should be guarded against accidental personnel contact. The branch circuit switch or circuit breaker on the distribution panel or switchboard may serve as the disconnect device if it meets all requirements herein and if it is in the same compartment as the motor controller. A disconnect device that is not within sight of both motor and controller, or that is more than 15 m (50 ft) from either, should be arranged for locking in the open position by means of a padlock. (Locks are not to be furnished with switches or panels unless specifically required.) The disconnect switch, if not directly adjacent to the controller, should be provided with an identification plate.

In motor control centers, the disconnecting means should be interlocked with the hinged door of the associated motor controller so as to either prevent the controller door from being opened while the circuit is energized; or to cause the disconnect device to open in the event that the controller door is opened.

17.6 Manual starters and controllers

Manually operated controllers require manual operation of the main contact switching device to start or stop a motor. The device should contain a trip-free overload relay. The controller should be of rugged construction, and arranged for operation without opening the enclosure. Low-voltage protection should be included.

17.7 Magnetic starters and controllers

Magnetic starters and motor controllers utilize electromagnetic main contactors to control the motor circuits that remotely start and stop the motors. The magnetic controllers should be operated by control circuits that include overload protection devices and are actuated by local or remote pushbuttons or similar master switches to suit the intended motor application. Either low-voltage release or low-voltage protection should be used, depending upon the motor application and regulatory requirements.

17.8 Solid-state starters and controllers

Power may be supplied to a motor through a solid-state switching device that is controlled locally or remotely by suitable master switches. Soft-start or variable speed control may also be applied by the solid-state switching device. An electromagnetic device, such as a contactor, or a circuit breaker with shunt trip, or equivalent, should be provided for disconnecting the motor under fault conditions.

17.9 Medium voltage controllers

Medium-voltage motor controllers (1000 V rms or greater) should be electromagnetic controllers utilizing current-limiting power fuses, vacuum, sulfur hexaflouride (SF_6) or air break contactors and a medium-voltage isolating means to disconnect the medium-voltage supply. Generally, the features should be similar to those previously described for low-voltage controllers, but with the following additional recommendations:

a) The isolating means should be externally operable with position indication.
b) The isolating means should be capable of interrupting the no-load current of the control-circuit transformer supplied with the controller.
c) The isolating means may be a three-pole switch or a drawout-type contactor.

The medium-and low-voltage sections of a controller should be mechanically segregated by means of permanent barriers or movable shutters, where possible.

Mechanical means, or a combination of mechanical and electrical means, should provide the following interlocking features:

a) Prevent the isolating means from being opened or closed unless all line contactors are open.
b) Prevent the opening of a medium-voltage compartment door when the isolating means are closed.
c) Prevent the isolating means from being closed when any medium-voltage compartment door of the controller is open.

Control-circuit transformers should be provided with primary and secondary fuses. Instrument potential transformers should be provided with primary fuses. The control circuit voltage should be 115 V ac to permit contactor testing from an external control source. Interlocking for this test feature should be arranged so that power cannot be applied to the motor and so that the 115 V control circuit is disconnected from the normal control-circuit transformer.

Medium-voltage controllers should be wired and assembled as complete, enclosed, and freestanding units with provision for sway bracing. A means of ground connection of the enclosure by bare metal-to-metal contact with the ship's structure should be provided. The secondaries of instrument transformers should also be grounded to the ship's structure.

17.10 Pushbuttons

Separately mounted pushbuttons and master switches for use with magnetic starters and controllers should be of the oiltight type in dripproof or watertight enclosures, depending on their location. Pushbuttons mounted in accommodation areas may utilize a protected switchbox. Pushbutton and master switch enclosures may be of the nonmetallic, casting, or sheet metal type with corrosion protection as recommended in 1.7.1.

17.11 Resistors

Resistors, mounting devices, and enclosures should be rugged and able to withstand shipboard vibration. The elements of all classes of resistors should be of corrosion-resistant material or should be thoroughly protected against the corrosive action of salt spray and atmospheric moisture, either by an effective corrosion-treatment process, or by being embedded in a material that will protect against corrosion.

17.12 Circuit breakers

Circuit breakers in motor controllers and motor control centers should comply with the recommendations in 7.5 and 11.28.

17.13 Knife blade switches and contacts

Knife blade switches and contacts should conform to the requirements set forth in 7.4.

17.14 Corrosion-resistant parts

To prevent deterioration and corrosion, bolts, nuts, pins, screws, terminals, springs, and similar parts that would be seriously damaged or rendered ineffective by corrosion should be made of corrosion-resistant material or, if made of steel, suitably protected against corrosion. Steel springs should be treated to resist corrosion in a manner that will not impair the spring quality. See 1.8.1.

17.15 Nameplates

A nameplate providing the data listed below should be installed on each controller, secured to the front of the enclosure. An additional nameplate should be provided for each separately mounted component such as circuit breakers, contactors, relays, or resistors giving sufficient data to provide identification and to facilitate the ordering of repair parts.

a) Marine (name of apparatus)
b) Name of manufacturer
c) Manufacturer's type number or class identification
d) Horsepower of motor
e) Rated volts
f) Rated current
g) Frequency (ac controllers only)
h) Number of phases (ac controllers only)

17.16 Tests

Prior to delivery, tests should be performed to ensure that the control apparatus is in accordance with these recommendations and is suitable for controlling the motor to which it is to be applied. It is not intended that each individual item of control apparatus be tested completely to verify compliance with these recommendations. Tests should be made to determine that the apparatus functions properly, with other tests performed or information obtained from previous tests on duplicate apparatus as may be necessary to ensure that the apparatus meets these recommendations.

17.17 Limits of temperature rises

Temperature rise limits and measurement procedures are provided below. The temperature rise values are based on 50 °C (122 °F) ambient temperatures [see 17.7.8 for 45 °C (113 °F) ambient].

17.17.1 Coils

The temperature rise of coils, when tested in accordance with the rating, should not exceed the values given in Table 17-1. Temperatures are measured as indicated.

17.17.2 Contacts

The temperature rise of contacts, when tested in accordance with the rating, should not exceed the following values; laminated contacts 55 °C (131 °F), solid contacts 65 °C (149 °F). All temperatures should be measured by the thermometer method described in 17.17.6.

17.17.3 Mechanical parts

Mechanical parts not in contact with insulation may reach temperatures that will not be injurious in any respect.

17.17.4 Buses, connecting straps, and terminals

The temperature rise, when tested in accordance with the rating, should not exceed 40 °C (104 °F) when measured by the thermometer method described in 17.17.6.

17.17.5 Resistors

The temperature rise, when tested in accordance with the rating, should not exceed 365 °C (689 °F) when the thermocouple is placed in contact with the resistive conductor, or 240 °C (464 °F) when the mercury thermometer is placed in contact with the embedding material. The temperature rise of the issuing air, when measured 1 in from the enclosure, should not exceed 165 °C (329 °F). All temperatures should be measured by the thermometer method described in 17.17.6.

17.17.6 Thermometer method of temperature measurement defined

This method is the measurement of temperature by mercury or alcohol thermometers, by resistance thermometer, or by thermocouple, with the instrument being applied to the hottest accessible part of the apparatus.

17.17.7 Resistance method of temperature measurement defined

This method is the determination of the temperature rise by comparison of the measured winding resistance taken at operating conditions with the measured winding resistances taken at known minimum and maximum ambient temperatures. Measurements should be taken with the winding energized and de-energized.

17.17.8 Ambient temperature

Controllers installed in main and auxiliary machinery spaces containing significant heat sources such as prime movers and boilers should be selected on the basis of 50 °C (122 °F) ambient temperature. Controllers for other locations where the ambient temperature will not exceed approximately 45 °C (113 °F) may be selected on the basis of 45 °C (113 °F) ambient temperature. In the latter case, 10 °C (50 °F) additional rise should be allowed for all parts.

17.18 Insulation-voltage test

The standard test voltage for all switching and control apparatus should be as follows:

Voltage rating	Test voltage
0–600 V	1000 V + (2 × nominal voltage rating)
601–5000 V	2000 V + (2.5 × nominal voltage rating)

The test voltage should be successively applied between each electric circuit and grounded metal parts, and between each principal electric circuit and all other principal circuits. Caution should be used in choosing points of application when sensitive devices, such as semiconductors, are included. Circuits that may be grounded in use should be disconnected from ground for this test.

Other dielectric withstand test features such as; characteristics of test voltage, duration of tests, reduction of test voltage values for assemblies, etc., should be in accordance with ANSI/NEMA ICS 1-1993.

17.19 General requirements for contactors

When subjected to destructive arcing, contactors should be provided with effective removable arc-rupturing contacts and magnetic blowouts or equivalent. They should not open or close because of shipboard vibration and inclination conditions as described for switchgear in 1.5.

When testing a contactor for successful operation at the minimum voltage for continuous duty, the contactor coil should be subjected to the normal line voltage until constant temperature is reached and then tested for successful closing at the minimum voltage.

17.19.1 AC contactors

AC contactors should be able to withstand 110% of rated voltage continuously without injury to the operating coils and should close successfully at 85% of rated voltage. Contactor should remain closed without chattering, at 70% of rated voltage.

17.19.2 DC contactors

DC contactors should be able to withstand 110% of rated voltage continuously without injury to the operating coil and should close successfully at 80% of rated voltage when the coil is at its maximum working temperature.

Table 17-1—Limits of observable temperature rises for ac and dc control

Coil type	Method of temperature determination (see 17.17.6) and 17.17.7)	Limits of observable temperature rise (degrees Celsius above 50 °C ambient)			
		A	**B**	**F**	**H**
Wire-wound coils	Thermometer	55	80	105	130
	Resistance	75	100	125	150
Single-layer series coils with exposed surfaces uninsulated or enameled	Thermometer	80[a]			

[a]Applies to coils with a fiber or other similar insulating sleeve or collar for insulating the coil from the frame or core.

18. Control application

18.1 General

Auxiliaries for propulsion and ship service equipment should include the apparatus necessary for starting, stopping, reversing, and controlling the speed of motors, together with essential safety devices. The application of the various types of controllers and starters should be given careful consideration for the particular conditions surrounding each auxiliary, including the location, the nature and length of duty to be performed, and convenience of operation and maintenance.

Controllers should be manual, magnetic or solid-state depending on the required features, such as type of protection, performance, whether integral or remote control, and on the rating of the motor controlled.

18.1.1 Motor under-voltage protection

All controllers should provide motor protection against under-voltage conditions by either low-voltage protection (LVP) or low-voltage release (LVR). LVP and LVR disconnect the motor when the voltage has dropped below 80% of rated voltage and allow a motor to be restarted when the voltage is above 85% of rated voltage.

LVP will prevent automatic motor restart by requiring operator reset action. This can prevent overloading the electrical system by reducing the cumulative magnitude of starting inrush currents from simultaneous motor starting. LVP can also prevent damage to driven auxiliaries and prevent possible injury to operating personnel by inhibiting automatic restart.

LVR provides for automatic motor restart upon restoration of voltage. LVR should be provided for certain essential auxiliaries. The use of controllers of the LVR type should be limited to avoid excessive starting current when a group of motors with LVR controllers are restarted automatically upon return of voltage after a voltage failure. Sequential starting should be considered.

Each motor controller for a fire pump, passenger elevator, steering gear, or auxiliary that is essential to the vessel’s propulsion system should have LVR if automatic restart after voltage restoration is not hazardous. If automatic restart is hazardous, the motor controller should have LVP. Motor controllers for nonessential motors should not have LVR unless the starting inrush current and the short-time sustained current of the additional LVR load is within the capacity of one generator set.

Manual-type controllers may be used for small motors where the starting current limitation protective feature of LVP is not necessary and where the application results in smaller and lighter equipment.

18.1.2 AC controllers

AC controllers should be selected on the basis of the starting characteristics of the motor, the effects of voltage dips resulting from starting current on the distribution system, the torque, and the mechanical requirements of the drive. Controllers should be selected so that voltage dips on the power distribution system do not exceed the following values under motor starting conditions:

a) Motor-driven auxiliaries such as an air conditioner, air compressor, or refrigerator, which in normal operation may start several times an hour, should not produce a voltage dip at the generator switchboard in excess of 10% or a permanent voltage reduction in excess of 5%.
b) Other motor-driven auxiliaries such as fire pumps, anchor windlass, motor-generator sets, and steering gear which in normal operation do not start several times an hour, should not produce a voltage dip at the

generator switchboard in excess of 18%. This is the maximum permissible voltage dip at the generator switchboard.

c) Any motor fed from a remote load center that does not start several times an hour should not produce a voltage dip greater than 20% at the load center.
d) A group of motors that automatically restart upon closing a feeder breaker should not produce a voltage dip greater than 30% at the power panel from that supplied, or a dip which will prevent supplying the starting torque requirements of the most remote motor.

The use of open transition wye-delta windings on multispeed induction motors should be avoided as far as practicable because of the difficulties associated with the greater number of controller contacts and cable conductors required for the controllers for motors with such windings.

18.1.3 DC controllers

In general, across the line dc controllers should be used only with motors rated 0.75 kW (1 hp) and smaller. DC controllers should provide smooth acceleration of the load.

18.1.4 Overload relays and ambient temperature

When the controller is located in an area where the ambient temperature may differ from that of the motor controlled, or when the motor drives auxiliaries whose interruption of service would seriously interfere with the safe operation of the vessel, ambient compensated overload relays should be used. The change in pickup setting should not be more than 5% for each 10 °C (50 °F) change in ambient temperature in the range between 20 °C (68 °F) and 70 °C (158 °F).

18.2 Deck machinery

18.2.1 General

Deck machinery should use a reversible controller with speed control as required where the motor is directly connected to the machine. Unless the design prevents application of an overhauling load to the driving motor under all conditions of operation, care should be taken to accommodate the accompanying reverse power. Where electro-hydraulic drive is used, nonreversing controllers should be used for the pump motors.

Magnetic brakes should be used for stopping and holding the load, unless the equipment is inherently self-locking, or other type of load brake is supplied. On all dc installations, automatic dynamic braking should be provided on all points lowering. Automatic stalling protection should be provided where required by the application.

Resistors, where used, should be of the nonbreakable and corrosion-resistant type. Resistors and power electronics devices carrying motor load should be capable of carrying 125% load for 5 min. DC installations of the rheostatic type should have an armature shunt point on the first position in each direction.

18.2.2 Capstan and windlass

The control equipment of a line-handling capstan, or an anchor windlass with direct-connected motor used as a capstan, should be interlocked with the mechanical equipment and designed to provide the same speed-torque characteristic for both directions of rotation.

A jamming or step-back overload relay of the instantaneous type should be installed to provide current limiting of the motor circuit when the load exceeds approximately 200% of rated load and thereby limit the stalled motor current to approximately 125% of rated current. Magnetic controllers should be designed to automatically reset the jamming or step-back relay. The control setting should automatically return to a position corresponding to the setting of the master switch. Manual controllers should be designed to be returned to the first position to reset the jamming or step-back relay before the motor can be brought up to speed again.

For small vessels, where the capstan motor is less than 5 hp, a nonreversing controller with one running point may be used.

18.2.3 Cargo and utility winches

For cargo winch service, manual control may be used for ratings up to and including 7.5 kW (10 hp) at 115 V and 16 kW (20 hp) at 460 V and 575 V. General utility winches for infrequent service may be equipped with manual control up to and including 19 kW (25 hp) at 115 V and 37 kW (50 hp) at 460 V and 575 V.

18.2.4 Electric power-operated boat winches

Each motor controller and switch associated with an electric power-operated boat winch should be designed to prevent corrosion of its working parts. Each structural part, such as an enclosing case, if not made of corrosion-resistant materials, should have a corrosion-resistant finish. Insulating material should have low water absorption properties and the effect of such water absorption should not significantly decrease the material’s dielectric properties.

Each device in the weather should be watertight or in a watertight enclosure. Where a gasket is used for a water seal between parts of an assembly, the gasket should be fixed to prevent its falling out or becoming loose when the unit is disassembled. A hole in an equipment housing for the purposes of providing means for the attachment of a part on its interior or for securing a cover or similar device should not penetrate the total thickness of the housing. Each totally enclosed unit should have a valve, or at least one hole with a minimum diameter of 13 mm (0.5 in) closed by a pipe plug. The valve or hole should be at the bottom of the enclosure or as near the bottom as practicable.

Each boat winch motor controller should have a main line emergency disconnect switch. If accessible to an unauthorized person, the switch should have a means for locking in the open-circuit position. The switch should not be capable of being locked in the closed-circuit position.

18.3 Steering gear

18.3.1 General

When the main and auxiliary steering gears are electrically powered and controlled or when an arrangement of two or more identical power units are utilized, the vessel should have two separate steering systems, each consisting of a power unit, steering control system, steering gear feeder, and associated cable and ancillary equipment. The two systems should be separate and independent on a port and starboard basis.

Each steering gear motor controller should include the following apparatus:

a) Power input disconnect switch or nonautomatic circuit breaker
b) Power available indicator light
c) Steering motor START/STOP pushbutton
d) Motor running indicator light
e) Steering control system power supply transformer
f) Steering control power supply transformer output circuit breaker having only an instantaneous trip
g) Control power available indicator light
h) Steering control power transfer switch, LOCAL/NAVIGATING BRIDGE
i) Steering motor overload alarm relay

j) Input power failure alarm relay
k) Control power failure alarm relay
l) Phase failure trip relay (for three-phase fused power sources)

18.3.2 Feeder circuits

Vessels with one or more electric driven steering power units should have at least two feeder circuits. One of these feeder circuits should be supplied from the main switchboard. On vessels where the rudder stock is required to be over 230 mm (9 in) in diameter in way of the tiller (excluding strengthening for navigation in ice) and an emergency power source is required, the other feeder circuit should be supplied from the emergency switchboard or an alternative power supply. Where an alternative power supply is provided, it should be available automatically within 45 s of loss of power supply from the main switchboard, be located in the steering gear compartment, and be used for no other purpose. The alternative power supply should have capacity sufficient for one-half hour of continuous operation of the rudder from 15° on one side to 15° on the other side in not more than 60 s with the ship at its deepest sea-going draft while running at one-half of its maximum ahead service speed or 7 kn, whichever is the greater.

Vessels that have a steering gear with two electric motor driven power units should be arranged so that one power unit is supplied by one feeder and the other power unit is supplied by the other feeder. Each steering gear feeder circuit should be separated as widely as practicable from the other and should have a disconnect switch in the steering gear room. Each feeder circuit should have a current-carrying capacity of 125% of the full-load current rating of the electric steering gear motor or power unit plus 100% of the normal current of one steering control system including any associated motors.

The overcurrent protection for each steering gear circuit at the main and emergency switchboards should be an instantaneous circuit breaker set to trip at not less than 200% of the locked rotor current of one steering gear motor plus other loads that may be on this feeder for ac installations. For dc installations, the instantaneous trip should be set not less than 300% and not more than 375% of the rating of the steering gear motor. No other overload device or fuse that will open the power circuit should be provided in the motor or control circuits.

The opening of the main or emergency switchboard steering gear circuit breaker should operate audible and visual alarms located at the main propulsion control station and the navigating bridge.

Each steering gear motor circuit should be equipped with an overcurrent relay to operate audible and visual alarms located at the main propulsion control station and the navigating bridge. No other functions should be performed by this relay.

The steering gear motor circuit should be capable of accelerating the motor under a torque requiring a current of 150% of motor rating. If the inherent design of the steering gear does not prevent overhauling of the rudder, a magnetic brake should be installed.

A pilot light for each steering gear motor to indicate motor running should be provided at the main propulsion control station and the navigating bridge. This pilot light should be fused.

18.3.3 Direct-drive steering gear

The control for direct-drive ac steering motors should be of the solid-state, reversible, variable-speed drive type. For direct-drive dc motor installations, the control may be rheostatic or variable voltage. These controls should include step-back overload protection without opening the circuit.

18.4 Steering control systems

18.4.1 General

Electric control may be of the self-synchronous “follow-up” type or “non-follow-up” type.

The “follow-up” type uses a remotely controlled servomotor which, by means of signal feedback, gives a definite rudder position for each steering wheel position. A follow-up control system may be provided which produces at the steering gear machinery a motion and positioning that is in synchronism with the position and motion of the steering wheel in the remote location.

The “non-follow-up” type electric control consists of a master switch with spring return to the OFF position, which gives right or left rudder motion. Rudder motion is continuous in the direction indicated, until the limits of travel of the rudder are reached or the master switch returned to the OFF position. The rudder remains in the last ordered position until the master switch is moved from the OFF position.

Any of these electrically powered systems may function in conjunction with automatic steering systems. See Clause 30.

18.4.2 Steering control system installation

Each steering power unit should have at least one steering control system capable of being operated from the navigating bridge. Additional control stations may be provided as required elsewhere on the ship. Each steering control system on vessels of 300 gross tonnes and above should be arranged so that each steering gear power unit can be controlled in the steering gear room. A selector switch should be provided in the navigating bridge for delegating the control to any one of these stations. All circuits from each steering station should be entirely disconnected by the selector switch, except those circuits to the station in use. A rudder angle indicator should be provided at each such station (see 27.3).

The steering control system for a steering power unit should be separated as widely as practicable from each other steering control system and each steering power unit that it does not control.

Each navigating bridge steering control system should have a switch in the navigating bridge that is arranged in such a way that one action of the switch’s handle automatically puts into operation a complete steering control system and associated steering power units. If there is more than one steering control system, this switch should be:

a) Operated by one handle;
b) Arranged so that each one individually, or both steering control systems and all associated steering power units can be energized from the navigating bridge;
c) Arranged so that the handle passes through an “off” position when transferring from one steering control mode to another; and
d) Arranged so that the switches for each system are in separate enclosures or separated by fire-resistant barriers.

Each steering control system should receive its power from the feeder circuit for its steering power unit in the steering gear room and have a switch that is in the steering gear room and disconnects the steering control system from its power source. Each motor controller for a steering gear should be in the steering gear room and have low voltage release. A means should be provided to start and stop each steering gear motor in the steering gear room.

18.4.3 Steering indication and alarm system

A steering indication and alarm panel should be installed at the main propulsion control station and in the navigating bridge. The following items should provided:

a) A motor running indicator light for each steering power unit
b) A control power available indicator light for each steering control system
c) Visual and audible alarms for
   1) Low oil level in each hydraulic oil reservoir
   2) Steering power unit motor overload
   3) Power supply failure to steering power unit
   4) Power supply failure to steering control system

A common audible alarm may be used in conjunction with individual visual alarm indicators. Steering indication and alarm functions may be included with other vital alarm functions in a common panel or console, but should be grouped and clearly marked as steering system alarms.

18.4.4 Steering failure alarm system

Each vessel that has power driven main or auxiliary steering gear should have a steering failure alarm system that actuates an audible and visible alarm in the navigating bridge when the actual position of the rudder differs by more than 5° from the rudder position ordered by the follow-up control systems for more than

a) 30 s for ordered rudder position changes of 70°;
b) 6.5 s for ordered rudder position changes of 5°; and
c) The time period calculated by the following formula for ordered rudder position changes between 5° and 70°:

$$t = (R/2.76) + 4.64$$

Where

t = maximum time delay in seconds
R = ordered rudder change in degrees

The alarm system should be separate from, and independent of, each steering gear control system, except for input received from the steering wheel shaft.

Each steering failure alarm system should be supplied by a circuit that

a) Is independent of other steering gear system and steering alarm circuits;
b) Is fed from the emergency power source through the emergency distribution panel in the navigating bridge, if installed; and
c) Has no overcurrent protection except short-circuit protection by an instantaneous fuse or circuit breaker rated or set at 300% of either the current-carrying capacity of the smallest alarm system interconnecting conductors or the normal load of the system.

18.5 Ventilation fans

AC starters may be of the fused switch, across-the-line, reduced voltage, two-speed, solid-state, or wound-rotor type equipped with overcurrent protection for either manual or magnetic operation depending on the size and amount of speed control required.

DC starters may be arranged for speed regulation by armature or field control, or both, as required by the application. For motors of appreciable size, field control is recommended since the operating losses are kept to a minimum.

Motors that should not restart after voltage failure should be equipped with low-voltage protection.

18.6 Galley, laundry, workshop, print shop, and similar spaces

Control for appliances located in the above spaces should have dripproof enclosures unless the equipment enclosure provides an equivalent degree of protection. These controls should preferably be of the magnetic type where other than a line switch is required. Magnetic type control may be supplied to function with a master switch of either the pushbutton or drum type. Automatic appliances such as refrigerators, drinking fountains, etc., if permanently connected to the electric power system, should have an adjacent enclosed switch that disconnects all conductors, or should be fed from a distribution panel located near the appliances. If the appliance is connected to the power system by means of a portable cord and an attachment plug that disconnects all conductors, no switch is required.

18.7 Machinery space auxiliaries

Controllers for machinery space auxiliaries such as pumps, etc., should be provided with the degree of speed control required by the driven equipment. Low-voltage release should be provided on controllers for certain auxiliaries that are essential to the operation of the propulsion plant, such as lube oil, condensate, circulating, feed, and cooling water pumps, where the automatic restart after a voltage failure will not have any deleterious effects to the system voltage. Where deleterious effects to the system voltage may result, sequential starting should be considered to ensure compliance with the recommendations in Table 4-1.

18.8 Air compressor

Compressors equipped with more than one stage should have an automatic unloading device to facilitate motor starting.

18.9 Remote stopping systems

18.9.1 Power ventilation systems

All ventilation systems should be provided with remote means for stopping the motors in case of fire or other emergency. The emergency means for stopping machinery space ventilation fans, accommodation ventilation fans, and vehicular/cargo space ventilation fans should be separate and completely independent of each other.

The circuit breakers for ventilation circuits should be grouped on the main switchboard and marked, “IN CASE OF FIRE TRIP TO STOP VENTILATION.”

For the machinery space ventilation, the remote stop means should be provided in the passageway leading to, but outside of, the machinery space or should be in the machinery space fire fighting station. For all other ventilation systems, two emergency stop stations should be provided, one in the navigating bridge, and the second as far away as practicable. The circuit breaker feeding power to the equipment for these systems may be considered as the second station. The recommendations in this paragraph do not apply to closed ventilation systems for motors or generators, diffuser fans for refrigerated spaces, room circulating fans, or exhaust fans for private toilets of an electrical rating comparable to that of a room circulating fan.

18.9.2 Machinery systems

Each forced draft fan, induced draft fan, blower of an inert gas system, fuel oil transfer pump, fuel oil unit, fuel oil service pump, fuel oil centrifuge, lube oil centrifuge, lube oil service pump, lube oil transfer pump and any other oil pumps should have a stop control that is outside the machinery space, adjacent to the machinery space ventilation remote stop, and accessible in the event of fire in the space.

Emergency stop switches should be provided in a convenient location for any motor-driven pump whose overboard discharge is above the light load line and discharges in way of lifeboat or liferaft launching gear. These switches should be installed in waterproof locked enclosures with "break-glass" covers or an equivalent for emergency access. The stop control should be suitably protected against accidental operation or tampering and should be suitably marked.

18.9.3 Machinery and ventilation stop stations

The system for remote stopping of ventilation, fuel oil pumps, lubricating oil pumps, oil transfer, and centrifuge pumps should not require a separate power source.

The emergency stop stations should be protected by glass doors marked "IN CASE OF FIRE BREAK GLASS AND PUSH BUTTON TO STOP VENTILATION/OIL PUMPS" (or other suitable wording to reflect the type of switch or actuator and the equipment to be stopped). Each stopping device should be provided with a nameplate identifying the system it stops. The remote stop system should be of the undervoltage protection type and be arranged so that severe damage to the master switch or cable will automatically stop the equipment.

Means for stopping galley equipment exhaust fans should also be located in a station immediately outside the galley door.

18.10 Solid-state motor controllers

Solid-state motor controllers utilizing static power converters have a wide range of applications in controlling shipboard machinery. Variable speed or soft starting motor controls can be used for pumps, fans, cranes, deck machinery, or any other application where variable speed, reversing, or precise speed control is desired. Converters can be dc/dc, dc/ac, ac/dc, or ac/ac and be either regenerative (four quadrant) or nonregenerative (two quadrant).

The location of solid-state motor controllers should be given careful consideration, especially for units requiring forced air cooling. Weather deck locations or locations subject to spray or washdown should be avoided. Engine room locations are acceptable as far as moisture is concerned but elevated temperatures should be considered when sizing power components in high ambient temperatures. Units in machinery spaces should be rated for operation in a 45 °C environment. Solid-state motor controllers should be capable of operating in moist, dusty, and oil-laden atmospheres. Equipment should be able to withstand humidity levels of up to 100% and the vibration levels in 1.6.1. The units should be capable of continuous operation when the steady-state power supply voltage varies ±10% and when there is a 3 s voltage transient of ±20%. The unit should also be capable of continuous operation when the steady-state frequency varies ±5% and when there is a 3 s transient of ±10%.

Enclosures should be dripproof or watertight. Enclosure openings for cooling air should have filters. Devices requiring forced air cooling or controllers utilizing multiple load sharing power bridges should be equipped with over-temperature detectors for alarm (local and remote) and with remote shutdown. Backup equipment should be considered for units controlling vital machinery, or other critical functions. Power semiconductors should have a peak inverse voltage (PIV) of 1200 V when connected to a power source of 480 V ac or less. Series connection of lower-voltage devices should not be used to achieve the 1200 V rating. Semiconductors may be connected in parallel to increase current capacity provided circuitry is included to ensure equal load sharing.

In applications such as cranes, load lowering will cause power to be generated in the motors. This power must be absorbed by other power-consuming devices or the generator sets, or must be dissipated as heat into dynamic braking resistors. Failure to absorb regenerated power may cause reverse current relays to operate or cause an overspeed condition on the generator prime mover. Multiple step braking resistor assemblies are recommended over single step units. Multiple step control connects the minimum amount of resistance required to absorb a given level of regenerative power without causing undue stress on the generators or distribution system. Dynamic braking resistors should be protected against overheating.

19. Brakes

19.1 Types

Brakes may be of the shoe, band, or disk type, and may be mounted separately or attached to the motor.

19.2 AC brakes

All ac brakes should be wound for the motor supply voltage and frequency.

19.3 DC brakes

All dc brakes should be insulated for the same voltage as that of the motors for which they are used. The brake winding may be series or shunt type as desired. Series-wound brakes should be designed to release down to at least 40% full-load current and in every case on the starting current, and to set at not more than 10% full-load current. Shunt-wound brakes should operate satisfactorily at 80% rated voltage at maximum working temperature and the construction or protection should be such that the windings will not be damaged by inductive discharge. Shunt coils may have an external series and discharge resistance.

19.4 Accessibility

Shoe-type brakes should permit the removal of the brake shoes and brake wheel without the removal of the magnet, magnet housing, brake base, or without disturbing the base alignment of the brake. Disk-type brakes should permit the removal of the brake housing away from the motor or the motor away from the brake housing. The construction of the brake should be such that exact alignment of the shoe or disk with the centerline of the armature is not necessary.

19.5 Enclosures

The electric operating portion and the mechanical portion (wheel, shoes, etc.) of the brake may be open, dripproof, or waterproof as required for the application.

19.5.1 Open type

A shield should be provided over the mechanical portion for safety and protection. Brake coil housings should be dripproof or watertight. Brake coil housings of the waterproof type, if provided with drain plugs, should carry a CAUTION plate advising personnel not to drain when hot. The waterproof housing should be arranged for drilling and tapping to suit kick pipe or stuffing tubes.

19.5.2 Dripproof enclosed

A dripproof enclosure covering the entire brake should be provided.

19.5.3 Waterproof enclosed

A substantial waterproof housing should be provided to enclose all parts of the brake. Shaft seals should be included.

19.6 Construction

All bolts, nuts, pins, screws, terminals, springs, etc., should be of corrosion-resistant material or steel suitably protected against corrosion. Steel springs should be treated to resist moisture in such a manner as not to impair their spring quality.

All bolts, nuts, pins, screws, terminals, springs, etc., should be of corrosion-resistant material or steel suitably protected against corrosion. Steel springs should be treated to resist moisture in such a manner as not to impair the spring quality. A nameplate providing the following data should be mounted conspicuously on the brake:

a) Marine (name of apparatus)
b) Name of manufacturer
c) Type
d) Frame
e) Voltage
f) Armature travel
g) Torque
h) Spring compression
i) Rating (time)
j) Serial number
k) Coil specification number
l) Inrush current (ac only)
m) Frequency (ac only)
n) Number of phases (ac only)
o) Maximum continuous current (dc only)
p) Series or shunt (dc only)

19.7 Tests

Tests should be performed prior to delivery to ensure that the brake is in accordance with these recommendations. When a brake is a duplicate of one already tested, only such tests need be made that are necessary to demonstrate that the brake operates successfully. Spare coils should be given regular high-potential tests as described in 14.16. Other spare parts need not be tested in the entire assembled form. Temperature rise for coils need not be tested in the entire assembled form. Tests for waterproofness should be of the same nature as those for the motor to which the brake is attached. Temperature and insulation tests should be made in accordance with 14.14 and 14.15. Spare coils for ac brakes should be tested for short-circuited turns.

19.8 Limits of temperature rises for coils

The temperature rise of brake coils when tested in accordance with the rating should not exceed the values given in Table 17.1. The temperature rise of ac torque motors used as brake operators, when tested in accordance with the rating, should not exceed values given in Table 14-1.

19.9 Spare parts

Spare parts should be provided as recommended by the applicable Classification Society.

20. Brake application

Brake coils for intermittent rated motors should not overheat when energized for the time rating of the motor to which they are connected. Continuously rated coils should be capable of operation continuously at rated voltage and current.

Brakes should have a torque rating equivalent to the torque rating of the motors to which they are attached. Brake magnets should not be noisy when the armature is seated against the core. DC brakes may be used with power supplied from ac/dc rectifiers.

21. Magnetic friction clutches

21.1 General

Magnetic friction clutches should be insulated for the same voltage as that of the motors or other electric equipment with which they will be used. Magnetic clutches consist of two sections, one containing the magnetic winding and the other a steel disk or faceplate that forms the armature of the magnet. When current is passed through the winding, the clutch becomes engaged; when the circuit is opened, the clutch becomes disengaged. The disengagement should be assisted by a spring plate or springs and, when disengaged, the two sections should stand a short distance apart with a positive running clearance. The usual type of clutch provides direct magnet action, the magnet being located so that its direct pull produces the pressure between the friction surfaces on the magnet and armature. The engagement of the clutch members, when the coil is energized, should be smooth and positive. The clutch should have the pressure between the members balanced within the clutch itself so that there is no end thrust. Magnetic clutches should be accurately balanced at operating speeds.

The friction lining and magnet coil should be readily accessible without disturbing either the driving or driven shaft. Suitable means for adjustment of the friction surface should be provided.

All small parts should be protected against corrosion as recommended for motors. Collector rings for current supply to the clutch should be of noncorroding material. Double-brush contacts should preferably be supplied to ensure positive contact at all times.

A nameplate should be provided giving the following data:

a) Marine (name of apparatus)
b) Name of manufacturer
c) Type
d) Voltage
e) Maximum continuous current
f) Torque
g) Serial number
h) Normal revolutions per minute

21.2 Tests

Tests should be made prior to shipment for balance, temperature rise, and dielectric strength, in accordance with 14.13. The temperature rise should conform to Table 5-1 with the clutch stationary. The clutch should develop its rated torque under normal conditions without slipping.

22. Heating equipment

22.1 General

22.1.1 Construction

Heaters should be designed and constructed to heat the surrounding air by convection. They may be blower type design, where air is forced through the heating element by a fan integral to the heating unit. Heaters in accommodation, machinery, and service spaces should meet the following requirements:

Location	Max rating (V)
Accommodation spaces (bulkhead mounted)	240
Machinery and service spaces	575

Power requirements	Number of heating elements
1500 W or less	1
2000 W and above	2 or more

Heater construction should be strong and durable, with all parts solidly built to withstand vibration under service conditions. The framework should be of substantially proportioned metal, with parts securely fastened together. Heaters should have nonflammable insulating material, or adequate air circulation, between the heater and the mounting surface or between the heater and adjacent surfaces. Portable heaters should have a suitable clip or bracket fitted to retain the heater in a fixed position.

Heaters installed on or adjacent to decks or bulkheads should be protected by perforated or expanded metal coverings or the equivalent. The ends, back, and top of these heaters may be solid material.

Heaters with exposed surfaces installed flush with bulkheads should protect the elements with a screen or guard of perforated or expanded metal. The remaining sides of these heaters should be protected by a solid metal enclosure designed to meet recommended temperature limitations.

Heaters mounted on bulkheads should have the heater top slanted or otherwise designed to prevent the hanging of towels or similar flammable material on the heater. The protecting guard should be strong enough to resist being forced against current-carrying parts and to provide protection against electrical or mechanical injury. The heater openings should be sized small enough to prevent heating elements from being short-circuited or damaged by accident. All metal parts of the heater should be suitably protected against corrosion.

22.1.2 Heating elements

Heating elements should be of the enclosed type with the element jacket constructed of corrosion-resistant material. Heating elements should utilize uniform units, easily installed and replaced. The heating element material should not corrode or oxidize. Alloys containing zinc are not recommended for this purpose. Heating elements should not be constructed of flammable material. All heating element connections should be accessible and designed so that they will not loosen due to vibration. Heating element supports should be wired to a terminal block with the connectors and leads brought out through insulating bushings. All insulating parts should be unaffected by heat from the heating elements.

22.1.3 Control switches

A suitable regulating switch mounted on an approved insulating base should be provided. Heaters should be equipped with manual reset type thermal cutouts to prevent overheating of the elements. Thermostatically controlled contactors should be provided for multistage heaters.

22.2 Temperature and tests

Heater enclosure case temperatures should not exceed the following:

Type heater	Maximum enclosure case temperature
Flush type	100 °C (212 °F)
All others	125 °C (257 °F)

When heaters are mounted on, or adjacent to, a deck or bulkhead, heater construction should prevent the nearest deck or bulkhead surface from exceeding 55 °C (131 °F). For test purposes, an ambient temperature of 25 °C (77 °F) should be used. The heater, when hot, should withstand the application of 1000 Vac, 60 Hz, for 1 min between the frame and current-carrying parts.

22.3 Nameplates

Every heater should have a nameplate attached inscribed with the following data:

a) Marine (name of apparatus)
b) Name of manufacturer
c) Type
d) Voltage
e) Amperes
f) Watts
g) Model and serial number

23. Lighting equipment and illumination

23.1 Lighting fixtures

Each interior lighting fixture not located in a wet or damp location should be certified by a nationally recognized testing laboratory for compliance with an applicable lighting fixture standard. Additionally, exterior lighting and interior lighting in a wet/damp location should be certified by a nationally recognized testing laboratory for compliance to an applicable marine lighting fixture standard. See Clause 33 for guidance on lighting fixtures in hazardous locations.

No fixture should be used as a connection box for a circuit other than the branch circuit supplying the fixture.

Each lighting fixture installed in the weather or in a location exposed to splashing water should be watertight. Each fixture in a damp or wet location should at least be dripproof.

Each fixture and lampholder should be permanently mounted. Each pendant-type fixture should be suspended by and supplied through a threaded, rigid conduit stem. Each table lamp, desk lamp, floor lamp, and similar fixture should be secured in place so that it cannot be displaced by the roll or pitch of the vessel.

Exterior lighting should not interfere with required navigational lighting and should not impair night vision from the navigating bridge.

23.2 Location

The preferred location for fixtures for general lighting is on the overhead, except where decorative lighting is desired for special effects. The fixtures should be located for maximum protection and should not be obscured by moving or stationary objects. When located on bulkheads, they should be about 1.8 m (6 ft) above the deck.

An indicator light should be installed outside each refrigerated space to show when the refrigerated space lights are energized.

23.3 Provisions for portable devices

Receptacles for portable lights and similar equipment should be provided in or near chain lockers, deck machinery, steering gear, machinery spaces, shaft alleys, refrigeration spaces, and similar locations. Receptacles located where they could be exposed to moisture should be watertight. Non-watertight receptacles may be used in baggage rooms, mail rooms, deck lockers, storerooms, passenger and crew accommodations, deck fan rooms, and similar places. Portable lights should not be used for built-in berths. Lights on beds or other furniture connected by portable cable should have the cable secured to the furniture to reduce the amount of loose cable to a minimum. Cords for bed lamps, floor lamps, table lamps, and desk lamps for new installations should in general not exceed 1.5 m (5 ft) in length.

23.3.1 Receptacle configuration and marking

Where receptacles are provided that have a voltage other than the ships normal lighting voltage (typically 115 V) they should be of a type that will not permit attaching equipment for which the voltage is unsuitable, and they should be permanently marked with the receptacle voltage.

23.3.2 Desk lights

Desk lights should be secured to prevent displacement by roll and pitch of vessel. Means should be provided to effectively ground all external metal parts.

23.3.3 Fans

Desk and bracket fans should be permanently secured and provided with a guard on the front and sides to prevent contact with the blades. Overhead ceiling fans should be suitably guarded. Fan receptacles should be located within 1.5 m (5 feet) of the fan. Means should be provided to effectively ground all external metal parts.

23.4 Permanent watertight fixtures

In general, all lighting fixtures for locations exposed to weather or splashing seas should be watertight. Watertight lighting fixtures are not required for any interior locations, except refrigerated compartments, chain lockers (when permanently illuminated), or locations where exposed to splashing water.

Watertight fixtures installed in outside spaces should be constructed of corrosion-resistant material. The globe should be protected by a suitable guard. Watertight fixtures installed in inside spaces may have the junction box that forms a part of the fixture constructed of material suitably protected against corrosion, but the portion of the fixture containing the screw threads for the globe and guard should be constructed of corrosion-resistant material.

23.5 Permanent nonwatertight fixtures

Nonwatertight lighting fixtures may be provided for interior locations, except where watertight fixtures are recommended. Nonwatertight lighting fixtures provided for forecastle, deck houses (not used as living quarters), cargo spaces (when permanently illuminated), machinery spaces, steering gear rooms, windlass rooms, galleys, public bath and toilet spaces (when showers are installed), and similar spaces should be dripproof.

Nonwatertight fixtures should be ruggedly constructed and not susceptible to component loosening due to vibration. Incandescent dome fixtures should be ventilated and designed so that none of the surrounding material is directly exposed to the heat of the lamps.

23.6 High-intensity discharge lamp fixtures

High-intensity electric discharge lamp fixtures having a supply voltage in excess of 120 V should be permanently installed. Fixtures connected to an ungrounded electrical system should have isolated winding type ballasts. No discharge lamp circuit should use an rms voltage exceeding 600 V to ground, measured on open circuit. Ancillary equipment for high-voltage installations, including inductors, capacitors, resistors, and transformers should be either totally enclosed in a substantial grounded metal container (which may form part of the lighting fixture) or placed in a suitable ventilated enclosure of noncombustible material or of fire-resisting construction. A notice “DANGER, HIGH VOLTAGE” should be placed on every enclosure for high-voltage discharge lamps that is accessible to unauthorized persons. The word “DANGER” should be in block letters not less than 10 mm (0.4 in) high and the words “HIGH VOLTAGE” in letters not less than 5 mm (0.2 in) high. The letters should be painted red on white background and the size of each notice should be not less than 64 mm (2.5 in) by 50 mm (2 in) overall.

23.7 Lighting for hazardous locations

Lighting equipment and associated wiring should be in accordance with Clause 33.

23.8 Illumination

23.8.1 General

Lighting design, maintenance considerations, testing, and illumination levels for any space should be as recommended in IES RP-12-1998.

Except for cargo space lighting, and for lights mounted above the normal line of vision, such as those installed high in machinery spaces, any single incandescent lamp of more than 60 W rating, or multiple lamps of these types of more than 60 W total rating installed in a single lighting fixture, should be enclosed in a diffusing shade or otherwise shielded to avoid excessive brightness.

Berth lights should be installed to have minimum horizontal projection so that the light may not be covered with bedding.

Each exit light required on vessels should have the word “EXIT” in red block letters at least 51 mm (2.0 in) high.

There should be over-the-side lighting at each pilot embarkation station.

23.8.2 Lighting for cargo handling

High-intensity lighting fixtures used for the illumination of cargo spaces, hatches, and cargo handling gear should be mounted at a sufficient height to be above the normal viewing field of persons on the working deck. Outside lighting for lighters, wharves, gangways, decks, and hatches should be from overhead. In cargo spaces, lights should be located to project on cargo ports and hatches.

23.8.3 Lighting for lifeboat and liferaft area

Each vessel should have floodlights for the illumination of lifeboat and liferaft launching areas. Floodlights should be located where they can be directed to illuminate launching equipment and the area for launching, from the stowage position to the water. Each floodlight should have a manual means of positioning that does not require the use of tools, and should be connected to the supply circuit by a short length of Type S or Type SO flexible cord without the use of a plug and receptacle. Each floodlight should be supplied from an emergency lighting circuit.

24. Navigation, signal, and instrument lights

24.1 General

Navigation light installations should meet the appropriate "rules of the road." The international requirements for masthead, side, towing, special, and anchor lights can be found in the International Regulations for Preventing Collisions at Sea (COLREGS). The requirements for navigation light installations on United States inland waters can be found in the "Inland Navigational Rules."

24.2 Navigation lights

Each navigation light should be type-accepted by the cognizant regulatory body for the intended service. Side, masthead, and stern lights should have dual light sources and should be controlled by a navigation light indicator panel located in the navigating bridge. Electric navigation light fixtures should be watertight.

Spot lights to illuminate navigating bridge clocks, log books, etc. should be focused and shielded to provide illumination only at the required spot or surface. Lights for telegraphs, binnacles, pelorus, and other navigating instruments should be connected to an emergency lighting circuit and should be dimmable. Dimming for CRT display screens should be provided.

24.3 Signaling lights

Each self-propelled vessel on an international voyage should have a daylight signaling light. The signaling light should produce a narrow, high-intensity beam of light for daylight blinker communication at speeds up to 180 dots or dashes per min. The axial luminous intensity of the beam should be at least 60 000 cd. The luminous intensity of the beam in every direction with an angle of 0.7° from the axial should be at least 50% of the axial luminous intensity. The signaling light should have a sighting arrangement that the operator can use to direct the beam to the receiving station. Signaling should be by keying the current through the lamp or by the movement of shutters.

Each signaling light should be either a fixed unit mounted on the top of the navigating bridge, a semifixed unit with arrangements for quick mounting at either wing of the navigating bridge, or a portable unit. Each fixed or semifixed signaling light should be energized from an emergency lighting circuit. Each portable signaling light should be energized from a self-contained storage battery that can operate the light continuously for two hours without recharging.

24.4 Navigation light indicator panel

The navigation light indicator panel should provide audible and visual indication of failure of a lamp in use and should provide a semiautomatic fused switch for immediate transfer to the second light source. The switch should have a position that silences the audible signal while the visual signal remains. The panel should also have control switches for other navigation lights not requiring dual light sources and failure indication.

Terminals should be provided for two twin-conductor cables or one four-conductor cable to each supervised navigation light receptacle or receptacles. Each conductor should be fused. Fused or circuit-breaker type feeder disconnect switches should be provided on the indicator panel. The overcurrent protection on the supply end should be at least twice the capacity of the line fuses in the indicator panel (see 11.14).

Recommended circuit diagrams for control of the navigation lights are shown in Figure 24-1.

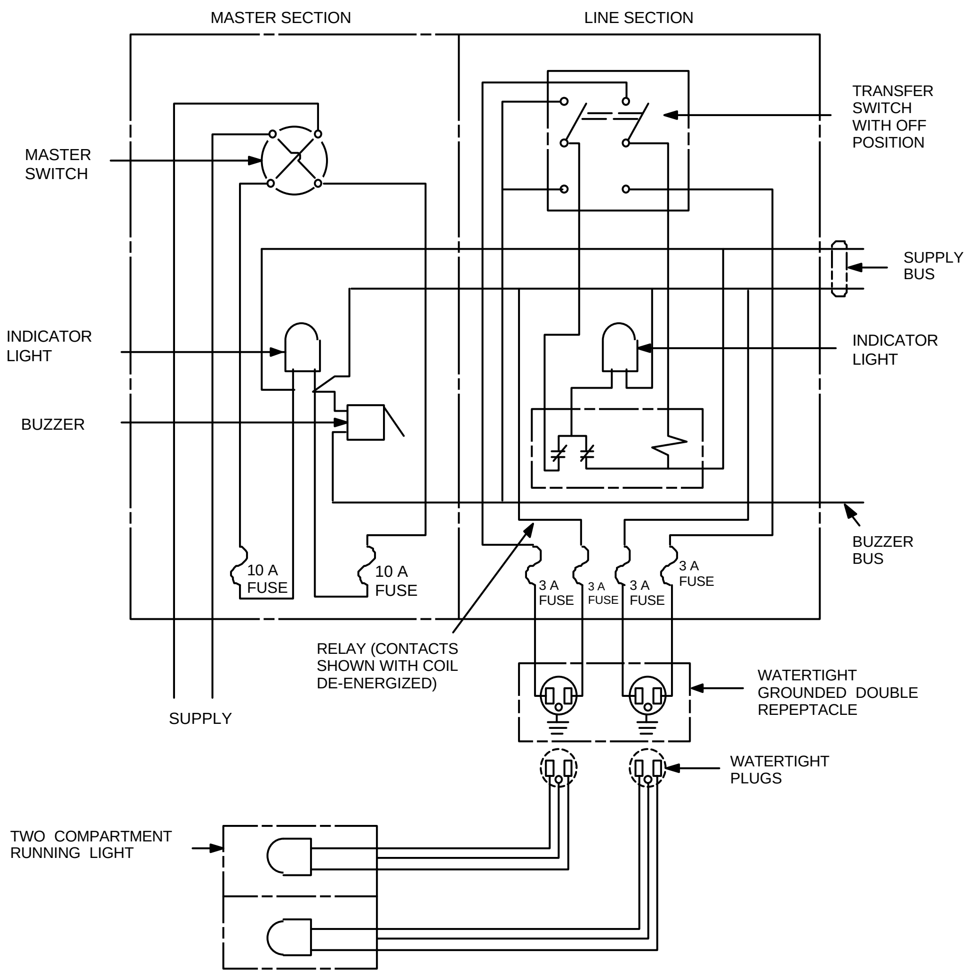


Figure 24-1—Semiautomatic navigation light panel circuit

25. Searchlights

25.1 General

Ship searchlights may be permanent or removable. They should be capable of elevating and rotating through their intended operating range. When two searchlights are provided, they should be mounted at the extreme sides of the vessel. When mounted in an area other than a bridgewing, they should be provided with remote operating controls and local operating controls.

25.2 Construction and installation

Searchlight and searchlight controls should be watertight. Construction and materials should be appropriate for the mounting location. To permit immediate operation, searchlight covers should not be used. The control switch should be mounted close to the point of operation of the light.

Heat-producing controls and junction boxes should be mounted on metal bulkheads with ample ventilation space. Where mounting on a metal bulkhead is not practical, a backing of heat insulating material should extend 30 cm (1 ft) beyond the extent of the heat-producing equipment. Mounting should be sufficiently rigid so as to restrict vibration. A suitable cable clamping device should be employed where the cable enters the body of the light.

25.3 Lifeboat searchlights

Searchlights installed on lifeboats should meet ASTM F1003-86. When the lifeboat has a cabin, mount the searchlight securely to the top of that cabin. Where there is no cabin, the searchlight should be capable of being attached to a sturdy stanchion or other structure. Searchlights mounted on stanchions should be safely stowed when not in use. Mounting hardware should be adequately sized and corrosion-resistant.

The searchlight should be wired with a rubber-jacketed, hard-service, flexible cord, Type SO or equivalent, of a size not less than 16 AWG. The cord should be of sufficient length to permit rotation and elevation of the light.

26. Emergency power and lighting systems

26.1 General

Emergency power and lighting is required by regulatory authorities and classification societies depending on vessel type, tonnage, and voyage. The recommendations in this recommended practice are general. For specific requirements, consult the appropriate regulatory authorities and classification societies.

Every vessel equipped with an electric plant should be provided with an independent emergency source of power installed above the uppermost continuous deck, as described in the following subclauses. Its location in relation to the ship service supply should be such as to ensure that a fire or other casualty to the machinery spaces will not interfere with the supply or distribution of emergency power. The emergency source of power should not be located forward of the collision bulkhead.

All emergency lights should have a distinguishing mark, such as a red "E," for easy identification. Emergency lights should provide adequate illumination, generally a certain percentage of normal illumination, to permit safe operation of the vessel, as well as emergency egress.

If equipment requires an emergency power supply with characteristics other than those directly available from the emergency sources, the motor-generators, converters, rectifiers, or other apparatus supplying this equipment should automatically start and assume the load upon establishment of emergency supply.

26.2 Cargo vessels

The emergency source should consist of storage batteries or a generating set capable of continuous operation for the time indicated in 26.9. This source should supply the navigating light circuits, telegraphs, binnacles, daylight signaling lamp, searchlights and the emergency lighting of machinery spaces, steering-gear room, radio room, emergency power stations, passageways, exits from crew's quarters, and other spaces and equipment necessary for use in an emergency in accordance with SOLAS 1997, as amended. The emergency system should consist of independent circuits from the emergency switchboard, and the emergency switchboard should be normally energized from the ship service switchboard.

When the emergency source of power is a generator, it should be driven by a suitable prime-mover with an independent supply of fuel, having a flash point of not less than 43 °C (109.4 °F). The generator set should be started automatically upon failure of the normal electric supply unless a transitional source of emergency power, in accordance with 26.2.2, is provided in conjunction with a manually started generator set. If the emergency generator set is automatically started, it should be automatically connected to the emergency switchboard and the services listed in 26.2.2 should be energized from the generator as quickly as is safe and practicable, but in not more than 45 s. Unless a second independent means of automatically starting the emergency generator set is provided, a single source of stored energy should be protected to preclude its depletion by the automatic starting system.

26.2.1 Emergency storage battery

Where the emergency source of power is a storage battery, it should be capable of carrying the emergency load without recharging while maintaining the voltage of the battery throughout the discharge period within +5% and –12% of its nominal voltage. The storage battery should be automatically connected to the emergency switchboard in the event of failure of the main power supply and should immediately supply at least those services specified in 26.2.2.

26.2.2 Temporary emergency power source

Where a temporary source of emergency power is required, it should consist of a storage battery suitably located for use in an emergency. The battery should operate without recharging while maintaining the voltage of the battery throughout the discharge period within +5% and –12% of its nominal voltage. A converter may be used for supplying the temporary emergency bus for ac loads. The battery should have sufficient capacity and should be arranged to automatically supply at least the following services for 30 min (if they depend upon an electrical source for their operation) in the event of failure of either the main or emergency source of power:

a) The lighting required in 26.2 (For this transitional phase, the required emergency lighting for machinery spaces, accommodation and service areas, may be provided by permanently fixed, individual, automatically charged, relay-operated battery lamps.);
b) All essential internal communication equipment, fire detection, and associated alarm equipment;
c) All internal communication equipment required in an emergency;
d) Intermittent operation of the daylight signaling lamp, the ship's whistle, the general alarm, the manual fire alarms, and all internal signals that are required in an emergency, unless they have an independent supply from an accumulator battery suitably located for use in an emergency and sufficient for the period specified;
e) When storage batteries are used as the source of emergency lighting and power, transfer to the batteries should be automatic upon of failure of the ship service source. Upon restoration of ship service power, the emergency system should be automatically reconnected to the ship service source.

26.3 Cargo vessels without an emergency power source

Cargo vessels not required by regulatory authorities to have an independent emergency source of power should have, as a minimum, permanently fixed, individual, automatically charged, relay-operated battery lights having a minimum period of operation of 12 h. Lights should be located along exit routes, in machinery spaces, and at launching stations for survival craft.

26.4 Passenger vessels

The emergency power source on passenger vessels required by regulatory authorities to have an emergency generator (final emergency source) should consist of at least one diesel-engine or gas-turbine driven generator arranged for automatic starting and loading upon failure of ship service supply. It should have sufficient capacity and fuel supply to carry the full emergency load continuously for at least 36 h.

If two emergency generating sets are provided, one should have sufficient capacity for all emergency loads except the bilge, fire, and sprinkler pumps (see 26.4.2) and should be arranged for automatic starting and transfer. The other may be either automatically or manually started.

The emergency generator supplied power source should be supplemented by a temporary emergency source consisting of storage batteries having sufficient capacity to supply the connected load continuously for at least 30 min.

The capacity of the temporary emergency source should be determined by the connected load of all emergency circuits listed in 26.4.1, except that consideration may be given to the short-time demand for 26.4.1i) and, when an automatic cut-off is provided, 26.4.1m).

26.4.1 Temporary emergency circuits

The following circuits should be connected to the temporary emergency bus:

a) Navigation lights
b) Machinery space emergency lighting sufficient to permit performance of essential operations and the observation of all necessary gauges, gauge glasses, and instruments required under emergency conditions to facilitate restoration of service and to permit escape from all normally occupied spaces
c) Radio room lighting
d) Lighting (including low-level emergency egress lighting) for passenger and crew exits and passageways, including public spaces [Lighting should be adequate to permit passengers and crew to find their way to the embarkation deck. At least one light should be located in each section of each passageway and in each stairwell and stairwell exit on each deck. In no case should the distance between lights exceed 23 m (75 ft).]
e) At least one light in each berthing compartment accommodating 20 or more persons
f) One or more lights in the galley, pantry, steering gear room, space containing emergency power sources, chartroom, navigating bridge, all public spaces, and crew's mess rooms and recreation rooms
g) Boat and embarkation deck lighting
h) Essential communication circuits between the navigating bridge, machinery spaces, and the steering gear room
i) Watertight door operating gear (if electric) and indicating system
j) Emergency loudspeaker system
k) General or emergency alarm and the fire alarm systems
l) Gyro compass
m) Holding magnets for self-closing fire doors (To reduce battery capacity, holding magnets may be provided with a timing relay to cut off power if final emergency supply is not established or ship service supply restored within the maximum time provided for automatic cranking of the emergency generator prime mover, but not less than 2 min.)

26.4.2 Final emergency circuits

The following circuits should be connected to the final emergency bus:

a) All temporary emergency circuits listed in 26.4.1 (through an automatic bus transfer switch)
b) Daylight signaling lamp
c) Whistle and siren control
d) Lifeboat flood lights (lighting in the vicinity of the lifeboats and the boat handling equipment, including lighting of the water at the sides of the vessel, should be sufficient to permit the complete operation of loading, lowering, and releasing of the lifeboats)
e) Emergency bilge pump, one fire pump, and one sprinkler pump, if provided
f) Other interior communication systems essential for the emergency operation of the vessel
g) Main and emergency radio (This is in addition to the separate storage battery source required by the regulatory agencies for emergency radio installations.)
h) Navigation equipment required by the regulatory agencies

26.4.3 Emergency switchboard configuration

The emergency switchboard should be arranged such that normally, all emergency circuits are energized through an automatic bus transfer switch from the ship service generating plant. If two ship service generating plants are provided, with parallel or alternative feed to a distribution switchboard, normal supply to the emergency switchboard should be from the distribution switchboard. If a common distribution switchboard is not provided, there should be an emergency bus feeder from each ship service switchboard connected to an automatic bus transfer on the emergency switchboard. The temporary emergency bus should be supplied from the final emergency bus through an automatic bus transfer switch.

Upon failure of ship service supply, the temporary bus should automatically be transferred to battery supply and should return to the normal supply when the final bus is energized by the emergency generator or by restoration of ship service power.

Upon restoration of ship service power, the final bus may be returned automatically to the normal supply. The emergency generator should continue to run without load until shut down manually.

The emergency switchboard should be in the same compartment as the emergency generator set and in a compartment adjacent to the storage battery room.

Indication should be provided in the machinery space, preferably at the principal propulsion control station, to indicate when the emergency generator is operating and when the emergency storage battery is being discharged.

26.5 Passenger vessels (coastal and inland waters)

Where permitted by regulatory agencies, the emergency power and lighting system for passenger vessels operating in coastal and inland waterways should be as described in 26.4, except as follows:

a) The source may be either a storage battery or an automatically started generator set feeding a single emergency bus
b) The circuits of 26.4 may be supplied from the emergency bus, and the gyro compass, daylight signaling lamp, lifeboat flood lights, and interior communication systems may be omitted
c) The time rating of the emergency source should be at least 12 h or twice voyage time, whichever is less

26.6 Passenger vessels (other)

For passenger vessels not included in 26.4 and 26.5, the emergency source for lighting and power should consist of a storage battery having sufficient capacity to carry the full emergency load for the time stated in 26.9. Upon failure of main power supply, the emergency circuits should transfer automatically to emergency supply and should return automatically to main supply upon its restoration.

26.7 Passenger vessels with ro-ro cargo spaces

Passenger ships with ro-ro cargo spaces should be provided with supplementary electric lighting in all public spaces and passageways. The lighting should be capable of operating for at least 3 h when all other sources of electrical power have failed and under any condition of heel. The illumination provided should be such that the approach to the means of escape can be readily seen. The source of power for the supplementary lighting should consist of accumulator batteries located within the lighting units that are continuously charged, where practicable, from the emergency switchboard. The supplementary lighting should be such that any failure of the lamp will be immediately apparent. Any accumulator battery provided should be periodically replaced. The replacement intervals should consider the specified battery service-life for ambient conditions seen in service. Portable, rechargeable, battery-operated lamps should be provided in every crew space passageway, recreational space, and working space that is normally occupied, unless supplementary emergency lighting, described above, is provided.

26.8 Passenger vessels without an independent emergency source of power

Passenger vessels not required to have an independent emergency source of power should have, as a minimum, permanently fixed individual, automatically charged, relay operated battery lights having a minimum period of operation of 12 h. Lights should be located in exit routes, in machinery spaces and at launching stations of survival craft.

26.9 Time factor for supply of emergency power

The time factor for supplying emergency power, unless otherwise recommended, is as indicated below:

Minimum time factor (h)		
	Passenger vessels	**Cargo vessels**
Ocean and coastwise		
100 to 1600 gross tonnes	12	See 26.3
1600 gross tonnes and over	See 26.4	18
Great Lakes		
Vessels navigating more than 4.8 km (3 mi)	8	8
Vessels navigating not more than 4.8 km (3 mi) offshore	3	3
Ferries on runs over 1 h	2	
Ferries on runs 1 h and under	1	
Great Lakes and rivers		
Ferries on runs over 1 h	2	
Ferries on runs 1 h and under	1	
Other vessels	3	3

27. Interior communication systems

27.1 General

Each required interior communication system (voice, data, control, or alarm) should be designed and installed to provide clear, distortion-free and uninterrupted operation under all operating conditions. Interior communication system power sources should be in accordance with regulatory agency requirements (see Clause 26). Communications data may be conveyed by electrical (copper) or fiber-optic conductors.

All components should function continuously without adverse effect when supplied with power having the characteristics described in Table 4-1.

All enclosures for use in essential circuits should be watertight. Other enclosures installed in exposed or wet locations, machinery spaces, galleys, and similar locations should also be watertight. Enclosures for nonessential interior communication circuits (e.g., entertainment systems) when installed in dry locations may be dripproof. Each terminal should be identified and each individual wire should be marked at the terminal. When more than one voltage level is found in an enclosure, conductors of differing voltages should be kept separated as much as practicable. All voltages within an enclosure should be indicated, and recommended creepage distances observed. Each enclosure should be of a corrosion-resistant material, and nonmetallic enclosures should be flame- and impact-resistant.

All indicators and controls should be installed to provide for operational accessibility, serviceability, visibility and mechanical protection. Each installation should not hinder the operation or the accessibility of other equipment. Vibration mounting of equipment should be considered where necessary due to abnormal conditions at the installed location.

The various instruments should be constructed and selected to meet the service conditions. Enclosures for each control and indicator instrument should provide adequate protection against mechanical damage and ingress of liquid and foreign particles. (See 1.10 and 3.7.)

Each alarm signal should be an electrically operated bell, klaxon, or other warning device capable of producing an audible signal. Audible alarms utilizing electronic devices may also be considered. Enclosures for each audible alarm should be appropriate for the service intended and the location in which it is installed. Visual alarms may be considered in addition to any audible alarms. All actuating devices (contact makers, pushbuttons, etc.) should be readily accessible for operation and clearly labeled as to function. Each device enclosure should be appropriate for the service intended and the location in which it is installed.

All equipment should be equipped with a suitable nameplate giving important information, such as manufacturer's name and equipment identification (model, catalog number, etc.), operating voltage, maximum current rating, and degree of enclosure (e.g., NEMA or IP rating).

27.2 Engine order telegraphs

Every vessel, except vessels on which the propulsion plant is controlled entirely from the navigating bridge with no means of engine control from within the engine room, should be equipped with a repeat-back signaling system from the navigating officer's stations to the engine control station. On vessels with more than one engine, a separate system should be provided for each engine. In any telegraph system, transmission of orders to the engine control station and replies to the navigating bridge should be instantaneous, accurate, and unambiguous under all conditions of ambient light and weather. Engine order telegraphs should be electrically operated. Indication at each station in use should include the direction and speed ordered and answered, and such advisory information as needed. A typical list of orders would be as follows:

a) Full Ahead
b) Half Ahead
c) Slow Ahead
d) Dead Slow Ahead
e) Standby
f) Stop
g) Finished with Engine
h) Navigating Bridge Control (for vessels with navigating bridge propulsion control)[20]
i) Dead Slow Astern
j) Slow Astern
k) Half Astern
l) Full Astern

The navigating bridge and engine control station units may be operated by means of a lever, knob, pushbuttons, or equivalent. The arrangement of the navigating station order indicators, pushbuttons, or lever motion should relate to the desired direction of motion of the vessel, e.g., ahead orders to the bow. However, on round-dial, flush-mounted units on the navigating bridge, ahead orders should be on the right unless only 180° of the dial is used, in which case ahead orders should be toward the bow.

On vessels not equipped with propulsion control on the navigating bridge, on which the engine order telegraph is the primary means of transmitting speed and direction orders from the navigating bridge to the machinery spaces, the bridge station should be limited to the fore and aft moving lever type transmitter with “Stop” in the vertical position.

An audible and visual “wrong direction” signal should be provided in the engine control station. This signal should activate whenever a control is operated in such a manner as to produce propulsive thrust in a direction opposite to that required by its engine order transmitter. This signal should be de-energized when propulsion control is assigned to the navigating bridge. When a system includes more than one topside electrical transmitter, a transmitter transfer control should be provided so that when any one is operated, it will automatically be connected in the system and the other transmitters will be disconnected. On transfer, an alarm should sound at every station. The reply should be indicated at all transmitters at all times.

Telegraph instruments exposed to the weather should have watertight enclosures of corrosion-resistant material. Instruments mounted in consoles located in enclosed spaces should be at least dripproof. Engine control station instruments should be mounted as near to the operating station as possible.

Engine order telegraphs may be combined with navigating bridge propulsion control systems when separate internal components are used for the two systems, so that failure of one system will not affect the operation of the other system. The only common parts should be the operating lever, housing, illumination components, and interlock devices. Generally, the propulsion control station (engine room) should be capable of assuming control at all times and should be capable of blocking orders from other associated remote control stations. Control transfer arrangements should be provided that prevent the propelling thrust from altering significantly when transferring control from one station to another. To this end, the system should employ alarms and/or interlocks to ensure that thrust lever positions are matched before transfer is effected.

Each electrical engine order telegraph should have an alarm on the navigating bridge and in the engine spaces that automatically sounds and visually signals loss of power to the system. A means to reduce the audible alarm tone by no more than 3 dB may be provided. Each engine order telegraph should be provided with an audible alarm at each transmitter/receiver that sounds continuously when the transmitter and indicator do not show the same order.

[20]For navigation bridge control, the use of a graduated scale (e.g., 0 to 10 ahead, 0 to 10 astern) in addition to the listed orders is also acceptable.

Each mechanical engine order telegraph should be provided with an audible alarm at each transmitter/receiver that sounds when the transmitter and indicator do not show the same order. The audible signal should not be dependent upon any source of power for operation other than the movement of the transmitter or indicating handle.

27.3 Rudder angle indicator

An independent signal system for transmitting the position of the rudder should be provided. The system transmitter should be separate and independent of transmitters for steering control system feedback. The transmitter should be located at the rudder head and actuated by the movement of the rudder, and the angular movements indicated on the navigating bridge and bridge wings, and in the steering gear room and other appropriate locations. Indicators located on the navigating bridge and at the after steering station (where provided) should be illuminated. Indicators should be located at each steering station. See 18.3.

27.4 Refrigerated and cold storage spaces

Signal and communication equipment, except as noted below, should not be located in refrigerated spaces nor located where affected by such spaces.

A locked-in alarm should be provided for refrigerated and cold storage spaces that can be locked so that they cannot be opened from the inside. The actuator for the locked-in alarm should be located inside at the exit. The locked-in alarm signal shall be located in a space where persons are present at all times. The alarm should be both visual and audible. The signal and the actuator should be provided with nameplates to indicate the function.

An actuating control element for the refrigeration system, such as a thermal bulb or thermocouple, which initiates an operation, may be in the space.

27.5 General emergency alarm system

A general emergency alarm system should be provided on all vessels over 100 gross tons and should consist of bells of not less than 200 mm (8 in) in diameter, or electronic sound-generating devices producing signals of a distinctive type from other sound generating devices in the vicinity, and located so that the audible alarm will be heard by all persons on board the vessel. The sound-generating devices should be controlled by manually operated contact makers or system actuating switch from the navigating bridge, fire control stations or other location as required by the cognizant regulatory agency.

Not more than five sound-generating devices (all on one deck) should be supplied by one branch circuit. The distribution panel and the branch circuit distribution panels should be located above the bulkhead or the freeboard deck, whichever is the higher. Power supply for the general emergency alarm should meet SOLAS requirements. General emergency alarm feeder circuits should be connected to the power source through overcurrent protective devices capable of being locked in the closed position.

27.6 Call systems

On passenger vessels, all passenger staterooms should be equipped with a means to call for assistance, such as a telephone or a call bell alarm actuator. A call bell alarm, when initiated, should sound in a space where persons are present at all times. Indication of the source (location) of the alarm should be provided.

On all vessels, a call bell or telephone call system should be provided for each berth located in a hospital area.

A call system should be considered for all vessels in accommodation and public spaces.

27.7 Whistle and siren control systems

There should be a mechanical means for operating the ship's whistles from the navigating bridge regardless of other systems installed. The manual actuating lead should be as direct as possible, amply protected, and when suspended for more than 4.5 m (15 ft), supported by corrosion-resistant hardware. The system should be provided with ample corrosion resistant springs to counteract the force on the lever and to ensure the proper functioning of the system.

When electrically operated whistles and sirens are installed, all parts should be independent of the mechanical system. If a motor-operated timer is installed, particular attention should be given to its construction and location so that it will be inaudible in the navigating bridge and will not affect the magnetic compass. The power supply for electrically operated whistles and sirens should be taken from the emergency system. See Clause 26.

When an electrically operated actuating valve is located more than 1.5 m (5 ft) from the whistle, an automatic drain feature for the whistle steam/air supply pipe should be installed.

27.8 Daylight signaling lamp

When a daylight signal lamp (fixed or semifixed) is required by the cognizant regulatory agency, the electrical supply should be from the emergency switchboard. See Clause 26. A portable daytime signal lamp should be powered from a rechargeable battery source capable of providing power for at least 2 h without recharging.

27.9 Alarm system for lubricating oils, refrigeration, and other fluid systems

Whenever a fluid system is installed, the functioning of which affects the operation of vital ship's equipment or the safety of life, such as lubricating oil systems for prime movers, cooling water systems, and refrigerating systems, a dedicated alarm for each system should be installed.

For fluid systems supplying essential equipment, the alarm system should indicate audibly and visibly at the central operating station or other location where persons are always present, when fluid temperature or pressure is outside of the normal operating range. Additionally, another alarm should be provided at the point at which automatic shutdown occurs due to low lube oil pressure or high coolant temperature. The set points should be selected to provide a warning for as long as possible before shutdown occurs, without excessive false warnings.

In a fully automatic chilled-water refrigerating system, an alarm should be set to sound and shutdown the refrigerating machinery when the pressure in the circulating water system reaches a predetermined low pressure.

27.10 Voice communication systems

Voice communication systems typically include sound-powered (or equivalent) systems, public address/general announcing systems, talk-back amplifier and announcing systems, and dial telephone systems.

27.10.1 Sound-powered (or equivalent) systems

Each vessel should be equipped with a reliable sound-powered telephone communication system (or other system not dependent upon ship power) for providing a means of two-way voice communication. The system should be of the selective ringing, common talking type, and should have telephones at the following locations:

a) Navigating bridge
b) Steering gear room
c) Alternative steering station, if outside the steering gear room

d) Machinery control room console
e) Local engine, or propulsion unit control panels, if provided
f) Maneuvering platform, if provided
g) Between the gyrocompass and navigating bridge if the gyrocompass is not in or next to the navigating bridge
h) Between the radar and ARPA stations if not located on the navigating bridge
i) Between the navigating bridge and the fire detection and alarm system central control panel
j) Between the radio room and the navigating bridge
k) Between lookout positions and the navigating bridge
l) Between the navigating bridge and damage control or emergency lockers, if installed

Each station should be provided with an enclosure appropriate to the environmental conditions in which the telephone station is installed. On installations that are totally enclosed, an external indication that the station is being called should be provided. Alternatively, stations so constructed as to inherently provide an equivalent degree of protection are not required to be installed in a separate environmental enclosure. Where more than one telephone is installed in the same location, visual indication of the station being called should be provided.

In machinery spaces or similar noisy locations, an acoustic booth or suitable auxiliary amplification equipment should be provided, as necessary, so that a telephone conversation can be carried on while the vessel is being navigated. In addition, an audible and visual signaling device should be provided external to the booth to signal an incoming call.

On sound-powered telephone systems, the talking circuit should be electrically independent of the calling circuit. A short or open circuit or a ground on either side of the calling circuit should not affect the talking circuit in any way.

27.10.2 Public address/general announcing system

Each vessel required to have a general emergency alarm should also have an amplifier-type public address announcing system to supplement that alarm. The system may be of the centralized or decentralized amplifier type and provide for the transmission of information throughout the vessel by means of microphones and loudspeakers. Decentralized amplifier systems should not suffer in overall performance due to the failure of one unit (station). This system may be combined with the general emergency alarm and/or the fire detection and alarm systems, and should be protected against unauthorized use.

The announcing station should be located adjacent to the general emergency alarm contact maker on the navigating bridge and there should be a means to silence all other audio distribution systems at the announcing station. The system may be arranged to allow broadcasting separately to, or to any combination of, various areas on the vessel. If the amplifier system is used for the general emergency alarm, the operation of a general emergency alarm contact maker should activate all speakers in the system, except that a separate crew alarm may be used if permitted by the regulatory agency. The amplifier and device (tone generator) used to produce the general emergency alarm signal should be provided in duplicate. The power supply should be in accordance with Clause 26. Each electrical component in a weather deck location should be watertight or in a watertight enclosure.

Each vessel should have a public address system capable of broadcasting separately or collectively from the navigating bridge to the following stations:

a) Survival craft stations
b) Survival craft embarkation stations
c) Public spaces used for passenger assembly points
d) Crew quarters
e) Accommodation and service spaces

Loudspeakers should be located to eliminate feedback or other interference that would degrade communications and should be located to provide intelligible and audible communication throughout the vessel. Weather-deck loudspeakers should be watertight and suitably protected from the effects of the wind and seas. There should be a sufficient number of loudspeakers throughout the vessel. The public address system should be designed and installed to consider acoustically marginal conditions. With the vessel underway in normal conditions, the minimum sound pressure levels from broadcasting emergency announcements should be

— In interior spaces, 75 dB(a) or, if the background noise level exceeds 75 dB(a), then at least 20 dB(a) above the maximum background noise level
— In exterior spaces, 80 dB(a) or, if the background noise level exceeds 80dB(a), then at least 15 dB(a) above the maximum background noise level.

Loudspeakers should not have external volume control switches.

For passenger vessels and other vessels where the public address and general alarm systems are combined, a feeder distribution panel should be provided to divide the system into the necessary number of zone feeders. Where, because of the arrangement of the vessel, only one zone feeder is necessary, a branch circuit distribution panel should be used. The feeder distribution panel should be in an enclosed space next to the public address system power supply and should have at least one feeder for each vertical fire zone.

Each system should have one or more branch circuit distribution panels for each zone feeder, with at least one branch circuit for each deck level. The distribution panel should be above the uppermost continuous deck, in the zone served, and there should be no disconnect switches for the branch circuits. A branch circuit should not supply speakers on more than one deck level, except for a single branch circuit supplying all levels of a single space if all other requirements of this clause are met.

On a vessel not divided into vertical fire zones by main vertical fire bulkheads, the vessel should be divided into vertical zones not more than 40 m (131 ft) long. There should be a feeder for each of these zones.

Feeders and branch circuit cables should be in passageways. They should not be in staterooms, lockers, galleys, or machinery spaces, unless it is necessary to supply public address speakers in those spaces.

27.10.3 Talk-back amplifier and loudspeaker systems

A talk-back type amplifier and loudspeaker system may be employed for communications between the navigating bridge and locations such as the survival craft, fueling, or mooring stations. Many of the recommendations given for public address systems are applicable to the talk-back system. The talk-back system enables communication to the navigating bridge, after pushing a button to transmit. Components for this system need not be supplied in duplicate. Components located in the weather should be watertight or in a watertight enclosure.

27.10.4 Dial telephone systems

Dial telephone systems and equipment should be suitable for marine use. Telephone sets may be of the bulkhead or panel type (surface or flush mount) or of the desk type. Sets in exposed locations should be appropriately enclosed.

The power source for the central power and switching unit (PBX switch) should be as specified by the manufacturer and should comply with the recommendations in Clause 26. The PBX switch should, as a minimum, be dripproof or in a dripproof enclosure, and be readily accessible.

The dial telephone system should be capable of transmitting and receiving data (e.g., fax and modem) and interfacing with commercial land line systems, the public address systems, and commercial satellite communications or cellular telephone systems.

28. Fire detection, alarm, and sprinkler systems

Fire detection, alarm, and sprinkler systems are required by regulatory agencies for various vessels types and applications, including periodically unattended machinery spaces. Specific system and equipment requirements can be found in SOLAS, classification society rules, and regulatory agency regulations. System/equipment type approval is often required. The latest edition of these documents should be consulted prior to system design.

Automatic fire detection systems are recommended for all vessels, with detection in all accommodation and machinery spaces, including passageways, stairwells, work spaces, store rooms, and pumprooms. Cargo holds and vehicle ro/ro spaces should be fitted with fire detectors.

28.1 General

Each component of an installed shipboard fire detection and fire alarm system should be constructed for the marine environment, including electromagnetic interference (see 1.5 and 37.23). The system, and its components, should have been tested by an independent laboratory to nationally or internationally recognized testing protocols.

All detectors should be capable of being operationally tested and restored to normal operation without replacing parts. Detectors installed in damp or wet locations, such as ro/ro spaces or machinery spaces, should be specifically designed and tested for such use.

Every fire detection and fire alarm system should be provided with two sources of power, one of which should be from an emergency source that switches automatically to provide power upon failure of the main power source. The emergency source can be a storage battery.

Detecting systems should be designed so that the indication of a fire on any circuit will not interfere with the operation of an alarm on any other circuit. The system should be designated so that failure of a detection circuit will not interfere with the operation of any other detection circuit.

System cables should be so arranged to avoid galleys, machinery spaces, and other enclosed spaces having a high fire risk except to connect fire detection equipment in those spaces.

Fire alarm systems should not be used for the transmission of other than fire alarm signals.

28.2 Manual fire alarm systems

Manual fire alarm systems should be provided on all ships and at least one alarm box should be provided in each zone. The systems should be installed in all areas, other than main machinery spaces, that are normally accessible to the passengers and crew. All boxes should be finished in bright red with operating instructions finished in a contrasting color.

The system should be arranged to indicate, both visibly and audibly, on the navigating bridge or at the fire control station, when a manually operated call point has been actuated. The visible notice should indicate the zone in which the alarm originates. The system, when activated, should also energize an indicating light and an audible alarm in the engine room. The fire alarm should also sound in the quarters of the firefighting crew, unless a separate alarm system is provided for this purpose.

In vessels fitted with an automatic fire detecting and alarm system in accommodation spaces, the manual system may be a part of the automatic system.

28.3 Automatic fire alarm systems

An automatic fire alarm system consists of a fire detection and alarm central control panel, repeater panels (if provided), detectors and manually operated call points located throughout the vessel in the various structural fire zones, and audible and visual alarms to signal the presence or indication of fire.

Every fire detection and fire alarm central control panel should be self-diagnostic and provide at least visual indication of fire, fire location, fault, and panel operational status. Each central panel should audibly alarm upon fire or fault. Each central panel should indicate faults resulting from open circuit, alarm tone generator failure, system/circuit ground, battery failure, open fuse, loss of ac power, and fire zone circuit interruption.

The central control panel should be located on the navigating bridge or at a continuously monitored fire control station. A repeater panel should be provided in all other locations where direction to the fire-fighting team or crew and passengers may be given. The system should sound alarms and provide visual indication of alarm.

The activation of any detector or manually operated call point should initiate a visual and audible fire signal at the control panel and indicating units. If the signals have not received attention within 2 min, an audible alarm should be automatically sounded throughout the crew accommodation and service spaces, control stations, and main machinery spaces.

Indicating units should, as a minimum, denote the zone in which a detector or manually operated call point has operated.

Where the detection system does not include means of remotely identifying each detector individually, no detector section should cover more than one deck within accommodation, service, and control spaces (exclusive of enclosed stairways), and on passenger ships, should not serve spaces on both sides of the ship. In order to avoid delay in identifying the source of fire, the number, and arrangement of detectors within a section may be further limited by regulatory agencies. Where the detection system identifies each detector individually, the sections may cover spaces on both sides of the ship and on several decks, but should not cover spaces in more than one main vertical fire zone.

Fire detection systems with the capability of identifying each detector individually should be designed so that

a) Means are provided to ensure that any fault (power interruption, short-circuit, ground) occurring in a loop will not make the entire loop ineffective.
b) All arrangements are made to enable the initial configuration of the system to be restored in the event of failure (electrical, electronic, programming).
c) The first initiated fire alarm will not prevent any other detector from initiating further fire alarms.

28.4 Fire detection and fire alarm system for periodically unattended machinery spaces

A fire detection and alarm system should be provided for periodically unattended propulsion machinery spaces. A fire detection and alarm control panel should be provided in the machinery control room. Means to manually activate the fire alarms in the engineers' accommodation and propulsion machinery spaces and on the navigating bridge should be provided. Automatic activation of fire detectors and manual activation of call points should be initially alarmed at the machinery control room panel, when operating in an attended mode. When operating in an unattended mode, alarms should meet 37.13, except that selective switching should not be provided.

28.5 Smoke extraction systems

Smoke pipe systems for fire detection consist of individual pipes installed from collectors located in the compartments to be protected to an indicating cabinet located on the navigating bridge or in the fire control station.

A circulation of air is maintained through the pipes by means of a suction fan located adjacent to the indicating cabinet. In case of fire in a compartment, the smoke is drawn through the pipe to the indicator cabinet. This type of system should be fitted with an audible alarm that will call attention to the receipt of smoke in the indicator cabinet, and indicate the location of the alarm. Sequential sampling may be used. Suction fans should be provided in duplicate and arranged so that the idle unit is ready for immediate operation in case of failure of the operating unit. Two sources of power should be provided, one of which should be from an emergency source that switches automatically to provide power upon failure of the main power source. The emergency source can be a storage battery. All electric circuits should be supervised to automatically provide a trouble alarm in case of failure of suction fan motor failure or power supply failure.

28.6 Detector types

Optical smoke detectors use light scattering to detect the presence of airborne particulates. Optical smoke detectors should be designed to prevent airborne contaminates from disabling the detector or causing a false alarm.

Ionization smoke detectors register the presence of the products of combustion by the detecting a decrease in electron transfer between polarized elements. Ionization smoke detectors should be designed to prevent airborne contaminates from disabling the detector or causing a false alarm.

Heat detectors utilize an electronic sensing element of low thermal mass to provide response to temperature rise. Heat detectors should operate on a fixed temperature basis.

Flame detectors detect the presence of fire by sensing the ultraviolet (UV) rays emitted by flames. Flame detectors should be principally used in areas considered to be of high risk where naked flames are likely, such as a flammable liquid storage area. Flame detectors should be used in conjunction with optical, ionization, or heat detectors.

Smoke detectors in accommodation spaces, stairwells, escape routes, and similar locations should be certified to operate before a smoke density exceeds 12.5% obscuration per meter, but not until the smoke density exceeds 2% obscuration. In other locations, sensitivity limits should take into consideration for the avoidance of false alarms.

Generally, heat detectors should be certified to operate before the temperature exceeds 78 °C (172.4 °F) but not until the temperature exceeds 54 °C (129.2 °F), when the temperature is raised to those limits at a rate less than 1 °C (33.8 °F) per minute. At higher rates of temperature rise, the detector should operate within temperature limits determined by the regulatory agency.

When installed in hazardous locations, detectors should be of the intrinsically safe type.

When installed in accommodation spaces, or other areas with public access, detectors should be designed to prevent tampering or unauthorized removal. Each detector unit should be fitted with a visual indicator to show that it is in an operational mode. Additionally, each detector unit should be fitted with a visual indicator that latches when in the alarm mode. The operational status and alarm mode visual indicators may utilize the same visual component.

Each detector unit located in a passenger cabin should be provided with an integral audible alarm.

28.7 Automatic sprinkler, fire detection, and fire alarm systems

An automatic sprinkler, fire detection, and fire alarm system is a water-flow fire extinguishing system comprised of distribution piping, an automatic water supply, automatic water discharge devices, and central and remote alarm indicating units. The system diffuses water over a predetermined area. An automatic device operates the sprinkler supply and produces audible and visual signals. No action by the crew is needed for system operation.

Each section of sprinklers should include means for giving a visual and audible alarm signal automatically at one or more indicating units whenever any sprinkler comes into operation. Such units should give an indication of any fire and its location in any space served by the system and should be centralized on the navigating bridge or in the main fire control station. In addition, a remote alarm should be installed so that any alarm from the system is immediately received in a continuously monitored location. Such alarm system should include provision for monitoring and alarming system faults.

An independently operated seawater pump should be provided solely for the purpose of continuing automatically the discharge of water from the sprinklers. This pump should be started automatically by a pressure drop in the piping system and supply the sprinkler system before the freshwater sprinkler tank is completely empty.

There should be not less than two sources of power supply for the seawater pump and automatic alarm and detection system. Where the sources of power for the pump are electrical, there should be two dedicated feeders, one from a main switchboard and the other from the emergency switchboard.

The feeders should be arranged to avoid galleys, machinery spaces, and other enclosed spaces of high fire risk except insofar as it is necessary to reach the appropriate switchboards, and should be connected to an automatic transfer switch located at the sprinkler pump motor controller. The normal source should be the feeder from the main switchboard. The feeder circuit breakers should be clearly labeled and normally kept closed. No other switch should be installed in the feeders. Loss of power on either feeder should be alarmed. One of the two sources of power for the alarm and detection system should be an emergency source.

29. Gyro compass systems

29.1 General

A gyrocompass system generally includes the following items:

a) A master compass, which provides the ship's true heading at all times, and transmits this indication to repeating instruments and other equipment and systems, such as radar, anti-collision system, navigation computers, etc.
b) Repeaters of various types such as steering and bearing, and other equipment such as radio direction finders, course recorders, and autopilots
c) Power conversion units, if required, to convert ship's power to power required by the gyrocompass system
d) A control panel or panels for controlling power and signals supplied to and from the gyrocompass system
e) Alarm circuits to indicate failure of power supply and malfunction of gyrocompass system (alarm circuits should be powered from a source independent of the compass power supply)
f) An integral source of back-up electric power, including a chargeable battery supply, that assumes the system load upon failure of the normal source of power.

29.2 Installation and location

The master compass, power conversion unit, control panels, and batteries are ideally located together in a centerline compartment, near the metacenter, and as close to the navigating bridge as possible.

The master compass should be mounted with its fore and aft datum lines parallel to the ship's fore and aft datum line, within 0.5°. The lubber line should be in the same vertical plane as the center of the compass card and should be aligned accurately in fore and aft direction. This alignment requirement also applies to bearing repeaters. The master compass should be mounted on a rigid, level foundation.

All equipment should be arranged to provide easy access for servicing, and to minimize damage from heat, dust, oil vapors, steam, or dripping liquids. Items exposed to the weather, seas, splashing, or other severe moisture conditions should be watertight or protected by watertight enclosures. If the method of installation does not ensure positive equipment grounding, then separate grounding conductors should be provided. Control equipment should be in metal enclosures.

When installed in the pilothouse or similar spaces, steering and bearing repeaters should be provided with illumination that can be dimmed or intensified.

29.3 Power supply

Power should be normally supplied from a separate feeder from the emergency power distribution switchboard. A battery charger and battery dedicated to the operation of the gyrocompass should be provided adjacent to the unit for back-up electric power. Automatic transfer to the back-up source should be provided. An alarm should be installed on the navigating bridge to indicate loss of normal power and transfer to back-up power. If a vessel does not have an emergency power system, normal power to the gyrocompass system should be from a dedicated feeder from the ship service switchboard.

30. Automatic steering systems

30.1 General

An automatic steering control system consists of the following apparatus:

a) A heading data sensor consisting of a gyrocompass, a sensor equipped magnetic compass, or both
b) A device for defining the prescribed course
c) Error sensors to measure the difference between actual heading and prescribed course
d) A heading control system
e) A rudder position indicator and rate of turn indicator
f) A rudder control system
g) Power supplies for the automatic steering control system
h) An alarm circuit to indicate electrical supply failure or other major malfunction, including divergence of the actual and prescribed course by more than a set amount
i) Additional circuits such as manual auxiliary rudder controls, override controls, or interfaces to navigation systems for the purpose of automatic changing of the prescribed course.

In the past, the division between an autopilot (frequently referred to as a gyropilot), and the electric, mechanical, or hydraulic portion of the steering system that actually moved the rudder(s) was separate and distinct. The small size of the modern electronic autopilot permits the steering stand to include the manual wheel for follow-up steering, nonfollow-up controls, steering pump controls, and indicators for rudder order and rudder position.

30.2 Navigating bridge installation

The arrangement of the steering controls in the navigating bridge should provide full follow-up control of the rudder. In addition, the following installation details apply:

a) The arrangement of the steering station should be such that the helmsman is abaft the steering device and can readily observe all steering indicators and controls
b) A suitable notice should be installed directly in the helmsman's line of vision, to indicate the direction in which the steering device must be turned for "right rudder" and "left rudder."
c) There should be an indication at the steering station as to what steering control system and pumps are being used.

30.3 Power supply

The steering control system power supply should be fed from the same feeder(s) as the steering gear (see 18.3).

30.4 Alarm system

Required alarms (see 18.4) are frequently included in the autopilot stand.

31. Exterior communication and navigation systems

31.1 General

These systems include electrical, electronic, and electromechanical devices intended for the purposes of vessel navigation and communication to and from the vessel. These systems transmit or receive radio frequency audio and data signals. On new vessels, the Global Maritime Distress Safety System (GMDSS) installation replaces or supplements traditional radio room equipment.

31.2 Safety

As components of these systems often have dangerous voltage levels or emit hazardous electromagnetic energy, the following safety precautions should be observed:

a) Suitable guards and warning signs should be provided to prevent personnel from coming into contact with or being exposed to dangerous voltages or electromagnetic energy.
b) Interconnecting cables, waveguides, coaxial cables, and connectors should provide satisfactory electrical connections while precluding personnel from coming in contact with any energized leads or pins.
c) Antenna base and feedthrough insulators should be installed to protect personnel from accidental shock, and to prevent arcing to adjacent structures.
d) Proper grounding practices should be employed to protect personnel from accidental chassis potentials and to avoid the presence of ground loops (see 11.39).
e) Warning signs should be placed near all emitting antennas providing information regarding safe distances. (One possible method is to indicate the distance at which radiation levels of 100 W/m^2, 25 W/m^2, and 10 W/m^2 exist.)
f) Provisions should be made for securing primary power to equipment.

31.3 General installation guidelines

All materials, devices, equipment, and installation material and practices should be suitable for marine use. All equipment should be located and installed in a manner that will provide for adequate equipment security and protection, operational and maintenance access, and easy connection to auxiliary equipment and adequate ventilation, and that will minimize the effects of radio/audio interference. Installation should also minimize interference with night vision from light sources and daytime glare. High-voltage components should be adequately shielded. Where practical, receiving and transmitting equipment should be physically separated. Orientation of equipment should be in accordance with the manufacturer’s recommendations.

Navigation and communication equipment should be installed with regard to functionality. On the navigation bridge, equipment should be grouped into navigation, maneuvering, communication, and monitoring functions. All consoles and individual equipment items should be positioned to be viewed by a person looking forward, and each workstation or console should present all of the information necessary to carry out the particular functions required.

Consoles should be designed so that information is presented on the vertical part of the console and controls are on the horizontal part. Height, width, and depth of consoles should be in accordance with ergonometric principles.

The communications equipment should be located as high in the vessel as practicable.

31.4 Power supplies

In general, these systems are required by regulatory authorities to have duplicate or backup power sources. Where required, the following power arrangements should be made:

a) The radio system power supply should be able to simultaneously energize the equipment at full load and charge any batteries forming a part of the system, while maintaining the voltage within 10% of its rated value.
b) The radio system backup power supply should be independent of any other electrical system and of the propelling power of the ship and should have the capability to simultaneously operate the radio equipment at full load for at least 6 h and operate automatic alarm signal devices for at least 1 h.
c) The radio system backup power supply should be located as near to the reserve transmitter and receiver (or to the GMDSS) as practicable. Where a reserve supply unit is provided, it should be located adjacent to the equipment.
d) Independent radar systems and integrated navigation systems should be supplied from separate emergency feeders or branch circuits.

31.5 Radio interference

In general, steps should be taken during design and installation to minimize electromagnetic interference to and from other equipment. This interference takes two basic forms: conducted and radiated. The following techniques can be used for reducing EMI:

a) Locate transmitting and receiving antennas as far apart as practicable.
b) Use two-conductor, twisted-pair wiring.
c) Separate wiring carrying high-level signals from low level-signals and separating power cables from cables carrying low-level signals.
d) Shield feeder (e.g., cables mechanically shielded or cables constructed with shields) cables and limit the length of unshielded feeders.
e) Minimize the length of ground leads.
f) Electrically bond or isolate all stays, shrouds, and wire rigging. Where stays are isolated, insulators should be of a type that will not part the stay upon failure.
g) Use suitable protection against power line transients in the equipment.
h) Ground the armor on armored coaxial cable.

31.6 Antennas

Antennas should be mounted as high as practicable with the maximum physical spacing. Radar antennas and satellite system antennas should be positioned to minimize shadowing. Antennas should be physically separated to reduce electrical interaction and to avoid physical contact due to antenna deflection cause by ice loading, wind, or sea conditions. Antennas should be mounted so that their failure will not foul other antennas. Antennas, insulators, or radomes should not be painted or coated. The following, more specific installation guidelines apply:

a) Wire antennas should be continuous from entrance insulator to the extreme end, and should be installed free from kinks, sharp bends, deformations, and broken strands. Shackles, insulators, and similar antenna hardware should be sized so that the antenna wire will fail before the hardware.
b) VHF and UHF whip antennas should be kept at least one wavelength from any vertical conductor. Supporting structures should be made electrically smaller by inserting insulators into the length of the structure.
c) Larger whip antennas should be mounted to the deck or appropriate structure. Consideration should be given to reinforcing the mounting area to support the added weight and bending moment.

d) Antenna couplers should be installed, and connected to the antenna in a manner expected to minimize detuning of the circuit.
e) Lightning protection should be provided at the base and at feedthrough insulators where practicable.

31.7 Equipment installation guidelines

In addition to the foregoing general recommendations, the following equipment-specific recommendations apply:

a) Radar installations
   1) Provision should be made in the navigating bridge for radar plotting if this feature is not built in to the equipment.
   2) Where two radar antennas are fitted, they should be situated so as to minimize the risk of one transmitting into the other.
   3) The antenna(s) should be located to avoid shadow sectors. If this is not possible, the placement of the shadow sectors should be such as to minimize the impact on the navigation of the vessel.
   4) The antenna foundation platform should be constructed to provide safe access for maintenance and be located to minimize fouling of the antennas by running rigging.
   5) Displays should be designed so that light from the display does not interfere with night vision and that light from navigating bridge windows does not interfere with viewing radar screens.
   6) At least one display should be located as to be viewable while facing forward by at least two persons.
   7) The position of the displays should adhere to the applicable safe compass distance.
b) Radio direction finder installation
   1) The antenna should be mounted as high as possible on the centerline of the vessel so reception of bearing signals are not degraded by the proximity of other antennas, cranes, wire halyards, or large metal objects.
   2) Fixed metallic structures rising above the base of the antenna should be no closer than 1.8 m (6 ft).
   3) All wire and self-supporting antennas having a part rising above the base of the direction finder antenna within 17 m (55 ft) of the antenna should be able to be isolated during use of the direction finder.
c) Echo sounders and speed logs
   1) The most important consideration to take into account during the installation of this equipment is the placement of the transducer(s). These should be placed so as to be in “quiet” water where the effect of aeration, cavitation, surface, engine, and propeller noise is a minimum.
   2) The transducer should be located near the centerline, away from obstructions such as bow thrusters, water intake/discharges, drains, anodes, stabilizing fins, keels, and other transducers.
   3) There should be dry access to the transducer. Where necessary, the interior of the bottom should be built up to allow the transducer to be level. Care should be taken to ensure that the transducer is not covered with grease or antifouling paint.
   4) Where the operating frequencies are similar, care should be taken to physically separate the transducers so as to avoid interference between the echo sounder and log.
d) Satellite communications equipment
   1) Objects should not be located within 10 m (33 ft) and within –5° of the antenna horizontal plane.
   2) Objects that can subtend an arc of greater than 6° of the antenna beam should be avoided.
   3) The antenna should not be placed near sources of flammable or combustible vapors, exhaust gas, dust, dirt, or heat.
   4) The antenna foundation platform should provide for safe access to the interior of the radome.
e) Waveguide and coaxial cable installation
   1) The runs should be kept as short as possible, and the number of bends, offsets, connections, and adapters should be minimized.
   2) Routing should be selected to avoid strain on the material and to minimize temperature changes. Waveguide should be routed to minimize the collection of condensation.
   3) Waveguide should not be distorted and should be adequately supported along the entire length. Waveguide should not be secured to surfaces that can move with respect to each other.

4) Bends and twists should not exceed manufacturers' recommendations.

32. Galley equipment

32.1 Electric cooking equipment

32.1.1 Construction

All electric cooking equipment, attachments, and devices should be of rugged construction and designed to permit complete cleaning, maintenance, and repair. All servicing should be possible from the front or top without moving the equipment. Equipment should meet the shipboard equipment requirements of a recognized standard. Range, oven, broiler, fry kettle, and griddle units should be sectional. Equipment should be rigid, and self-supporting. Joints between equipment sections should be bolted. Equipment should comply with ANSI/UL 197-1993, or the equivalent shipboard equipment requirements of a nationally recognized testing laboratory.

All external surfaces of cooking equipment, exclusive of cooking tops, should be thermally insulated to improve efficiency and reduce the burn hazard to personnel. Electric cooking appliances should be constructed so that parts that must be handled cannot become heated to a temperature exceeding the values given in Table 32-1.

Table 32-1—Temperature limits for noncooking surfaces on cooking equipment

Handles, grips, etc., made of	Maximum temperature during normal use held in the hand	
	For long periods	For short periods
Metal	55 °C (131 °F)	60 °C (140 °F)
Porcelain and vitreous material, molded material, rubber or wood	65 °C (149 °F)	70 °C (158 °F)

Higher temperatures may be acceptable for parts that normally will not be handled with unprotected hands, such as handles of drawers for spilled liquid in cooking ranges.

All component parts should be made of corrosion-resistant material, or should be adequately protected against corrosion. Unit exteriors should be stainless steel, or should have a baked enamel, or other corrosion-resistant finish. Chrome nickel stainless steel is preferred for cleanliness and maintenance. Oven linings should be chrome nickel stainless steel or aluminized steel.

Doors on electric cooking equipment should be equipped with heavy duty hinges and a locking device to prevent door opening in a heavy sea. Grab rails should be provided on the front of cooking equipment for use by the crew in heavy seas.

Appliances should be marked with the manufacturer's name and address, equipment model designation, rated voltage(s), current, number of phases and frequency.

Portable cooking appliances should be weighted or shaped so that they cannot easily overturn.

32.1.2 Mounting

For any equipment, if legs are provided for mounting, they should be a minimum of 100 mm (4 in) high. If the unit is to be platform mounted, a base should be provided that can be easily sealed to the platform. Where a platform is provided, its edges should not extend beyond the device to prevent the accumulation of foreign matter. All equipment should be mounted to prevent dislodgment by rolling or pitching.

32.1.3 Electric power

Electric cooking equipment should be designed to operate on a standard voltage, not in excess of 600 V. AC units may be single- or three-phase. If a branch circuit supplies only one appliance or device, the rating or setting of the branch circuit overcurrent device should not be more than 150% of the rating of the appliance or device, or 15 A, whichever is greater. The individual phase loads of the heating elements in ac cooking equipment should be given on the equipment wiring diagram to facilitate adjustment of the overall galley phase balance. Cooking units and all non-current-carrying metal parts should be suitably grounded.

32.1.4 Heating elements

All heating elements should be of the metal-clad enclosed type. No open and exposed resistance wire should be used. Porcelain may be used to seal the end of a sealed unit and to obtain proper creepage distances on the unit terminal. Where elements are connected to the source of power through connectors, the contacts should have adequate area, be silver plated and have a contact length of 25 mm (1 in). There should be a positive locking device to prevent element loosening due to vibration.

32.1.5 Wiring

All power and control wiring within the unit should be Class H insulated or better, located away from sources of heat and adequately protected from spillage and grease. Terminal blocks, suitably identified, should be provided outside the heat zone for connection to external wiring. In the heat zone [temperatures in excess of 93.4 °C (200 °F)] all wiring should have Class H insulation (or better), stranded pure nickel wire or manganese wire. For ranges, ovens, and broilers built as independent units, wiring between the terminal blocks of the unit and the terminal blocks of the switchbox should have tinned stranded coppper conductors and Class H insulation. Type MI cable also may be used for connections between appliance and switch box.

All wiring should be adequately supported and protected from mechanical damage.

32.1.6 Controls

All controls for ranges, ovens, and broilers, excluding thermostats, should be mounted in a separate dripproof switchbox located on or adjacent to the unit. The section of the switchbox that covers contactors should be hinged and equipped with a locking device. Other front access panels should be secured with screws to prevent accidental opening. Connections for external wiring should be made at suitably identified terminal blocks. A switchbox located on the unit should be insulated and ventilated to prevent damage to any of the controls or wiring.

Controls for fry kettles and griddles may be located in the units or on a remote control panel. When located in the unit, they should be as far from sources of heat as possible, protected against spillage and grease, and readily accessible with a minimum of disassembly. Fry kettle controls should be located in positions where the user does not have to reach over the cooking area to operate a control device. If controls for fry kettles and griddles are remotely located, they should be similar to those described for ranges.

The type of control and the temperature range for various appliances should conform to the guidelines of Table 32-2.

Thermostats for ranges should be mounted on the units and be adequately protected against spillage, grease, and mechanical injury. An automatic temperature control should be located on the unit in a position readily accessible for setting by the operator. The contactors controlling the power supply to the heating element should be located in the control panel. Broilers built as independent units (that is, not combined with range type ovens) need not be furnished with thermostats.

Where thermostats are used on range top griddles, a sufficient number should be furnished to ensure even heat distribution over the entire cooking area.

Switches, relays, thermostats, and control devices may contain nonhygroscopic, high-specific gravity porcelain having a cross-section adequate to prevent cracking. Switches for ac service should be rated at not less than 30 A, and should be capable of at least 100 000 complete cycles of operation (50 000 in each direction) under full rated load without failure.

A temperature-regulating thermostat whose failure will not result in a fire hazard should be capable of operating for a minimum of 30 000 cycles under full load. A combination temperature regulating and limiting thermostat that serves to prevent a fire hazard under abnormal operating conditions should be capable of operating a minimum of 100 000 cycles.

Table 32-2—Type of control and temperature range for appliances

Service	Temperature range
Rangetop griddles:	
Indicating 3 heat switch or thermostat with OFF position Range Top hotplates:	90–230 °C (194–446°F)
Indicating 3 heat switch or thermostat with OFF position Range griddle-hotplates:	110–480 °C (230–896 °F)
Indicating 3 heat switch or thermostat with OFF position Range over compartment:	110–480 °C (230–896 °F)
Thermostat and separate indicating 3 heat switch for both upper and lower unit:	90–260 °C (194–500 °F)
Range oven broiler:	
Top unit 3 heat switch	90–230 °C (194–446 °F)
Fry kettle:	
Indicating reversible switch and thermostat	90–230 °C (194–446 °F)
Griddle:	
Thermostat with OFF position or 3 heat switch	90–230 °C (194–446 °F)

Rotary switches for operation with dc power should be capable of at least 50 cycles of operation at 125% of rated current, at rated voltage and 6000 cycles of operation in each direction at rated current and voltage, without failure. Switches controlling relays and other similar functions should have a continuous rating at least equal to the circuit load.

Control circuits should be protected in accordance with 17.1.

Where the power input voltage is over 250 Vac and a lower control voltage is required, control power should be furnished by a control transformer that is an integral part of the appliance. The control transformer should be de-energized when the power circuit is opened.

32.1.7 Range tops and griddles

Cooking surfaces of ranges and griddles should be made of material that can be easily cleaned, such as polished hot rolled steel, cast iron, or stainless steel. To ensure positive grease collection, drip pans should be fitted under, and should project out from, the cooking surfaces, or the cooking surfaces should be equipped with grease deflecting baffles. Any spillage from the drip pan due to rough seas or handling should drain out the front of the unit. The unit should be designed so that spillage cannot flow to any place where it cannot be readily removed. Adequate drip pan drainage should be provided. Ranges should be provided with sea rails with adjustable barriers to prevent cook pot movement.

Griddles may have either heat selection switches or automatic temperature controls but need not be provided with both.

Working height of ranges and griddles should be 910 mm (36 in). Ranges may be sectional (base, body, and cooking top).

Heating elements should be removable from the top or front of the appliance without disassembly of the units.

32.1.8 Ovens and broilers

Ovens should be sectional and include legs of proper height for optimum working level. Each section should be independently operated with provision for controlling the amount of top and bottom heat. Broilers should be sectional and designed to permit stacking one above the other on a cabinet base or an oven. Back-shelf broilers should be designed to permit mounting on the rear of a range and should have at least 75 mm (3 in) movement of controlled adjustable griddle height where three heat switches are used.

Heating elements should be removable from the front without disassembly of the unit.

Broilers should be provided with rugged, movable grids, each provided with a counterbalanced means to vary the grid height approximately 150 cm (6 in) where heat selection switches are used and a positive stop to retain the grid at the desired height. Where automatic temperature controls are provided, stationary grids with a positive stop should be provided. A removable drip pan should be installed beneath the grid. A second drip pan should be installed at the bottom of the broiler compartment for positive grease collection and easy removal.

32.1.9 Fry kettles

A fry kettle unit may be a sectional (body, legs, and fat container) or a one-piece design. The fat container should be fabricated from corrosion-resistant material and should have adequate capacity to accommodate foaming. The bottom of the fat container should drain toward the center and should have a minimum 25 mm (1 in) diameter drain pipe with gate valve, arranged to provide straight through drainage with minimum clogging.

Fry kettle fat containers having a weight, when full, of 11 kg (25 lb) or more should not be movable manually but should be provided with a drain pipe and valve for grease drainage.

The heating elements should be controlled by an indicating reversible switch and thermostat and be removable from either the top or front of the fry kettle unit with a minimum of disassembly.

32.1.10 Testing

Cooking appliances, including their control equipment, should be tested at the manufacturer’s facility.

For portable appliances, the leakage current should not exceed 1 mA, and for stationary appliances 1 mA or 1 mA per kW rated input, whichever is the larger, for each heating element that can be switched off separately.

32.2 Motor-driven commissary equipment

Motor-driven commissary equipment such as dough mixers, meat grinders, and potato peelers, should be rigidly constructed and self-supporting. All component parts should be made of corrosion-resistant material or should be adequately protected against corrosion. All equipment should be designed for easy cleaning and servicing from the front.

Each electric motor-operated appliance should meet an appropriate standard such as ANSI/UL 73-1993, ANSI/UL 471-195 (Refrigerators), ANSI/UL 921-1992 (Dishwashers), ANSI/UL 399-1993 (Water Coolers), or the equivalent shipboard equipment requirements of a nationally recognized testing laboratory.

Motors and controls for motor-operated commissary appliances located in damp or wet locations should, where practical, be watertight or placed in watertight enclosures. Controls should be of heavy duty construction. Where it is impractical to obtain appliances with watertight motors and controls, appliances with standard commercial motors and control enclosures may be used.

33. Hazardous locations, installations and equipment

33.1 General

Hazardous (classified) locations are those areas where fire or explosion hazards may exist due to the presence of flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings. Electrical equipment and wiring should not be installed in such locations unless essential for operational purposes. When installed in these locations, special precautions should be taken to ensure that the electrical equipment is not a source of ignition. The recommendations in this clause reflect traditional U.S. practices and standards, as reflected in Articles 500 through 504 of the National Electrical Code (NEC), ANSI/NFPA 70-1996. Except as indicated in this standard, electrical installations in hazardous locations should meet those NEC articles. Alternatively, Article 505, which is based upon the International Electrotechnical Commission (IEC) zone concept of classification, may be used where permitted by the regulatory agency. Annex A provides additional information on the IEC classification concept and equipment requirements. All electrical equipment installed in classified locations should be suitable for the specific classification of the space in which it is installed.

33.2 Classification

Hazardous locations are established depending on the properties of the flammable vapors, liquids, or gases, or combustible dusts or fibers that may be present, and the likelihood that a flammable or combustible concentration or quantity is present. Examples where flammable gases or vapors may exist include battery rooms, paint lockers, pump rooms, cargo tanks, and weather deck locations above cargo tanks on tank vessels, and operating rooms on passenger vessels and hospital ships where flammable anesthetics are administered.

The NEC classifies hazardous locations in Article 500. The type of explosive hazard (gases or vapors, dusts, fibers) and the likelihood of its presence, the “Class” and “Division” respectively, are the determining factors for the designation of the classified location. The NEC classifies gas, vapor, and combustible liquid hazards as “Class I,” dust hazards as “Class II,” and fibers and flyings hazards as “Class III.” In each class, locations are designated “Division 1” or “Division 2,” depending upon the likelihood of the presence of the hazardous gas, vapor, dust, or flyings. Division 1 locations are more likely to have the hazard present than Division 2. A specific “Group” designation is assigned based upon the particular characteristics of the atmosphere (e.g., Group A: atmospheres containing acetylene).

33.3 Approved equipment

Electrical equipment in hazardous locations should be of a type suitable for such locations (Class, Division, and Group) and be type tested and certified (or listed) by an independent testing laboratory acceptable to the regulatory authority.

NOTE—For cables, see 33.6.

33.4 Protection by enclosure

33.4.1 Explosionproof equipment (Class I locations)

Each item of electric equipment that is explosionproof should be approved for use in the proper group according to the gases or vapors that may be present. If the cargo is an inorganic acid, explosionproof equipment should be approved for use in a Group B atmosphere.

33.4.2 Dust ignitionproof equipment (Class II locations)

Each item of electric equipment that is dust ignitionproof should be approved for the proper group according to the dust that may be present.

33.4.3 Purged and pressurized equipment

Purged and pressurized equipment may be used as an alternative to explosionproof equipment and should meet the requirements of ANSI/NFPA 496-1993.

33.5 Intrinsically safe systems

Intrinsically safe systems are those systems that do not contain sufficient electrical or thermal energy, under normal and abnormal conditions, to cause ignition of specified gases or vapors. Intrinsically safe systems should be approved. Electric cable for intrinsically safe systems should be spaced 51 mm (2 in) or more from nonintrinsically safe circuits (and identified as cable for an intrinsically safe circuit), partitioned by a grounded metal barrier from nonintrinsically safe circuits, or be a metallic armored or sheathed cable where the metallic sheath cladding or armor is capable of carrying fault current to ground. Enclosures housing intrinsically safe barriers should segregate cable entries between intrinsically safe circuits. If terminations within the enclosure are not located on the barrier device, separate terminal blocks are required for intrinsically safe and nonintrinsically safe circuits. Cables for intrinsically safe circuits should not contain conductors for nonintrinsically safe circuits and should not contain conductors for other intrinsically safe circuits unless specifically approved for that arrangement. More than one intrinsically safe circuit of the same intrinsically safe system may be run in a multiconductor cable.

Where multiple intrinsically safe systems are interconnected, ANSI/ISA-RP 12.6-1995 should be used to determine the acceptability of combinations of intrinsically safe apparatus and connected associated apparatus that have not been investigated for such interconnection.

The manufacturer of intrinsically safe systems typically provides installation instructions and identifies system restrictions. Typical restrictions include supply voltage limitations, allowable interconnect cable parameters (including cable length), and the ability of the system to accept passive devices. These restrictions should be followed.

33.6 Wiring methods—hazardous locations

Armored shipboard cable constructed in accordance with Clause 8 may be used in Class I, Division 1 and Zone 1 locations. Unarmored shipboard cable constructed in accordance with Clause 8 may be used in Class I, Division 2 and Zone 2 locations. Cable entrances to explosionproof enclosures should be made with approved seal fittings, termination fittings, or glands. Cable entrances to equipment in Class II and Class III locations should be made with dusttight cable entrance seals. Flexible cords and cables, where permitted, should be constructed for extra hard usage.

33.7 Switches

Each explosionproof switch and each switch controlling explosionproof equipment should have a pole for each ungrounded circuit conductor.

33.8 Ventilation

The interior of a ventilation duct has the same classification as the space it ventilates. Fans used for ventilating hazardous locations should be nonsparking.

33.9 Belt drives

Belt drives in hazardous locations should have a conductive belt and should have pulleys, shafts, and driving equipment grounded in accordance with ANSI/NFPA 77-1993.

33.10 Flammable anesthetics

Electrical installations in spaces where flammable anesthetics are used or stored should meet ANSI/NFPA 99-1996.

33.11 Battery installations

The interior of rooms containing batteries that are connected to a battery charger that has an output of more than 2 kV (computed from the highest possible charging current and the rated voltage of the battery installation) shall be classified Class I, Division 2, Group B, with the additional requirement that all wiring and equipment except the batteries, the jumpers connecting their cells, and the positive negative battery cable leads shall be suitable for Class I, Division 1, Group B.

33.12 Paint stowage or mixing spaces

A space for the stowage or mixing of paint is a Class I, Division 1, Group D location.

33.13 Vessels specially designed for vehicles

For vessels carrying vehicles with fuel, the space from the vehicle deck to a height of 460 mm (18 in) above the deck is a Class I, Division 2, Group D location. Regulatory authorities and classification societies generally require effective ventilation in order to maintain this Division 2 classification. Where moveable decks are provided, the Division 2 location extends from 460 mm (18 in) above the uppermost moveable deck down to the nonmoveable deck. Electrical equipment in the vehicle space that is above the Division 2 location should be totally enclosed or dripproof and protected by guards or screens to prevent the escape of sparks or metal particles under fault conditions.

33.14 Electrical installations on tank vessels

33.14.1 Distribution systems

Electrical distribution systems of less than 1000 V (line-to-line) should be ungrounded. Grounded distribution systems greater than 1000 V and localized systems under 1000 V (such as for engine starting) may be used where current resulting from a fault condition would not flow through the cargo tank or other hazardous location.

33.14.2 Electrical installations on tank vessels carrying combustible liquid cargo with a closed cup flashpoint of 60 °C (140 °F) or higher

On a vessel that carries combustible liquid cargo, all electrical equipment in cargo tanks should be intrinsically safe.

33.14.3 Electrical Installations on tank vessels carrying flammable or combustible liquid cargo with a closed cup flashpoint below 60 °C (140 ° F) (including bulk liquefied gas carriers), ammonia, liquid sulfur carriers, and inorganic acid carriers

The following locations in the weather are Class I, Division 1 locations:

a) The open deck area on tankships over the cargo area extending 3 m (10 ft) forward and aft of the cargo area for the full beam and to a height of 2.5 m (8 ft) above the deck. (The open deck area on a tankship carrying inorganic acid is considered a nonhazardous location.)
b) A open deck area within 3 m (10 ft) of a cargo tank vent opening, a cargo tank ullage opening, a cargo pipe flange, a cargo valve, a cargo handling room entrance, or ventilation opening. An area within 5 m (16 ft) of a pressure/vacuum valve outlet with an unlimited height.
c) Within 10 m (33 ft) of a vent outlet for free flow of vapor mixtures and high velocity vent outlets for the passage of large amounts of vapor, air, or inert gas mixtures during cargo loading and ballasting or during discharging.

A cargo tank is a Class I, Division 1 hazardous location that has additional electrical equipment restrictions (IEC Zone 0; see Annex A). Cargo tanks should not contain any electrical equipment except intrinsically safe equipment and submerged cargo pumps with their associated cable.

An enclosed space that is adjacent to a cargo tank has the same hazardous location classification as the cargo tank. Such spaces should not have any electrical equipment except intrinsically safe equipment, and hermetically sealed devices or watertight enclosures with bolted and gasketed covers containing equipment for depth sounding, speed logging, or electrodes for impressed-current cathodic protection. There may be through-runs of cable in these spaces.

A cargo handling room, a space for cargo hose storage, and a space that contains cargo piping has the same area classification as the cargo tank. The space should not have any electrical equipment except intrinsically safe equipment, explosionproof lighting fixtures, and electric cable. A cargo handling room should have only cable supplying equipment in the room. A space that has a direct opening into a hazardous location has the same classification and equipment restrictions as the hazardous location, unless the additional precautions described below, are taken.

An enclosed space that has direct access to a Division 1 location is a nonhazardous location if the access has two self-closing gas-tight doors forming an air lock. The ventilation pressure in the air lock is to be greater than in the Division 1 location. Loss of air lock ventilation overpressure should cause an alarm at a normally attended location. An enclosed space that has direct access to a Division 1 location may be considered a Division 2 location (or similarly an enclosed space that has direct access to a Division 2 location may be considered a nonhazardous space) if the access has a self-closing gas-tight door that opens into the space and has no hold-back device. The ventilation in the Division 2 (or connecting nonhazardous location) is to be at an overpressure with respect to the Division 1 location (or the Division 2 location in the case of a nonhazardous location). Loss of overpressure should cause an alarm at a normally attended location.

A vessel carrying carbon disulfide must have only intrinsically safe electrical equipment in the Class I, Division 1 locations identified above.

Submerged cargo pumps should have a low liquid level, motor current, or pump discharge pressure shut-off that automatically removes power to the motor if the pump loses suction. An audible and visual alarm should be actuated at the cargo control station by the shut-off of the motor. There should be a lockable circuit breaker or switch that disconnects power to the motor.

Where practical, lighting for cargo handling rooms should be through a suitable wire-inserted fixed glass lenses in the bulkhead or overhead from a nonhazardous location. Fixed lenses should be constructed as to maintain the gastight and watertight integrity of the structure. The fixture should be designed so venting and relamping is performed from the non-hazardous location. The temperature of the lens should not exceed 180 °C (356 °F) in a 40 °C (104 °F) ambient. Where through-bulkhead lighting is impractical, compromises the fire rating of the bulkhead, or cannot provide adequate illumination, explosionproof lighting fixtures should be provided.

At least two lighting branch circuits should be provided for hazardous spaces so that one may be de-energized for relamping. Lighting for enclosed hazardous spaces should be switched using double pole switches located outside of the space.

Ungrounded distribution systems, except intrinsically safe circuits, feeding or passing through a hazardous location should have a device capable of continuously monitoring the insulation level to ground and giving an audible alarm at a normally attended location when the current exceeds 30 mA.

33.14.4 Additional recommendations for tank vessels carrying bulk liquefied gas or ammonia

The weather deck of an ammonia carrier is a nonhazardous area. Equipment in a hold space that has a cargo tank that is not required to have a secondary barrier should meet the recommendations above for a space adjacent to a cargo tank, except that explosionproof lighting is also permitted. Electrical equipment in a space separated by a gastight steel barrier from a hold space having a tank that must have a secondary boundary should meet the requirements above for a space adjacent to a cargo tank, except that explosionproof lighting, explosionproof motors operating cargo and ballast valves, and explosionproof general alarm bells are also permitted.

33.15 Vessels carrying coal

Vessels carrying coal present a unique hazardous location problem. Both a coal dust hazard and a methane gas hazard can exist simultaneously. Equipment suitable for use in a combustible dust atmosphere does not typically provide the protection needed in a flammable gas atmosphere, and equipment for use in a flammable gas atmosphere does not typically provide the protection needed in a combustible dust atmosphere. Equipment selection is further complicated by the need for equipment that can withstand compartment hose-down to reduce dust accumulation.

From a coal dust aspect, the following areas are Class II, Division 1 locations: the interior of each coal bin and cargo hold, each compartment that has a coal transfer point (where coal is dropped or dumped), and each open area within 3 m (10 ft) of a coal transfer point. A space that has a coal conveyor is a Class II, Division 1 location on a vessel that carries anthracitic coal, and a Class II, Division 2 location on a vessel that carries bituminous coal.

When carrying coal that is known to, or that may emit methane gas, the following shall be fitted:

a) A ventilation system shall be provided to holds and adjacent spaces such that ventilation is carried out at a rate of 33 L/min (1.2 f^3/min) times the maximum weight of coal, in tonnes, that the ship may carry.
b) All electrical fittings in cargo holds and adjacent spaces shall comply with the requirements of either Class I, Division 1 (Group D) or Class I, Division 2 (Group D), as applicable, and Class II, Division 1, or Division 2, as applicable. If the electrical equipment is of the Class I, Division 2, Group D type, an interlocking system shall be installed such that the failure of the ventilation system shall remove power from all Division 2 electrical equipment in the holds or adjacent spaces effected by the ventilation loss.

Class I electrical equipment may generate temperatures in excess of those permitted for Class II (Dust) locations if they become blanketed with coal dust. Therefore, care must be taken to ensure that the installed Class I electrical equipment that can generate heat is also certified for operation in a Class II location.

From a methane aspect, the locations identified above are considered Class I, Division 1, Group D locations. Electrical equipment installed in these locations should be suitable for use in both Class I and Class II areas; this requires dual approvals (dual labeled). Explosionproof equipment that is not watertight should be provided with approved drains. Explosionproof general alarm bells may be permitted in Class II, Division 2 locations. General alarm sound generating devices approved for Class I Division 2 locations may be installed in Class II, Division 2 locations.

34. Transformers

34.1 General

Transformers should have copper windings, be of the dry type, air cooled by natural circulation, and have a dripproof enclosure as a minimum. Where used for essential services and located in areas where sprinkler heads or spraying devices for fire prevention are fitted, they should be enclosed so that water cannot cause malfunction. In cases where capacity, space, or other restrictions warrant, transformers may be of the immersed (nonflammable liquid) self-cooled, or other suitable type. Immersed type transformers should be suitable for operation at 40° inclination without leakage and provided with a liquid level gauge to give indication of the level of liquid. Drip tray(s) or other suitable arrangements should be provided for collecting liquid leakage. All transformers should be capable of withstanding the thermal and mechanical effects of a short-circuit at the terminals of any winding for 2 s without damage. Foil-wound transformers constructed of conductors that are uncoated should be vacuum impregnated. Transformers should comply with *the Distribution, Power, and Regulating Transformers Standards Collection,* as applicable to the type, size, application and voltage rating of the units installed.

34.2 Installation and location

Transformers should be located in dry, well-ventilated places, avoiding exposure to the possibility of leaking pipes or condensation. Transformers should be placed so that, insofar as practicable, they are not exposed to mechanical damage. Transformers should be located and mounted to preclude excessive noise in accommodation areas. Suitable lifting lugs or eye bolts should be provided for transformers weighing more than 50 kg.

34.3 Type, number, and rating

The number and rating of transformers supplying services and systems essential to the safety and/or propulsion of the ship should have sufficient capacity to ensure the operation of those services and systems even when one transformer is out of service. Transformers should be either the three-phase type or single-phase type, suitable for connection in a three-phase bank, with a Class B temperature rise. All distribution and control transformers should have isolated primary and secondary windings. Transformers with electrostatic shielding between windings should be used in distribution systems containing nonlinear load devices. Auto-transformers should be used only for reduced voltage motor starting or other suitable special applications.

34.4 Voltage regulation

The inherent voltage regulation of transformers, at rated output, should be such that the maximum voltage drop to any point in the system in which the transformers are applied does not exceed the system voltage drop values in Clause 11.

34.5 Parallel operation

Transformers for parallel operation should have coupling groups and voltage regulation characteristics that are compatible. The actual current of each transformer operating in parallel should not differ from its proportional share of the load by more than 10% of full-load current. A means of isolating the secondary connections should be provided.

34.6 Temperature rise

The limits of temperature rise in a 40 °C ambient should be in accordance with Table 34-1. Transformers should also be designed to operate in an ambient temperature of 50 °C without exceeding the recommended total hot spot temperature, provided the output kilovoltampere at rated voltage does not exceed 90% of the rated capacity of the transformer with Class A insulation and 94% of the rated capacity of a transformer with Class B insulation.

34.7 Terminals and connections

Provision should be made to permit the ready connection of external cables to the primary and secondary leads in an enclosed space of adequate size to prevent overheating. Terminals should be readily accessible for inspection and maintenance.

Single-phase transformers should permit the use of single conductor cables, without undesirable inductive heating effects, when interconnecting three single-phase transformers in a three-phase bank.

Transformers should be furnished with a permanently attached diagram plate showing the leads and internal connections and their markings and the voltages obtainable with the various connections.

34.8 Nameplates

The following is the minimum information that should be given on nameplates:

a) Serial number or catalog number
b) Type or form
c) Number of phase (except single-phase)
d) Kilovoltampere ratings
e) No-load voltage rating
f) Frequency
g) Temperature rise
h) Percent impedance
i) Connection type (e.g., delta-delta)

Table 34-1—Transformers and dc balance coils

	Copper temperature rise by resistance				Hottest spot temperature			
	Class of insulation							
Part	**A**	**B**	**F**	**H**	**A**	**B**	**F**	**H**
Insulated windings	55 °C (131 °F)	80 °C (176 °F)	115 °C (239 °F)	130 °C (266 °F)	65 °C (149 °F)	110 °C (230 °F)	145 °C (293 °F)	180 °C (356 °F)
NOTE—Metallic parts in contact with or adjacent to insulation shall not attain a temperature in excess of that allowed for the hottest spot copper temperature adjacent to that insulation.								

35. Rectifiers

35.1 General

This clause addresses power semiconductor rectifiers of the copper oxide, selenium, and silicon types. Copper oxide and selenium rectifiers are also known as metallic rectifiers. It should be noted these latter types of semiconductor rectifiers may exhibit changes in resistance characteristics with age, use, and temperature history.

Semiconductor rectifier cells (or devices) may be arranged in series assemblies, often referred to as “stacks,” which themselves may be connected in various combinations of series and parallel circuits to form bridge, half wave, voltage doubler, or other combinations.

Rectifier cells (or devices) may be connected to form various circuits, some intended to be operated from single-phase power sources and others from polyphase power sources.

The thermal and instantaneous overload protective devices incorporated in the unit should be coordinated with the capacities of the cells.

Surge suppression circuitry may be required to prevent any transient voltages from exceeding the rated peak reverse voltage rating of the cells in the rectifier unit.

The rectifiers may be naturally cooled, forced-air-cooled, or liquid-cooled. Immersed and liquid-cooled rectifiers should use a nonflammable liquid. Immersed rectifiers should be capable of operation without leakage when the ship is inclined to an angle of 22.5° each side of the vertical.

35.2 Installation and location

Rectifiers should be installed in such a manner that the circulation of ventilating air to and from the rectifier or its enclosure (if any) is not impeded and the temperature of the inlet air to the air cooled rectifiers does not exceed that for which the rectifier is designed. Caution should be exercised in the mounting of rectifiers near resistors, steam pipes, engine exhaust pipes, or other sources of radiant heat energy.

Semiconductor rectifier systems rated for continuous 50 °C (122 °F) ambient temperatures should be installed, except where provisions are made for ensuring an ambient temperature of 40 °C (104 °F) or less. Installed systems should be capable of satisfactory operation down to 0 °C (32 °F) ambient.

Naturally cooled rectifier cabinets should be designed with sufficient ventilating openings, or with sufficient radiating surface in the case of totally enclosed rectifiers, to operate within allowable temperature limits.

35.3 Accessibility

Rectifier stacks should be within at least a dripproof enclosure and mounted in such a manner that they may be removed without dismantling the complete unit.

35.4 Insulation

The insulation and clearances of semiconductor rectifier stacks and units should be capable of withstanding for a period of 1 min, the application of a 60 Hz ac rms potential of 1000 V plus twice the rated ac voltage between current-carrying parts of the ac input circuit and: (1) non-current-carrying metal parts that may be grounded, and (2) current-carrying parts of an insulated secondary circuit where such a circuit exists.

If the semiconductor rectifier stack is connected in an insulated secondary circuit operating below 60 V, it should be capable of withstanding an ac test voltage of 600 Vrms to all grounded non-current-carrying metal parts. If the secondary voltage is in the range of 60 V to 90 V, the ac test voltage should be 900 Vrms.

Rectifier units having watertight enclosures should meet the above insulation test after having been subjected to an enclosure watertight test (see 3.7).

For purposes of maintenance and inspection, the insulation resistance of rectifier stacks measured to ground with an applied dc potential of 500 V should have an insulation resistance of not less than 10 MΩ. Should the insulation resistance measurement indicate the need for drying by heating, special care should be taken not to exceed the total maximum temperature limitations.

Mercury-type fungus protection will damage selenium-type semiconductors and should not be used.

35.5 Terminals

The ac terminals of semiconductors rectifiers stacks should be marked with the letters ac. The positive dc terminal should be marked with (+). The negative dc terminal should be marked with a minus (–). Solder-type or solderless-type terminals should be supplied on semiconductor rectifier stacks.

35.6 Corrosion-resistant parts

Enclosures, working and other parts of semiconductor rectifiers should be made of corrosion-resistant material or of material suitably protected against corrosion.

35.7 Ambient temperature

All semiconductor rectifiers should be rated for continuous duty at 50 °C (122 °F) ambient, due to the harmful effects of excessive junction temperatures on semiconductor devices for even a short time. In the case of water-cooled rectifiers, equipment should operate satisfactorily with a maximum cooling water inlet temperature of 30 °C (86 °F). All equipment should operate down to 0 °C (32 °F) ambient conditions. Cooling water temperatures and ambient air temperatures should be measured at the point where the cooling medium enters the rectifier unit enclosure.

Where higher than the above ambient temperatures may be encountered, semiconductor rectifiers should be derated to limit the total maximum temperature.

35.8 Temperature rise

The temperature rise under all operating conditions should be limited to a value that will permit the rectifier to meet the specified performance requirements.

35.9 Application

Where forced cooling is utilized, the circuit should be designed that so power cannot be applied to or retained on rectifiers, unless effective cooling is maintained. Failure of the cooling system should initiate an audible and visual alarm.
All semiconductor rectifiers should operate under conditions of ±5% frequency and ±10% voltage variation, or both, from the nominal values unless specifically designed otherwise.

35.10 Rectifier transformers

Transformers used with rectifiers should conform to Clause 34. Auto-transformers should not be used.

Transformer voltage output adjusting means should be provided to take care of any increase in rectifier forward resistance and to obtain the necessary performance characteristics of the rectifier unit in which the transformer was used.

35.11 Power converters for ship service applications

The number and rating of power converters that supply services and systems that are essential for the propulsion and safety of the ship should be such that with any one converter not in operation, the remaining converter(s) are capable of supplying the services and systems. Each power converter should be installed in a separate enclosure as an individual unit.

35.12 Instruction books and nameplates

An instruction book, with wiring diagrams and schematics, should be provided for each installation.

A nameplate, with the following information, should be provided on each semiconductor rectifiers:

a) Marine semiconductor rectifier
b) Manufacturer’s name and address
c) Manufacturer’s serial number
d) Rated input voltage
e) Rated input amperes
f) Number of phases
g) Frequency
h) Rated output voltage
i) Rated output amperes
j) Duty cycle (continuous or intermittent)
k) Maximum ambient temperature

Additionally, the manufacturer’s identification should be shown on the rectifier stack.

When the above information cannot be shown on the rectifiers because of space limitations, a nameplate should be provided that identifies the manufacturer and catalog number. The other information should be shown on the schematic or wiring diagram supplied in the instruction book.

35.13 Tests

Tests should be made at the manufacturer’s factory to ensure that semiconductor rectifiers are in accordance with these recommendations. When a rectifier is a duplicate of one already tested, only tests required to demonstrate that the rectifier operates successfully need be performed.

36. Electric propulsion systems

36.1 Scope

The application of power electronics technology to large motor drive systems has resulted in the successful installation of shipboard electric propulsion systems that derive input power from a central, fixed frequency power generation plant that also provides power to the ship service loads. These integrated electric power systems require careful consideration of the physical location requirements of system equipment, cable protection, and control devices as well as special attention to power distribution and load management to ensure an uninterrupted supply of power to vital systems.

This clause provides recommendations covering general specifications, testing, installation, operation, and maintenance of electric propulsion systems. While these recommendations relate specifically to the electric propulsion equipment, they also address mechanical equipment where required for the successful functioning of the entire system.

36.2 Regulations

Classification societies and regulatory agencies generally provide detailed rules and regulations for structural foundations, strength of materials, inspection, tests, plans, and data. These regulations should be consulted in the design and installation of electric propulsion systems and equipment.

36.3 General requirements

The normal torque available from the propulsion motors for maneuvering should be adequate to permit the vessel to be stopped or reversed, when the vessel is travelling at its maximum service speed, in a time that is based on the estimated torque-speed characteristics of the propeller during maneuvering and on other necessary ship design characteristics as determined from hull model testing. Adequate torque margin should be also be provided in ac propulsion systems to guard against the motor pulling out of synchronism during rough weather and on a multiple screw vessel, when turning. This margin should be based upon information related to propeller and ship characteristics. As a minimum, ac motors should be designed for a 5% for 30 min torque overload rating and should have 125% stator/armature current and 200% field voltage overload capability for 10 min.

In order to prevent excessive torsional stresses and vibrations, careful consideration should be given to coordination of the mass constants, elasticity constants, and electrical characteristics of the system. The entire system includes prime movers, generators, converters, exciters, motors, slip-couplings, gearing, shafting, and propellers.

Where the electrical system arrangements permit a propulsion motor to be connected to a generating plant having a continuous rating greater than the motor rating, means should be provided to limit the continuous input to the motor to a value not exceeding 5% torque overload, based on the continuous full-load torque for which the motor is designed. For systems in which excessive overspeeding of the propulsion motors may occur, such as under light load conditions or upon loss of a propeller, suitable overspeed protection should be provided. Provision should be made for protection against severe overloads, excess currents, and electrical faults that could result in damage to the plant. The protective equipment should be capable of being set so that it will not operate on overloads or excess currents likely to be experienced in a heavy seaway or when maneuvering.

The main propulsion circuit should be provided with ground leakage indicating devices that will operate when the insulation resistance is 100 000 Ω or less. Excitation circuits should be provided with lamps, meters, or other suitable means to indicate continuously the state of the insulation of the excitation circuits under running conditions.

For dc equipment operating at voltages exceeding 500 V and for all ac equipment, both audible and visual ground fault alarms should be provided. The alarms should operate automatically on the occurrence of a ground fault, but the operation of such devices should not interrupt the power supply. A switch may be provided for silencing the audible device, but the visual alarm should remain on until the fault has been cleared. Where a ground connection is used for the operation of the indicator, the ground circuit should be opened automatically in order to stop the circulation of fault current.

Where separately driven dc generators are connected electrically in series, means should be provided to prevent reversal of the rotation of a generator upon failure of the prime mover.

There should be no overload protection in excitation circuits that would cause the opening of the circuit. Semiconductor elements in static power converters should have short-circuit protection.

An audible alarm device should be provided for rotating machines and equipment having enclosed-ventilating systems and should alarm in the event the internal air temperature exceeds a predetermined safe value.

36.4 Prime movers

All prime movers should be provided with a governor capable of maintaining the preset steady-state speed within a range not exceeding 5% of the rated full-load speed for load changes from full load to no load. Where the speed control of the propeller requires speed variation of the prime mover, the governor should be provided with means for local manual control as well as for remote control. For parallel operation of generators, the governing system should provide for proportional load sharing over the entire operational speed range of the prime movers.

The prime mover rated power, in conjunction with its overload and large block load acceptance capabilities, should be adequate to supply the power needed during transitional changes in operating conditions of the electrical equipment due to maneuvering, sea, and weather conditions. Special attention should be paid to the correct application of diesel engines equipped with exhaust gas-driven turbochargers to ensure that sudden load application does not result in a momentary speed reduction in excess of 5%.

When maneuvering from full propeller speed ahead to full propeller speed astern with the ship making full way ahead, the prime mover should be capable of absorbing a proportion of the regenerated power without tripping from overspeed. The setting of the overspeed trip device should automatically shut down the unit when the speed exceeds the designed maximum service speed by more than 15%. The amount of the regenerated power to be absorbed shall be agreed to by the electrical and mechanical machinery manufacturers. Means external to the mechanical and electrical rotating machinery may be provided, such as dynamic braking resistors, to absorb excess amounts of regenerated energy and to retard the speed of rotation of the propulsion motor. Alternatively, the amount of regenerated power may be limited by the action of the control system.

Electronic governors controlling the speed of a propulsion unit should have a backup mechanical fly-ball governor actuator. The mechanical governor should automatically assume control of the engine in the event of electronic governor failure. Alternatively, electronic governors should have two power supplies, one of which should be a battery. Upon failure of the normal supply, the governor should be automatically transferred to the alternative battery power supply. An audible and visual alarm should be provided in the main machinery control area to indicate that the governor has transferred to the battery supply. The alternative battery supply should be arranged for trickle charge to ensure that the battery is always in a fully charged state. An audible and visual alarm should be provided to indicate the loss of power to the trickle charging circuit. Each governor should be protected separately so that a failure in one governor will not cause failure in other governors. The normal electronic governor power supply should be derived from the generator output power or the excitation permanent magnet alternator. The prime mover should also have a separate overspeed device to prevent runaway upon governor failure.

The machinery control system should be designed to prevent overloading the prime mover by limiting the propulsion power. The load limiting circuits should ensure that vital power requirements of the ship service system have priority over propulsion under all conditions. An audible and visual alarm should be installed at each throttle location and should operate when the load limiting circuitry restricts the available propulsion power in order to maintain power to vital ship service loads.

36.5 AC generators for integrated electric plants

Generators should be polyphase with a voltage between phases not exceeding 13 800 V. They should be of substantial and rugged construction and should be in accordance with Clause 5. The generators should be sized to provide adequate load margin to guard against large motors pulling out of step during rough weather and while maneuvering. All windings should utilize vacuum pressure impregnated solventless epoxy Class F or H insulation systems to resist moisture, oil vapor, and salt air. The windings should have a Class B temperature rise. If the insulation is not comprised of self-extinguishing material, a fire extinguishing system should be provided for the generator.

Generators should be enclosed ventilated, or otherwise provided with substantial wire guards or mesh screening to prevent personnel injury and the entrance of foreign material, and protected from dripping liquid.

Generators should be provided with forced ventilation when required by the service, preferably by fans attached to the rotor where the speed is sufficient or by separate motor-driven blowers. The heated air should be discharged through ducts from the generator enclosures. These ducts should be arranged to prevent warm exhaust air from entering the intake. Ventilation may be provided by the recirculation of air through a closed or partially closed system, employing water coolers. In this case, extreme care should be taken to prevent water from entering the generator via leaking cooler tubes. Where the coolers are of sufficient capacity to provide 40 °C (104 °F) cooling air at the maximum condition, allowable temperature rises should be based on this ambient temperature. The air entering the generators should filtered to minimize the entrance of oil vapor and foreign material.

The temperature of the cooling air of machines provided with forced air ventilation, air ducts, or air filters should be continuously monitored by means of direct reading thermometers that are readable from outside the machine. A remote audible alarm actuated by suitable temperature detectors should be provided. For machines with a heat exchanger type closed-circuit cooling method, either the flow of primary and secondary coolants or the winding temperatures should be monitored and alarmed. Consideration should given to providing coolant leakage detection and alarm.

Effective means, such as electric heating, should be provided to prevent the accumulation of moisture from condensation when the generators are idle for appreciable periods.

AC propulsion generators should be provided with means for obtaining the temperatures of the stationary windings. A minimum of one embedded temperature detector per phase should be provided for this purpose. The temperatures are to be displayed at a convenient location such as the main control console.

All generators should be provided with terminal boxes appropriate to their type of enclosure. Terminal boxes should be of sufficient size to accommodate wiring without crowding, and of adequate mechanical strength and rigidity to protect the contents and prevent distortion under normal conditions of service. Cables of differing voltage should not be included in the same terminal box unless each voltage is clearly and permanently identified and effective barriers provided within the enclosure to separate each voltage. Generators should have the terminal leads suitably secured to the frame. The end of these leads should be fitted with connectors suitable for use with terminal lugs on incoming cables. All connections should be provided with efficient locking devices.

AC machines should be capable of withstanding a short circuit at their terminals under rated conditions for 30 s without suffering damage. Means should be provided to prevent circulating currents passing between the journal and the bearings. Means should also be provided for conveniently conducting insulation tests between phases.

The generators should be constructed so that they withstand, without mechanical damage, an overspeed of 25%. The generators should be able to operate in parallel and share load proportionately, and should be furnished with armortisseur windings.

The power factor rating of integrated electric plant generators is not limited to the recommendations in Clause 5. Power factor should be calculated for each particular application, and should allow for the combined demands of the ship service load and the propulsion drive static power converters when operating at low ship speeds (high commutation angle).

36.6 DC propulsion generators

Generators should be of substantial and rugged construction. All windings should utilize vacuum pressure impregnated solventless epoxy Class F or H insulation systems to resist moisture, oil vapor, and salt air. The windings should have a Class B temperature rise. If the insulation is not comprised of self-extinguishing material, a fire extinguishing system should be provided for the generator. Means should be provided to prevent circulating currents passing between the journal and the bearings. The generators should be provided with protective devices as described in 36.12. The voltage of each generator should not exceed 1000 V.

Generators should be enclosed ventilated, or otherwise provided with substantial wire guards or mesh screening to prevent personnel injury and the entrance of foreign material, and protected from dripping liquid.

Air ducts should be provided with thermometers external to the machine, high temperature alarms, dampers, and means of access for inspection. Dampers need not be provided for recirculating systems. Effective means, such as electric heating, should be provided to prevent the accumulation of moisture from condensation when the generators are idle for appreciable periods.

The generators should be provided with forced ventilation when required by the service, preferably by fans attached to the rotor where the speed is sufficient, or by separate motor-driven blowers. The heated air should be discharged through ducts from the generator enclosure. These ducts should be arranged to prevent warm exhaust air from entering the intake. Ventilation may be provided by the recirculation of air through a closed or partially closed system, employing water coolers. In this case, extreme care should be taken to prevent water from entering the generator via leaking cooler tubes. Where the coolers are of sufficient capacity to provide 40 °C (104 °F) cooling air at the maximum condition, allowable temperature rises should be based on this ambient temperature. The air entering the generators should be filtered to minimize the entrance of oil vapor and foreign material.

All generators should be provided with terminal boxes appropriate to their type of enclosure. Terminal boxes should be of sufficient size to accommodate wiring without crowding and of adequate mechanical strength and rigidity to protect the contents and to prevent distortion under normal conditions of service. Cables of differing voltage should not be included in the same terminal box unless each voltage is clearly and permanently identified and effective barriers provided within the enclosure to separate each voltage. Generators should have the terminal leads suitably secured to the frame. The end of these leads should be fitted with connectors suitable for use with terminal lugs on incoming cables. All connections should be provided with efficient locking devices.

36.7 AC propulsion motors

Motors may be of the induction type with a separate self-contained squirrel-cage rotor winding for starting, or the ordinary form-wound-rotor type with external starting resistance, or of the synchronous type designed for starting and operating in conjunction with a solid-state, variable frequency, propulsion drive system. Motors should be of substantial and rugged construction. All windings should utilize vacuum pressure impregnated solventless epoxy Class F or H insulation systems to resist moisture, oil vapor, and salt air. The windings should have a Class B temperature rise. If the insulation is not comprised of self-extinguishing material, a fire extinguishing system within the motor should be provided.

Motors should be enclosed ventilated and should be provided with forced ventilation when required by the service. The exhaust air should be discharged through ducts from the motor enclosure. These ducts should be arranged to prevent the entrance of water or foreign material. Ventilation may be provided by the recirculation of air through a closed or partially closed system employing water coolers. Where the coolers are of sufficient capacity to provide 40 °C (104 °F) cooling air at the maximum condition, allowable temperature rises should be based on this ambient temperature. In this case, extreme care should be taken to prevent the water from entering the motor via leaking cooler tubes. The air entering the motors should be filtered to minimize the entrance of oil vapor and foreign material. Means should be provided for totally enclosing the motor when not in use if forced air cooling is provided by external (in the weather) ventilation ducts. Abnormal brush wear and slip ring maintenance may occur in motors containing silicon materials. Silicon should not be used in any form that can release vapor in enclosed motor interiors.

Air ducts should be provided with thermometers external to the machine, high temperature alarms, dampers, and means of access for inspection. Dampers need not be provided for recirculating systems. Effective means, such as electric heating, should be provided to prevent the accumulation of moisture from condensation when motors are idle.

Motors should be polyphase and of a voltage between phases not exceeding 13 800 V. Temperature detectors should be provided. Such detectors should be provided for all sizes of propulsion motors and not limited to machines of certain sizes and rating.

All motors should be provided with terminal boxes appropriate to their type of enclosure. Terminal boxes should be of sufficient size to accommodate wiring without crowding and of adequate mechanical strength and rigidity to protect the contents and prevent distortion under normal conditions of service. Cables of differing voltage should not be included in the same terminal box unless each voltage is clearly and permanently identified and effective barriers provided within the enclosure to separate each voltage. Motors should have the terminal leads suitably secured to the motor frame. The end of these leads should be fitted with connectors suitable for use with terminal lugs on incoming cables. All connections should be provided with efficient locking devices. Terminal boxes should be airtight with respect to the motor interior. Means should be provided for conveniently conducting insulation tests between phases.

Motors should be mounted on extended slide rails so that the stator can slide a sufficient distance to uncover the rotor for inspection and repair. A socket or telescope dummy shaft should be provided when necessary for supporting the rotor when moving the stator. Alternative provision for removal of the rotor without shifting the stator may be made. If the windings of synchronous motors can be satisfactorily repaired by removal of field poles, these provisions need not be made.

Means should be provided to prevent circulating currents from passing between the motor shaft journal and the bearings.

The lubrication of propulsion motor bearings and shafting should be effective at all normal speeds from continuous creep speeds to full speed, ahead, and astern. The shafts and bearings should be self-lubricated. They should not be damaged by slow rotation, under all reasonable temperature conditions, either when electrical power is applied to the motor or when rotation is induced by the propellers.

Pressure or gravity lubrication systems, if used, should be fitted with a low oil pressure alarm and provided with an alternative means of lubrication, such as an automatically operated standby pump, an automatic gravity supply reservoir, or oil rings.

36.8 DC propulsion motors

The voltage of any single-motor armature should not exceed 1000 V. Where multiple motor armatures are used in series and the voltage exceeds 1000 V, the system should be such that one or more generators are interspersed between the armatures, or some other arrangement employed, so that the voltage between any two points of the system is reduced to a value not in excess of 1000 V. Motors should be of substantial and rugged construction. All windings should utilize vacuum pressure impregnated solventless epoxy Class F or H insulation systems to resist moisture, oil vapor, and salt air. The windings should have a Class B temperature rise. If the insulation is not comprised of self-extinguishing material, a fire extinguishing system within the motor should be provided.

Motors should be enclosed ventilated and should be provided with forced ventilation when required by the service. The forced ventilation should be provided by separate motor-driven blowers. The heated air should be discharged through ducts from the motor enclosure. These ducts should be arranged to prevent warm exhaust air from entering the intake. Ventilation may be provided by the recirculation of air through a closed or partially closed system, employing water coolers. In this case, extreme care should be taken to prevent water from entering the motor via leaking cooler tubes. Where the coolers are of sufficient capacity to provide 40 °C (104 °F) cooling air at the maximum condition, allowable temperature rises should be based on this ambient temperature. The air entering the motors should be filtered to minimize the entrance of oil vapor and foreign material. Abnormal brush wear and slip ring maintenance may occur in motors containing silicon materials. Silicon should not be used in any form that can release vapor in enclosed motor interiors.

Air ducts should be provided with thermometers external to the machine, high temperature alarms, dampers, and means of access for inspection. Dampers need not be provided for recirculating systems. Effective means, such as electric heating, should be provided to prevent the accumulation of moisture from condensation when motors are idle.

Terminal boxes should be of sufficient size to accommodate wiring without crowding and of adequate mechanical strength and rigidity to protect the contents and to prevent distortion under normal conditions of service. Cables of differing voltage should not be included in the same terminal box unless each voltage is clearly and permanently identified and effective barriers provided within the enclosure to separate each voltage. Motors should have the terminal leads suitably secured to the motor frame. The end of these leads should be fitted with connectors suitable for use with terminal lugs on incoming cables. All connections should be provided with efficient locking devices. Terminal boxes should be airtight with respect to the motor interior. Means should be provided for conveniently conducting insulation tests.

Means should be provided to prevent circulating currents from passing between the motor shaft journal and the bearings. The lubrication of the bearings and shafting should be effective at all normal speeds from continuous creep speeds to full speed, ahead, and astern. The shafts and bearings should be self-lubricated. They should not be damaged by slow rotation, under all reasonable temperature conditions, either when electrical power is applied to the motor, or when rotation is induced by the propellers.

DC propulsion motors should have a 5% for 30 min torque overload rating and should withstand 125% armature current and 200% field voltage for 10 min. The motors should be furnished with commutating poles and compensating windings.

36.9 Propulsion motor drives

Static power converters for propulsion motor drive applications should be of a type that limits harmonic content on the input voltage side, minimizes losses in the damper windings, minimizes torque ripple when starting and during load commutated operation, and complies with the design guidelines of IEEE Std 519-1992 to the maximum extent practicable. Drive enclosures and other parts subject to corrosion should be made of corrosion-resistant material or of a material rendered corrosion resistant. Ambient air temperature should be assumed to be 45 °C (113 °F) for the design of air-cooled units. For water-cooled converters, the inlet cooling water temperature should be assumed to be at least 30 °C (86 °F). In all cases, the temperature rise under all conditions should be limited to a value that will permit the converters to meet the motor performance criteria. If drives are fitted with forced-ventilation and/or water cooling, means should be provided to monitor the cooling system. In the case of a cooling system failure, the current should be reduced automatically and failure of the cooling system and/or automatic reduction of current should be indicated by an audible and visual alarm. The alarm signal can be generated by the flow of liquid coolant, by the electric supply to the ventilation fans, or by the temperature of diodes and thyristors.

The following information should be included on the drive nameplate:

a) Marine propulsion drive power converter
b) Manufacturer's name and address
c) Manufacturer's serial number
d) Type (silicon, transistor, copper oxide, etc.)
e) Rated input volts
f) Rated input amperes
g) Number of phases
h) Number of pulses
i) Frequency input/output
j) Rated output volts
k) Rated output amperes
l) Ambient temperature range
m) Cooling medium

In addition to manufacturer testing on individual parts, the insulation of propulsion drives should be tested with all the parts completely assembled. The dielectric strength should be tested by the continuous application for 60 s of an alternating voltage having a crest value equal to 2 times the specified test voltage and a frequency of 20 Hz to 60 Hz. The standard test voltage should be twice the normal voltage of the circuit to which it is applied plus 1000 V, except that where the secondary circuit operates below 60 V, the test voltage is to be 600 V rms and where in the range of 60 V to 90 V, the test voltage should be 900 Vrms. The dielectric test voltage should be applied between each circuit and grounded metal parts. Alternative test procedures should be used where the above testing could result in damage to sensitive components.

Propulsion drive enclosures should be dripproof. If installed in an area subject to spray, they should be watertight. Units having a watertight enclosure should successfully meet the insulation test specified after being subjected to a stream of water from a nozzle not less than 25 mm (1 in) in diameter under a head of 11 m (35 ft), directed at the enclosure for at least 15 min from a distance of 3 m (10 ft).

Transformers used with propulsion drives should conform to the requirements of Clause 34. Additionally, transformer design should consider the harmonic spectrum and flux variation resulting from converter operation. Transformers should utilize vacuum pressure impregnated solventless epoxy Class H or better insulation systems to resist moisture, oil vapor, and salt air. They should have a Class B temperature rise. Means should be provided to protect transformers from the effects of asymmetrical loading. Temperature detectors should be provided to monitor the core temperature. Thermal overload protection for propulsion transformers should include temperature detectors in all low-voltage windings that will cause a remote alarm indication at a preset temperature followed by protective device tripping at a higher temperature. Voltage regulation and impedance characteristics of the transformer should be designed to support the necessary performance characteristics of the converter equipment.

Propulsion drive static power converter units should incorporate, as a minimum, the following design characteristics:

a) The following limiting repetitive peak voltages should be used as a base for the semiconductor devices:
   - When connected to a generation source specifically for propulsion drives:
     $VRM = 1.5\ V_p$
   - When connected to a generation source for integrated electric plants:
     $VRM = 1.8\ V_p$
   - Where V_p = is the peak value of the rated voltage at the input of the semiconductor converter.
b) If the semiconductors are connected in series, the values mentioned above should be increased by 10%. Equal voltage distribution shall be ensured and the drive circuits should be able to withstand the maximum transient overcurrent to which the system is subject during ship maneuvering.
c) For parallel-connected semiconductor devices, an equal current distribution should be ensured.
d) Where convertors are force-ventilated, the unit should be capable of operation at reduced power upon fan failure.
e) If several semiconductor elements are connected in parallel and a separate fan is fitted for each parallel branch, only those branches for which ventilation is not available need be shut down.

Whenever propulsion drive power convertors are applied to integrated electric plants, the drive system should be designed to maintain the electric plant power quality to the values in Table 4-1 and to limit the effect of disturbances, both to the integrated power system and to other motor drive converters. Attention should be paid to the power quality impact of the following:

a) Multiple drives connected to the same main power system.
b) Commutation reactance, which, if insufficient, may result in voltage distortion adversely affecting other power consumers on the distribution system.
c) The relation between the power generation system subtransient reactance and the propulsion drive commutation resistance. Unsuitable matching may result in the production of harmonic values beyond the power quality limits in Clause 4 that could cause overheating of other elements of the distribution system and improper operation of power consumers utilizing nonlinear loads. Drives of 12 pulse, or better, are usually applied to meet these requirements.
d) Any adverse effect of the propulsion drives on the windings and commutation of dc machines.
e) Any adverse effect, in the regenerating mode, of voltage drop during drive operation.
f) Conducted and radiated electromagnetic interference and the introduction of high-frequency noise to adjacent sensitive circuits and control devices.

When harmonic filter tuned circuits and capacitors are used for nonlinear current compensation, attention should be paid to any adverse effect of frequency variations on the rms and peak values of system voltage.

The following propulsion drive unit protection should be provided:

a) Drive input overvoltage protection by suitable devices applied to prevent damage. Protective fuses for these devices should be monitored.
b) Load limiting control to ensure that the permissible operating current of semiconductor elements cannot be exceeded during normal ship operation.
c) Short-circuit current limiting by specially adapted fuses, or equivalent protective devices. These semiconductor protective devices should be monitored. In case of protective device operation, the respective part of the drive should be taken out of operation and power output reduced without shutting down the drive. Fuses in harmonic filter circuits should also be monitored.
d) Excessive current ripple protection.

36.10 Propulsion exciters

Excitation current for generators may be derived from brushless rotating exciters or from static exciters. Where a multiple prime mover system is used with direct driven exciters, each exciter should be capable of supplying the excitation requirements of its connected generator. If a propulsion system contains only one generator and one motor and cannot be connected to another propulsion system, more than one exciter should be provided for each machine. However, this is not necessary for self-excited generators, or for multipropeller ships where one additional exciter may be connected to any propulsion motor.

Electric propulsion generators should be arranged so that propulsion can be maintained in case of failure of a generator excitation system or failure of a power supply for an excitation system. Propulsion may be at reduced power under such conditions where two or more propulsion generators are installed, provided the such reduced power level is sufficient to provide a speed of not less than 7 kn or one-half of design speed, whichever is less.

There should be no automatic circuit-opening devices in excitation circuits except those affording short-circuit or phase-failure protection for the main propulsion circuit. For the protection of the field windings and cables, means should be provided for limiting the voltage induced when the field circuits are opened.

Each propulsion motor exciter should be supplied by a separate feeder.

For dc generator systems, arrangements for generator and motor excitation should be such that if the motor excitation circuit is opened by a switch or contactor, the generator excitation circuit is simultaneously opened or the generator voltage is immediately reduced to zero.

In constant voltage systems with two or more independently controlled motors in parallel on the same generator, the motor circuit-breaker should be tripped when the excitation circuit is opened by a switch or contactor.

When static excitation units are used, the arrangement of semiconductor fuses applied to protect diodes or thyristers necessary to protect the field coils against transient overvoltages should be such as to limit the protection to individual devices or groups of devices, without opening the entire excitation circuit. Where fuses are used for excitation circuit protection they should not interrupt the field discharge resistor circuit upon rupturing.

Static excitation power supplies for propulsion motors may be incorporated in the propulsion drive cabinets for the associated motor or may be in separate, free-standing, cabinets in the drive or motor room. The standby propulsion exciter power supply should be physically and electrically isolated from the main excitation power supplies and should incorporate an output transfer switch to apply excitation power to the main propulsion systems. Static excitation power supplies should comply with the requirements of IEEE Std 444-1973 to the maximum extent practicable.

36.11 Electric couplings for propulsion

Couplings should be of substantial and rugged construction, and all windings should be specially treated to resist moisture, oil, and salt air. The couplings should be enclosed and ventilated or otherwise provided with substantial wire or mesh screen to prevent personnel injury or the entrance of foreign material.

In general, the coupling design should be such as to provide at least 70% of full torque at 140% slip, for maneuvering. Limits of temperature rise should be the same as for ac generators, Table 5-2, except that when a squirrel-cage element is used, the temperature of this element should not reach values that can be injurious. Depending upon the cooling arrangements, the maximum temperature rise may occur at other than full-load rating so that heat runs will require special consideration. When an integral fan is fitted, the coupling temperatures should not exceed these limits when operated continuously at 70% of full load r/min with full excitation and rated torque. Vessels designed primarily for towing may require rated torque at a lower speed. The coupling should be so designed and installed to permit removal, as a single unit, without disturbing the engine or gear box. Coupling excitation should be provided as required for independent propulsion generators and motors.

All electric propulsion couplings should be fitted with nameplates of corrosion-resistant material marked with the following information:

a) Manufacturer's type and frame designation
b) Output (kW)
c) Kind of rating (e.g., continuous, intermittent)
d) Temperature rise at rated load and design ambient temperature
e) Revolutions per minute at rated load
f) Voltage
g) Exciter voltage
h) Excitation current in amperes at rating

36.12 Main power switchboards

Main power switchboards for electric propulsion and integrated plant applications should fully comply with the recommendations in Clause 7. All nuts and connections should be fitted with locking devices to prevent loosening due to vibration. Appliances controlling propulsion and ship's service equipment should include the apparatus necessary for starting, stopping, reversing, and controlling the speed of motors, together with essential safety devices.

All switches should be arranged for manual operation and so designed that they will not open under ordinary slamming or vibration. Contactors may be operated pneumatically, by solenoids, or by other means in addition to the manual method. For dc systems, air-break circuit breakers are recommended. For ac systems, vacuum, sulfur hexafluoride (SF_6) or air-break circuit breakers should be used.

Where necessary, field switches are to be provided with discharge resistors unless the discharge resistors are permanently connected across the field. For ac systems, means should be provided for de-energizing the motor excitation circuits by the phase unbalance relay and ground fault relay. All levers for operating contactors, line switches, field switches, and similar devices should be interlocked to prevent their improper operation. Interlocks should be provided with the field lever to prevent the opening of any main motor circuits without first reducing the field excitation to zero.

Access doors for switchboards and propulsion power panels operating at voltages in excess of 55 V should be provided with a lock. The key should be kept in a place accessible only to authorized personnel. All circuits, instruments, and apparatus should be clearly labelled for identification. Suitable interlocks should be provided to prevent damage to the plant as a result of incorrect switching such as the opening of switches or contactors not intended to be operated while carrying current.

Where electric, pneumatic, or hydraulic assist is used to provide normal operation of control devices, failure of the power assist device should not result in interruption of power to the propeller shaft. Control devices should be capable of purely manual operation without delay.

Buses and cables within the switchboard enclosures should be well supported and braced to withstand the full short-circuit stress of the system. Porcelain should not be used as an insulation support for buses, switch parts, etc., but may be used for resistor supports where it will withstand ship vibration.

36.13 Propulsion control equipment

Control consoles should be of substantial and rugged construction, and should group all instruments, CRT displays, and control devices used in the operation and control of propulsion systems.

Control location may be from the engine room only, or from either the navigating bridge or the engine room. Whenever navigating bridge control is used, an arrangement should be provided to also permit propulsion equipment control from the engine room. Whenever the equipment is arranged for control from two or more stations, a selector switch should be provided for connecting the control means to the delegated station. Simultaneous control from more than one control station should not be possible.

Changing of the control station should be possible only when the control actuators (typically levers) of the station in command and the incoming station are in the same position or when an acceptance signal set by the desired station is received. This is not required for systems in which the control actuators are electrically or mechanically interconnected in such a manner that each actuator will be set to the same position.

The control system should be designed so that damage to equipment outside the machinery space cannot prevent control from the control stations within the machinery space. Failure of power-assisted throttle controls, when used, should not result in an interruption of the power to the propulsion shaft, but should be indicated by an alarm.

All control means for operating prime movers, setup switches, contactors, field switches, etc., should be interlocked to prevent their incorrect operation.

Systems having two or more propulsion generators, two or more propulsion drives, or two or more motors on one propeller shaft should be so arranged that any unit may be taken out of service and disconnected electrically, without affecting the other unit.

In regulating systems with feedback control, duplex circuitry and components should be utilized to ensure a high degree of reliability. Failure of a control signal should not cause an increase in propeller speed. The reference value transmitters in the control stations and the control equipment should be so designed so that any defect in the value transmitters or in the cables between the control station and the propulsion system will not cause an increase in the propeller speed.

The control of the propulsion system should be initially activated only when the assigned control lever is in the “zero” or “stop” position and the system has main and control power available and ready for operation. Each control station should have an emergency stop device that is independent of the control lever. Where navigating bridge and other remote propulsion control stations are installed, indicating lights should be provided at each control station to indicate which station is in control.

The control consoles should be designed with a structural steel frame and instrument panels should be made of sheet steel. The control consoles should be protected at the side and back with sheet steel panels with ventilation louvers as required. A warning nameplate, giving the maximum voltage inside the enclosure, should be provided on all doors providing access to the enclosure.

Means should be provided at each propulsion control console for continuously monitoring prime mover output power and a power-limiting device supplied to automatically limit propulsion motor power levels to a value commensurate with generator power available, particularly when an integrated plant is also supplying ship service power. Indication should be provided when current limiting is in operation.

Ground detection and indication should be provided. The propulsion system ground-fault protection devices should limit the current at full rated voltage to a value not to exceed approximately 20 A upon a fault to ground in the propulsion system. Phase unbalance and ground protection relays should be provided that will open the motor field circuits upon the occurrence of a fault in the main propulsion power circuit.

The following instruments, meters, etc., should be mounted on the control console in the main control room:

a) AC propulsion systems
   1) For each propulsion generator:
   — Ammeter
   — Voltmeter
   — Wattmeter
   — Frequency meter
   — Power factor meter, if generators are to be operated in parallel
   — Temperature indicator for directly reading the temperature of the stator windings
   2) For each propulsion motor:
   — Temperature indicator for directly reading the temperature of the motor windings
   — Wattmeter for each motor
   — Ammeter for the field current of each synchronous motor
   3) For each propeller shaft:
   — Speed indicator
   4) For each semiconductor static power drive:
   — Ammeter for each bridge connection of semiconductors
b) DC propulsion systems
   1) For each propulsion generator:
   — Ammeter
   — Field ammeter
   2) For each propulsion motor:
   — Field ammeter
   — Ammeter for the armature current of each motor
   3) For each propulsion motor fed by a semiconductor static power drive:
   — Ammeter for the armature current of each motor
   — Voltmeter for the armature voltage of each motor
   — Ammeter in the input of each parallel bridge circuit of the convertor
   — Warning for excessive temperature of the interpole windings
   4) For each propeller shaft:
   — Speed indicator

When two or more control stations are provided for variable speed propellers, a propeller speed indicator should be provided at each control station.

Where control outside the engine room is used, displays giving the necessary information on the main electric propulsion system should be installed at a convenient location in the control consoles.

The propulsion system control consoles should have at least the following indications for each propeller:

a) “System Ready”—Power circuits and necessary auxiliaries are in operation and ready to accept control commands.
b) “System Fault”—System cannot respond to control commands; propeller not under control.
c) “Power Limit”—System disturbance. For example, loss of ventilation for propulsion motors or drives, loss of cooling water supply, or loss of motor power level limited due to insufficient generator capacity. Control commands restricted.

If the main control console is not located in the engine room, or if the prime-mover gauges cannot be conveniently read from the control console, principal prime-mover parameters should be displayed at the main control console. A clock with digital display fed from the control system master clock should be mounted in each control console.

Instrument and control wiring should be stranded, of the flame-retarding type, and not smaller than 0.82 mm^2 (1620 cmil). All ammeters and wattmeters should be marked in red at the rated value of the circuit in which they are connected. Metal cases of instruments should be grounded. Secondaries of all instrument transformers should be grounded.

A framed wiring diagram showing the complete propulsion system schematic should be located near the main control console.

If semiconductor drives are not used, overload protection should be provided in the console for dc propulsion generators, either by opening the armature circuit, or by opening the generator field circuits. If the generator field circuits are automatically opened, bringing the controller to the OFF position should reestablish the field circuits.

Control lever cabling from the navigating bridge and the engine room control consoles should be routed separately and directly to the control section of the motor drive units. Control transfer capability should be incorporated in the drive control section, with local manual transfer switching at the drive, and remote transfer capability from the engine room console. Emergency local control should be included in the drive control section.

36.14 Electric coupling control equipment

Electric coupling control should comply with the applicable portions of Clause 37. The electric control equipment should be combined with the prime-mover speed and reversing control to provide for integrated operational control, safety, and ease of manual operation. A two-pole disconnect switch, short-circuit protection, ammeter, and heavy-duty cycle discharge resistor (applied by a positive making and breaking device) should be provided for the coupling excitation circuit. Interlocking to prevent energizing the coupling when the prime-mover control levers are in improper position should be provided.

36.15 Limits of temperature rise

The observed temperature rise for propulsion equipment, after the generator, drive motor, or control has been operated continuously under full rated load until it has reached a constant temperature, should not exceed the values given in Tables 5-1, 17-1, 5-2, and 14-1 for the required temperature rise and total hot-spot temperature.

36.16 Nameplates

Suitable nameplates should be installed in a conspicuous place on generators, drives, motors, exciters, and control assemblies. Nameplates should provide essential equipment information, as indicated elsewhere in this standard for the specific equipment items, or for similar equipment.

36.17 Propulsion cables

If required for harmonic attenuation, propulsion cables should be armored or shielded and of the types identified in Clauses 8 and 9. Cables should be sized to provide 105% of motor and drive rated current continuously and 125% of rated current for 10 min. Voltage drop should not exceed 5%.

36.18 Tests—generators and motors

Generators and motors should successfully pass the following tests at the place of manufacture. The following tests should be conducted in accordance with IEEE Std 112-1996, IEEE Std 115-1995, or ANSI/NEMA MG 1-1993, as applicable:

a) Temperature rise under full-load conditions
b) Dielectric strength of insulation
c) Overload capacity, as specified
d) Cold resistance of all circuits
e) Electrical balance
f) Mechanical balance

36.19 Tests—electric couplings and control

Electric couplings and their control equipment should pass the following tests at the place of manufacture. The following tests should be conducted in accordance with IEEE Std 112-1996, IEEE Std 115-1995, or ANSI/NEMA MG 1-1993, as applicable:

a) Temperature rise under full-load conditions
b) Dielectric strength of insulation
c) Overload capacity, as specified
d) Cold resistance of all circuits
e) Sequence of operation of control equipment to ensure proper operation and reliability of the safety circuits and devices.

36.20 Tests—control equipment

Controls for electric propulsion equipment should be inspected when finished and dielectric strength tests and insulation resistance measurements made on the various circuits at the place of manufacture. The functional operation of controls and displays, and satisfactory tripping and operation of all relays, contactors, and various safety devices should also be demonstrated.

36.21 Tests—motor drives

Semiconductor static power converters for propulsion system drives should be tested and inspected at the place of manufacture. Duplicate units of previously tested power converters need be tested only as deemed necessary to demonstrate successful operation.

36.22 Tests—cables

The electrical tests of finished cables should be in accordance with Clause 8.

36.23 Tests—dock and sea trials

A dock trial of sufficient duration should be performed to prove, as far as practicable, that all propulsion machinery functions satisfactorily. Immediately prior to the trial and before the trial can proceed, the insulation resistance should equal that recommended in 36.39.

Complete tests should be carried out at sea, including endurance runs to achieve steady temperature rise values. Maneuvering tests should be conducted and should include a reversal of the ship from full speed ahead to full speed astern. The correct operation of protective circuits and the stability of control devices should be verified.

Immediately prior to sea trials, the insulation resistance should be measured and recorded to establish a baseline comparison value for assessing plant condition as the ship ages.

36.24 Spare parts

Consideration should be given to maintaining spare parts for vital components aboard the vessel. Regulatory agencies and classification societies should be consulted for specific spare parts requirements.

36.25 Spare parts storage

Particular attention should be paid to the storage of spare parts. Insulated parts, such as coils, should be protected against moisture and rodents, and stored in a room in which the temperature is maintained at a fairly constant level. Coils should be stored so their original form will be maintained. All exposed rubbing surfaces, such as bearings, should be protected against corrosion and damage, and should not be allowed to come in contact with wood or other hygroscopic substance. Additional recommendations for the storage of spare parts for rotating machines are in 5.22.

36.26 Tools

Special tools and wrenches for overhauling propelling machinery should be provided and kept onboard.

36.27 Instruction books

Preliminary instruction books, clearly illustrated, covering the operation, maintenance, and overhaul of the propelling machinery should be furnished prior to the completion of the installation. Final copies should be provided prior to the placing of the vessel into service, and should be maintained onboard.

36.28 System installation—general

In addition to equipment design requirements, the installation requirements for electric propulsion components are equally important in ensuring successful operation of the propulsion plant.

36.29 Propulsion equipment location

Equipment should be located where it will not to be exposed to mechanical damage or to damage from water, heat, steam, or oil. Equipment should be placed in well-ventilated compartments in which flammable gases and acid fumes cannot accumulate. Consideration should be given to locating the main power switchboard such that it will not be damaged in case of collision or grounding of the ship. The machinery should be arranged to provide ample access for inspection, adjustment, disassembly, and repair. A watertight well, with a provision for draining, should be provided around the base of the propulsion motors. Equipment should be located to avoid damage from bilge water.

For purposes of motor inspection and repair, provision should be made for access to the stator and rotor coils, and for the withdrawal and replacement of field coils.

36.30 Gratings

Gratings should be used where deck plates would interfere with proper ventilation of the electric machinery.

36.31 Ventilation

All areas of the engine room, propulsion equipment rooms, and motor rooms should be thoroughly ventilated to avoid hot air pockets. Main control rooms should be air conditioned. When ventilation ducts are provided, they should be so arranged that water or foreign material from outside is not directed at the machinery.

36.32 Bedplates and foundations

Bedplates, sub-bases, or feet of propulsion motors should be of rugged construction, arranged for fitted bolts, and secured to the structural foundations. Generators and associated prime movers should be resiliently mounted to their foundations if required for noise and vibration purposes.

Control consoles and switchboards should be secured to a solid foundation and may be either self-supporting or braced to the bulkhead or deck above. When braced to the deck above, the bracing should be flexible to allow deflection of the deck without buckling the assembly structure. Units should be located away from, or protected against sources of dripping liquid.

36.33 Lubrication

Propulsion motors using forced external, pressure, or gravity lubrication for bearings should be provided with an independent spare lubricating oil pump. Where oil coolers are used, two separate means should be provided for circulating water through the coolers. An alarm system should be installed in connection with all external lubricating oil systems (see 27.9). Systems depending on forced lubrication, pressure, or gravity should be arranged to shut down automatically on loss of oil pressure. The oil discharge from each forced lubricated main bearing should be visible. The lubricating oil system should be designed to prevent oil from coming in contact with parts having a temperature in excess of 343 °C (650 °F). Means should be provided to determine the temperature of oil leaving bearings.

Lubricating oil cooling should be provided. Extreme care should be taken to prevent the contamination of the oil supply by water or other extraneous matter, and the cooling water pressure should be less than the oil pressure. Oil filters or separators should be installed. The flash point of the lubricating oil should in no case be below 175 °C (347 °F).

Oil guards should be provided if necessary to prevent oil from creeping along the shaft to machine windings. Precautions should be taken to prevent oil vapors from passing into the generator windings. Openings in machines for oil vents and thermometer wells should be constructed so that vapor cannot escape into the windings.

All machines should lubricate and operate successfully when permanently inclined to an angle of 15° athwartship and 5° fore and aft and be capable of operating without spilling oil when rolling 22.5° from the vertical or pitching 7.5°.

36.34 Fire extinguishers

In addition to any fixed fire extinguishing systems, portable fire extinguishers should be provided in the vicinity of propulsion equipment.

36.35 Inspection before operation

Each piece of electrical equipment should be carefully inspected before initial start-up to ensure it is free of metal shavings, chips, or other foreign material.

36.36 Protection during storage and installation

All equipment should be protected as effectively as possible during storage and installation. From the time diesel engines, gas turbines, generators, drives, and motors for electric propulsion are completely tested until installation is completed and the vessel placed in service, special precautions should be taken to protect the machinery. All equipment should be located in a warehouse and protected during the period of storage to prevent the entrance of foreign matter, and to prevent wide and sudden internal temperature changes in the equipment. Covers should be used over all external openings in ac and dc apparatus.

During storage, machinery should be periodically inspected. When stored for an extended period, equipment should be given any special care recommended by the manufacturer. All shaft-machined surfaces should be thoroughly coated with a suitable rust-preventing compound that can be removed readily. Particular precaution should be taken to protect the equipment during the installation period.

36.37 Propulsion cable installation

Propulsion cable installation should be in accordance with Clause 10.

36.38 Propulsion drive installation

Drives should be installed away from sources of radiant energy in locations where the circulation of air is not restricted to and from the units, and where the temperature of the inlet air to air-cooled converters will not exceed that for which the unit is designed. Where forced cooling is used, the circuit should be designed so that power cannot be applied to or retained on the drives unless effective cooling is maintained. Semiconductor bridges should be in a dripproof enclosure, as a minimum, and mounted in such a manner that they may be removed without dismantling the unit.

36.39 System operation and maintenance

36.39.1 Fire extinguishing precautions

Arrangements should be made to shut off the generator, motor, motor drives, and propulsion control power supply when the fire extinguishing systems are operated. If a fire must be extinguished with salt water, apparatus that has been sprayed should be washed as soon as possible with fresh water to avoid corrosion and insulation damage from the salt water.

36.39.2 Cleanliness

Both the interior and exterior of machines should be kept free from dirt, dust, oil, or salt. Oil should be prevented from entering the machine with the cooling air. Insulation maintenance should be in accordance with IEEE Std 432-1992. As an excessive accumulation of dirt may eventually ground the coils and cause winding failure, machines that have an accumulation of dirt and oil should be thoroughly cleaned with nonflammable solvents. The ends of the stator and rotor coils should be wiped and any salt coating removed using fresh water, if necessary. It is essential to keep the air ducts in the stator core and the ventilating holes in the rotor retaining rings free from dirt accumulations as any restriction in these passages can seriously interfere with the flow of air necessary for proper cooling. Dirt is also a heat insulator and accumulations can cause increased temperatures. Vacuum cleaning is the most effective means of cleaning the interior of a machine. If compressed air is used for cleaning, care should be taken to ensure the air stream is free of water and other contaminants. Electrical equipment used in dusty locations should be vacuumed frequently.

DC machines accumulate conductive carbon dust from brush wear and require special attention to prevent the carbon dust from decreasing insulation resistance.

Although generators and motors are constructed with moisture-resistant insulation, the reliability of operation and the equipment life will be enhanced by keeping the insulation clean and dry.

36.39.3 Care of idle apparatus

The insulation resistance should be measured in equipment idle for a long time either during the installation period or due to interrupted service. It is recommended that a log sheet, similar to the following, be maintained for recording the insulation resistance monthly, so that deteriorating conditions can be detected.

Typical Log Sheet

Insulation Resistance	MΩ
Port motor stator	
Port motor rotor	
Starboard motor stator	
Starboard motor rotor	
Generator stators	
Generator rotors	
Port motor drives	
Starboard motor drives	
Cables	

Cable insulation resistance should be measured by self-contained instruments, such as a direct indicating ohmmeter of the generator type, applying a dc potential of 500 V. Where the operating voltage is greater than 500 V, the test instrument should apply a dc potential approximately equal to the operating voltage. Where circuits contain solid-state devices, care should be taken to ensure that devices having a voltage rating less than the test voltage are disconnected or shorted-out before the test voltage is applied. The insulation resistance test should be made with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltages above ground should be tested separately.

Insulation resistance testing of rotating machinery should be performed in accordance with the recommendations in IEEE Std 43-1974, including the corrections to be made for temperature and humidity conditions. The results obtained from the tests depend not only on the characteristics of the insulation materials and the way they are applied but also on the test conditions. It is recommended that the data recorded during the tests include ambient conditions, particularly those concerning the ambient temperature and the degree of humidity at the time of the test. The Polarization Index (ratio of 10 min to 1 min insulation resistance value) for the machine windings should be evaluated. The recommended minimum value of Polarization Index for ac and dc rotating machines is 2.0. The resistance should be measured with all circuits of equal voltage above ground connected together; circuits or groups of circuits of different voltages above ground should be tested separately. This test should be made at a dc voltage of 500 V, or higher as required by the system voltage, for a minimum of 1 min. The recommended minimum insulation resistance Rm for ac and dc machine armature windings and for field windings of ac and dc machines can be determined as follows:

$$Rm = \text{kV} + 1$$

where

Rm = recommended minimum insulation resistance in megohms at 40 °C (104 °F) of the entire machine winding
kV = rated machine terminal to terminal potential, in rms kilovolts

The actual winding insulation resistance to be used for comparison with the recommended minimum value *Rm* is the observed insulation resistance, corrected to 40 °C (104 °F), obtained by applying direct potential to the entire winding for 1 min to obtain the initial value and for 10 min to obtain the value for the polarization index. The minimum insulation resistance of the field windings of machines separately excited, with voltage less than the rated voltage of the machine, should be not less than 1 MΩ.

36.39.4 Drying windings

When it is necessary to dry machine windings, it should done by heating with the internal space heaters, or by circulating hot dry air through the machine. As an indication of the condition of the insulation during the drying process, resistance should be determined at intervals of not more than 3 h while the insulation resistance is falling and at less frequent intervals after that. The insulation resistance usually drops quite rapidly as the machine heats up, reaches a minimum, and then increases and finally becomes constant. In case of extreme moisture, or at the time of initial installation, the drying time may last 2 or 3 d. The windings are suitable for being placed in service after the insulation resistance becomes constant and equal to the values previously recommended.

36.40 Periodic surveys

The electric propulsion equipment should surveyed annually. The main propulsion generators and motors should be visually inspected as far as practicable. Particular attention should be paid to the ends of all windings of stators and rotors. All air ducts in stator coils and the ventilating holes in rotors and retaining rings should be carefully examined to ensure they are not blocked.

All cable runs should be examined over their entire length. Particular attention should be paid to the grounding of metallic protective coverings of sheaths. Insulation resistance should be measured.

Generator circuit breakers, motor circuit breakers, and setup switchgear should be examined and tested for mechanical operation at no load. Bus insulators and supports should be inspected to ensure they are free from oil, dust, or contamination liable to cause tracking.

The propulsion system drives and excitation and control systems should be energized and all permissive interlocks and indicators inspected. The output power excitation and control power need not be applied to the machinery during this inspection.

The insulation resistance of each propulsion motor and generator should be tested and the values obtained compared with the original manufacturer's readings and those in the ship's log. Corrective action should be taken where the measured insulation resistance is less than the recommended value in this clause or where any abrupt decrease in the order of 25% of the original or previously recorded values is noted.

36.41 Dock trials

Upon completion of major overhauls or propulsion system modifications, tests and trials should be conducted to ensure satisfactory system operation. A dock trial of sufficient duration should be made to prove that all propulsion machinery, controls, and interlocks function satisfactorily.

An insulation resistance test should be made on all motors, generators, drives, and main cabling in the cold condition immediately before the machinery is put into operation, and in the warm condition immediately after completion of trials. The values obtained should be not less than the recommended values in this clause. The insulation resistance values obtained should be recorded and kept onboard as a reference for future insulation resistance tests.

37. Control systems

37.1 General

This clause presents a guide for the design and installation of electrical and electronic equipment intended for automatic or centralized control of machinery in ships. This clause deals with electrical, electronic, and programmable equipment and systems for control, monitoring, alarm, and protection on board vessels. It includes alarm and monitoring systems, semiautomatic, fully automatic, and autonomous (unattended) systems, including

a) Propulsion plants and associated systems including lube oil and fuel systems
b) Boilers (oil, gas, or flue gas—main and/or auxiliary)
c) Incinerators
d) Steam or combustion turbines
e) Liquid and dry cargo handling and storage systems (including liquefied gases)
f) Bilge and ballast systems
g) Inert gas systems
h) Refrigeration systems
i) Electric power generating plants and Distribution equipment and machinery
j) Hotel auxiliary systems
k) Damage and fire control alarm and monitoring systems
l) Navigating bridge control systems

NOTE—Navigating bridge systems are included for those circumstances when machinery control is included in the integrated navigating bridge system. These recommendations address the remote machinery control, alarm and monitoring aspects only. The navigation system recommendations are in Clause 31.

37.2 Automatic control systems—general

When an automatic machinery control system is provided, the control and monitoring system should be designed and installed to ensure safe and effective operation, to at least the same level as could be obtained by skilled watch-keeping personnel. The system as installed should be capable of meeting all load and operational demands under steady-state and maneuvering conditions without the need for manual adjustment or manipulation.

37.3 Regulations

For regulations governing foundations, materials, inspection, tests, plans, and data, refer to the requirements of the appropriate regulatory agency and the classification society.

37.4 Documentation

Documentation for automatic control systems should be provided and should be maintained on board the vessel. This documentation should include plans and specifications, as well as technical manuals.

The plans and specifications should provide machinery arrangement showing location of controls in relation to the controlled units, arrangements and details of consoles, including all support systems, and plans for all safety-related support systems, including fire detection and protection systems.

Technical manuals should be provided for the controls and should contain, as a minimum, the following information:

a) General overall system functional description
b) Operating instructions
c) Test procedures to evaluate the operation and safety features of the complete system
d) Trouble identification charts
e) Maintenance and special repair procedures
f) Illustrated parts lists and descriptions

The operating instructions for the equipment should include sections providing examples and suggested use of the apparatus to maximize efficiency. The information should include types of conditions that can be encountered, and typical responses to those conditions. Normal routine care and testing of the equipment should be discussed. Immediate responses to fault conditions of equipment, including the monitoring or control system itself, should be emphasized.

The technical instructions for the equipment should provide complete technical information on the system and the individual equipment items that make up the system. Information should be provided in a manner and in sufficient detail to allow a skilled technician to troubleshoot, identify the fault, and undertake the repair. Detailed testing and calibration procedures for the equipment should be provided and should include recommended test equipment. The documentation should include information on the various interfaces between the specific items of equipment.

Other documentation that should be provided includes the following:

a) Overall description and specification of the system, software, and equipment
b) Block diagrams for the computer hardware showing interfaces between work stations, local controllers, input/output data acquisition units, communication controllers, communication buses, etc.
c) Logic flow and/or ladder diagrams
d) Description of the alarm system including how alarms are displayed, acknowledged, and assessed (if possible)
e) Description of system backup units and redundancy features
f) Description of the communication protocol(s) including estimated data transmission delays
g) Description of the system security protocol to prevent unauthorized changes to programs
h) Description of the system with regard to independence of the control/alarm/display systems, safety systems, and emergency shutdown systems
i) Description of the priority handling of system tasks
j) Description of uninterruptable power supply, its capacity, and the system's estimated power consumption requirements
k) Equipment ratings and environmental parameters
l) Installation methods
m) System alarm and sequencing matrix
n) System failure modes and effect analysis, or similar analysis

37.5 Definitions

See 3.11.

37.6 Control system design—general

The intent of these recommendations is to ensure that an automatic system is provided that improves the safety of the vessel. The safety of the vessel with the automation system should be at least equal to that of a vessel with its vital systems under direct manual or local control. Therefore the system design should ensure the following:

a) Unsafe effects of failure of automatic systems or remote control systems are minimized by design, and failures are limited to failsafe states.
b) Prompt alerting of an appropriate crew member, either directly or by reliable instrumentation and alarms, of machinery failure, flooding, or fire.
c) An alternative means to operate the vessel safely and to counteract the effects of the machinery failure, fire, or flooding.
d) Indication at an attended control station of the status of operation of the equipment controlled from that location.

Computer-based or computer-assisted systems are to be designed to ensure operational capability upon loss of any processing component of the system that may cause an unsafe operating condition of the plant. Unless backup, hardwired safety systems, and emergency shutdown systems are fitted, all of a computer-based system's equipment and/or peripherals should be provided in duplicate and should automatically transfer duty functions to the corresponding standby system/equipment upon failure of an on-line equipment or system. Such action should be alarmed at the remote station. Additionally, particular attention should be paid to the following criteria in the design and installation of automatic or centralized control systems:

a) *Maintainability:* The capability of keeping the control system in the designed state of operation.
b) *Availability of spare components:* The capability of the manufacturer to readily supply components to avoid delaying the operation of the vessel.
c) *Standardization:* The types of components used. Items that are readily available should be utilized wherever possible.
d) *Operational capability:* The capability of keeping display and control device movements as simple as possible. Direction of control device movements should be parallel to the axis of the display they control.
e) *Reliability:* The probability that a system will function within its design limits for a specified period of time.
f) *Accessibility:* The ability to maintain components and subsystems without removal of, or interference with, other components and subsystems.

The control system should be designed to incorporate hierarchical degrees of automation, starting from local manual control to full unattended automatic operation. The system should be designed such that loss of automatic features automatically shifts the level of control to the next lower step. The design of the system should be such that the transfer to the next lower step does not change the status of the plant or the commanded order from that of the higher level. Additionally, the system should incorporate a feature that allows the operator to set the level of control desired from the main control station.

37.7 Control system equipment location

Ship motion and anticipated structural vibrations are to be considered when selecting the locations of main and secondary control stations. Control spaces should be well ventilated, and should not require air-conditioning to maintain continuous operation of the control equipment within the prescribed temperature limits as described in 37.23.1. The routing of water, hydraulic, steam, waste, and other fluid systems piping, high-voltage cables, and other systems that could have a negative effect on the operation of the control system if breached or ruptured, should be avoided in the vicinity of the control consoles. If such routing is necessary, care should be taken to protect the consoles from any possible leakage. In the case of high-voltage equipment, defined for this purpose as equipment operating at or over 115 Vac, care should be taken to avoid installation of switching equipment in or around the control consoles, unless proper shielding from electromagnetic field pulses and power supply spiking is provided.

When an enclosed main control space is located within the machinery spaces, it should have two means of access/egress located as remote from each other as practicable. Windows, if provided, should be shatter-resistant.

The arrangement of control consoles should be such that the operator can safely and efficiently communicate with and control the equipment under all conditions. The indicators, meters, displays, control switches, and levers should be grouped so that trends, abnormal conditions, the indicators of possible trouble, and devices for corrective action, are in a localized area. If light-emitting diodes (LEDs) are used for any display, indicator, or meters and exposure to sun rays is possible, means should be provided to block sun rays and enhance direct sunlight readability.

37.8 Machinery control

37.8.1 General

The centralized control system should support real-time monitoring and control of ship propulsion, electrical, auxiliary, and steering functions.

When provided for essential machinery functions, standby machines should incorporate automatic changeover features. The changeover function should be alarmed. Vital control, safety, and alarm systems should automatically transfer power sources to backup systems upon failure of the operating power source. The system should be designed to ensure the changeover operation does not further degrade the plant condition by inadvertently compounding the situation.

Effective means should be provided to allow propulsion units to be operated under all sailing conditions, including maneuvering. The speed, direction of thrust and, if applicable, the pitch of the propeller, should be fully controllable from the navigating bridge. This includes all thrust conditions, from that associated with maximum controllable open-water astern speed to that associated with the maximum controllable ahead speed.

Control functions from a console may be designed for either remote manual or automatic control. Vital systems that are automatically or remotely controlled should be provided with the following:

a) *An effective primary control system.*
b) *A manual alternate control system.* A method should exist that provides for alternative positive control of the vital equipment.
c) *A safety control system.* Methodologies should be incorporated into the control system either in hardware or software that preclude the unsafe operation of the equipment. Unsafe operation is considered to be operation that will cause severe and permanent damage of the equipment, and/or risk to operating personnel.
d) *Instrumentation to monitor system parameters necessary for the safe and effective operation of the system.* The instrumentation installed should be sufficient to provide a skilled worker with an adequate ability to assess the status, operational performance, and health of the equipment under control. Human factors and ergonometric considerations should be included in the instrumentation design.
e) *An alarm system.* A method should be provided to alert the operator to abnormal and dangerous operating conditions.

Provision should be made for independent manual control in the event of a loss of an element of, or the entire centralized control system. The provision should include methods and means of overriding the automatic controls and interlocks. The instrumentation and control provided should be capable of supporting the manual operation for indefinite periods of time.

37.8.2 Control hierarchy

For ships with more than one control station, a decreasing authority should be assigned according to the following control station locations:

a) Local controls at the controlled equipment
b) Control station(s), in the machinery spaces, closest to the controlled equipment [local control station(s)]
c) Remote control station(s) outside of machinery spaces
d) Navigating bridge (and/or bridgewing) control station

The control station of higher authority should be designed to include a supervisory means for transferring control from a station of lower authority at all times, and to block any unauthorized request from any station of lower authority. A station of higher authority must be capable of overriding and operating independently of all stations of lower authority. The overriding action when executed should be alarmed at the remote location affected. Transfer of control from one station to another, except for the specific case of override by a station of higher authority, is to be possible only with acknowledgment by the receiving station.

The control function at a control station of higher authority should not depend on the proper functioning of the control station of the lower authority. The control functions from only one station should, except for emergency control actions, initiate a command signal to controlled equipment. Transfer of control between stations should be accomplished smoothly and control of the controlled equipment should be maintained during the transfer. Failure of a control function at a station of lower authority should automatically and smoothly transfer the control to the station of the next higher authority. This transfer should generate an alarm at both stations. Appropriate indications with discriminatory intelligence should be provided at each station, except locally at the controlled equipment, to identify the station in control and any loss of control.

37.8.3 Control, start, stop, and shutdown conditions

The control system should include a means for emergency stopping the propulsion system from the navigation bridge. This feature should be independent of the navigation bridge control system.

For remote starting of the propulsion machinery, the control system should include interlocks that prevent the remote starting of propulsion machinery under conditions that may be hazardous to the machinery or operating personnel, such as when machinery is being maintained or inspected.

Automatic shutdown of machinery should be alarmed at all control stations. Restoration of normal operating conditions should be possible only after a manual reset.

Loss of control for any reason, including loss of power, logic failure, or power conditioning failure, should be alarmed at all stations. Upon failure of the control system, the system should be designed to continue to operate the plant in the condition last received, until local control is established.

37.9 System design characteristics

Efforts should be taken to minimize the probability of a failure of any one component or device in the control circuit, causing unsafe operation of the machinery. There should be no single points of failure that will disable the control system. Where multiple auxiliaries such as normal and standby are installed for vital services, any single failure should be limited in effect to only one of the auxiliaries, and such failures should not render any reserve automatic or manual control, or both, inoperative.

All electric and electronic devices and components should be suitable for use in a marine environment, resistant to corrosion, treated for resistance to fungus growth, not affected by shipboard vibration or shock loading, and capable of providing their intended function at typical environmental temperature and humidity levels. All control equipment should be designed to perform satisfactorily without adverse susceptibility to electromagnetic fields, power switching spikes, or other electromagnetic noise that might typically be encountered in the operating environment, or induced on interconnecting cables (see 37.23).

37.10 Control system power supply

Feeders supplying power to the control console should be provided with overload and short-circuit protection. Where circuits are protected by fuses, control system protection should be subdivided and arranged so that failure of one set of fuses will not cause maloperation or failure of other circuits or systems. Isolation of faults should be readily accomplished.

Power for monitoring, alarms, and vital controls should be supplied from an emergency source upon failure of the main power supply. Power conversion equipment, if required by the design, should be of the solid-state type. Common power conversion devices should be supplied in duplicate, arranged to operate in parallel, with either capable of supplying the full load of all units powered by the system they serve.

Designs in which the control system is isolated into separate sections controlling major equipment and systems that are operated independently of each other may use separate power conversion devices for each section, with one spare, readily interchangeable with any unit.

Individual protective devices should be provided in the input and output of each power conversion device.

37.11 Continuity of power

The control system should be designed to include an uninterruptable power supply (UPS) that has sufficient capacity to maintain power to the control system for a period sufficient to bring the emergency power generator on line, or if necessary, to safely shut down the equipment. The quality and operation of the UPS supply should be such that the control's equipment experiences no disturbance or interruption in power. Nominal capacity should be for a period of not less than 15 min at full rated load with a voltage degradation not more than 10% of rated level.

37.12 Communication systems

Communications systems for control should include, as a minimum, voice, data, and emergency backup systems.

Voice systems should provide direct communication between control stations and controlled equipment on a priority link. When the voice communications systems depends on the ship's electrical system, a backup system should be provided that is independent of the electrical system, and that is capable of operating reliably for an indefinite period of time. The voice system should be independent of all other communication systems used for machinery/propulsion control.

Data communications between control stations and controlled equipment should be designed to incorporate industry standard protocol and interfaces. The system should include a built-in redundancy for the transmission of data. The data system should be separate from all other communication systems. The system should be designed to be relatively immune to negative effects induced by the operational environment. Within the data communication system, the fire alarm communication system should be a separate standalone system, not dependent on any other subsystem for its operation.

Digital systems and systems employing data "highways" or "buses" or local area networks (LANS) should be designed with full consideration of system bandwidth, redundancy, data senescence, and fault tolerance. In general, bandwidth should be sized to allow 50% growth upon completion of the design. Redundancy should include, as a minimum, two levels, with no single points of failure. Data senescence should be such that critical controls cannot be placed into oscillation, or degrade the performance of the control system under any fully loaded condition (when all systems capable of using the data highway are using it at their individual worst-case data transmission rates). Fault tolerance should be such that minor faults do not render the communication system wholly inoperative. The design should be such that the failure is limited in its impact to the immediate system, and at worst, results in a proportionately degraded system. In addition, when automatic or remote control and monitoring for specific machinery is to operate utilizing such data highways, the following items should be considered:

a) The network topology should be configured so that in the event of a failure between nodes or a failure of a node, the integrity of the system as a whole is maintained.
b) In the event of a failure of the network controller, the network should be arranged to automatically switch to a standby controller. The failure should be alarmed at the associated remote control station.
c) Safeguards should be implemented to prevent overloading of the network data transmission rates. Such overloading should be alarmed at the associated remote control station whenever such a condition is approached.
d) The communication data highway should be provided in duplicate, and should be arranged such that failure of the online highway automatically causes the standby highway to be switched online. The standby highway is not to be used to reduce the traffic in the online highway.

The control system should be equipped with various separate emergency backup communication systems that will allow the continued operation of the vessel in the event of a catastrophic failure of the normal communication systems. These communications systems might typically be hardwired links to a few limited critical systems. Backup communication systems might include:

a) *For voice communication systems:* Sound-powered, or battery-powered hard-wired or hull-transmitted communication systems between the machinery control stations and the machinery being controlled.
b) *For data communication systems:* Separate hard-wired or alternative data highway or hull-transmitted data communications circuits between the navigating bridge, machinery control stations, and the machinery being controlled. These circuits should provide abbreviated plant status monitoring.

37.13 Alarms

Alarm devices should be provided that automatically sound and visually indicate the loss of power to the control system. Provision should be made for silencing audible alarms. The system should indicate any fault requiring attention and should contain the following features:

a) Audible and visual alarms in the machinery control room or at the propulsion machinery control position, which indicate each separate alarm function at a central position.
b) Alarm indication circuits for the engineers' public rooms and selectable alarm indications to each engineer's stateroom.
c) Supervisory alarm activation if the alarm system malfunctions.
d) Supervisory alarm activation in an attended location if the alarm has not been acknowledged in a limited time (not exceeding 5 min).
e) A continuously energized system, with automatic transfer to standby power upon failure of normal power.
f) Capability to indicate more than one alarm condition simultaneously, while retaining the first fault, and providing descriptive information on the nature of each fault.
g) Prevention of nuisance alarm activation due to ship's dynamic motion.
h) Ability to acknowledge an alarm condition without preventing the alarm indication of other abnormal conditions.
i) Ability to override an audible alarm condition from reoccurring continuously if the alarm condition could not be rectified immediately.

Vital alarms should be readily distinguishable from nonvital alarms, both audibly and visually.

Alarms should be of the self-monitoring type (an open circuit will cause an alarm condition). With the exception of equipment running lights, provisions should be made for testing audible and visual alarms.

37.14 Control cabling

Cables for circuits susceptible to interference should be shielded or isolated to minimize spurious signals from outside sources. Wiring and electrical components within consoles should be arranged for maximum accessibility and for protection from steam, water, oil, etc.

37.15 Control power distribution

High-voltage equipment, such as rheostats and voltage regulators, mounted in control consoles should have barriers to separate live parts from equipment operating at lower voltage levels.

Input line disconnect switches or circuit breakers should be provided for all console power sources. They should be in a readily accessible location in or adjacent to the console.

Grounding should be in accordance with 11.39.

37.16 Hazardous location considerations

Intrinsically safe systems or explosionproof equipment should be installed where hazardous conditions may be present (see Clause 33).

37.17 Control system testing

Control systems should be tested in accordance with the specific requirements of the cognizant regulatory agency and classification society.

Testing should be accomplished in a hierarchical structure beginning with component inspection and qualification, proceeding to subassembly performance testing and qualification, and ending with installed system performance testing and qualification. Manufacturers should provide mechanical, electrical, and electronic components that have been inspected and performance-proven at the component and/or material level, subassembly, and system levels. These tests should be structured such that successful completion of the testing provides reasonable assurance of the system performance in the expected marine environment.

In addition to the requirements for testing of control systems during construction and assembly and during shipboard installation trials, control systems should incorporate features into the design that provide for routine in-service, built-in testing. Means for testing complex circuits and check points for calibration purposes should be provided. In assessing the requirements for built-in test equipment, it should be assumed that maintenance and repair will normally be carried out by removing faulty line replacement units to a test bench or suitably equipped workshop.

37.18 Maintenance philosophy and design

Equipment and systems should be designed to support a maintenance philosophy that establishes the line replaceable unit (LRU) as a circuit board, power supply, mechanical subassembly, or other self-contained unit or logical subassembly. Electronic or electrical equipment designated as an LRU should include an appropriate indicating device that distinguishes normal operation from a failed condition.

Repair of an LRU should consist of a removal and replacement operation. This operation should be designed to require no more than 120 min to complete from identification of the fault, through removal and replacement of the failed unit, to restoration of its normal operating condition.

A listing of recommended on-board repair parts should be provided with the control system.

37.19 Control system sensors

Sensors should be chosen to be appropriate to the local operating environment and type of service expected. In general, sensors should provide standard type of interfaces and modes of operation. When employed, "intelligent" sensors, or sensors containing embedded microprocessors or other logic circuits, should provide data via a generally accepted interface and protocol scheme. Care should be taken in the system design and selection of sensors to ensure that a failure of the sensor or sensor subsystem fails safe, and does not support propagating damage. For example, a sensor failure on an engine governing system should not cause the engine to overspeed.

37.20 Control system programming

Automatic and semiautomatic control systems utilizing embedded or high-level software programming to perform the control function should have such programs designed and implemented with the following considerations:

a) *Embedded programs should be utilized.* The embedded program should be written in a structured high-level language. Assembly language programming should be used only if code, for timing or space reasons, can be coded in no other way. Each procedure should be documented as follows:
   1) The procedure's actual calling name from within the program should be listed along with a one-line description statement for the calling name. The statement's purpose should clearly describe the task associated with the procedure's name.
   2) There should be a list of input/output parameters, a description statement for each parameter that describes the task associated with the parameter's name, a statement stating whether the parameter is an input into the procedure or an output of the procedure, and a range of valid values for each parameter that may be passed into or out of the procedure.
   3) There should be a list of calling/called procedures, a description statement for each procedure that describes the task associated with the procedure's name (this statement should be the same as the one describing the procedure's calling name), a statement stating whether the procedure is called from within the routine or is the caller of the routine, and the name of the module in which the calling/called procedure can be found.
   4) There should be a synopsis describing the program flow for the procedure. This should be a detailed plain-language narrative of what the code is doing.
   5) There should be a revision history for the procedure that includes the data and a description of the change. The description should include the new revision level for the overall program that has resulted from the module modification.

b) *The overall program should contain a documentation file.* The documentation file should include a list of files and module names within the program, a list of procedures associated with each module, and a list of procedures that each procedure calls (cross-referencing). The documentation file should also include a list of compiler/assembler/linker/locator commands required to convert the associated source code files into the program's operational absolute code. There should be a revision history for the overall program within this file. Included should be the date and a description of the revision change. The description should include the new revision level of the overall program, the name of the modules that were modified, and a description of the modification.

Operating systems, if used, should be limited to standard off-the-shelf products unless the vendor can justify why a custom operating system is required for an application.

Software programming required for the operation of the system should be contained in nonvolatile memory within the system. A preferred configuration is a hierarchical structure wherein the master program is maintained on a hard disk or tape, and loaded into the system on electronic programmable read only memory (EEPROM) for operational use.

For verification the vendor should develop a test plan that exercises all of the functions including operation, fault detection and recovery, data acquisition, and data dispersion of the software. This plan will be used to exercise, demonstrate, and verify to the customer, regulatory body personnel, and classification society personnel the proper operation of the equipment.

37.21 Design considerations

Circuits should be easy to adjust and maintain, and should be designed for maintenance by replacement. Components and circuits should be clearly identified or labeled. Circuit diagrams, in block form, should be prominently displayed in or near the associated cubicle.

Solid-state amplifiers should be provided as necessary to preclude overloading transducers that are used as a common signal source for display, such as loggers and alarms.

Where complex logic circuits are used for sequential startup, or for operating individual plant components; indicators should be provided showing successful completion of the sequence of operation. Where a particular step is not completed in the sequence cycle, indicators should be provided designating the incomplete function or control stopping the sequence at this particular point. Manual override should permit control in the event of the failure of a logic circuit.

Instruments exposed on the operating panels should be recess-mounted with the controls, meters, etc., as flush as practicable. Miniaturized equipment may be used to limit the size of control consoles.

Thermostatically controlled heaters should be provided for humidity and temperature control during cold ship or idle conditions, and should be automatically energized from a separate source of power when the main power source is turned off.

37.22 Instrumentation

Instrumentation and alarms should be at control consoles to provide all information for monitoring and alarming the operation of propulsion, electrical, and emergency systems.

Where readouts are required and are not continuous, there should be a demand readout. Displays should be easily readable and available with minimum effort by a watchstander.

Systems with remote reading instruments should have provisions for the installation of direct reading instruments at the equipment.

Printers with movable carriages should not be used for printout devices.

Instrumentation and control system actuators should have a physical differentiation from the alarm indicators. An illuminated pushbutton may be used as an alarm monitor, providing the proper designation is available.

37.23 Environmental conditions

Control components should be designed and type tested for operation at the following conditions. Equipment should be tested according to the environmental procedures as specified in Table 37-1, and in accordance with the performance procedures in Table 37-2. This does not modify the equipment ambient temperature conditions specified elsewhere in these recommendations.

Table 37-1—Environmental tests for control and monitoring equipment

No.	Test	Procedure according to	Test parameters	Other information
1	Visual inspection	—	—	1) Conformance to drawings, design data; 2) Quality of workmanship and construction.
2	Dry heat	IEC 60068-2-2: 1974, Environmental testing—Part 2: Tests. Test Bb, Dry heat for non-heat-dissipating specimen with gradual change of temperature.	Temperature: 55 °C (131 °F) ±2 °C (36 °F) Duration: 16 h or Temperature: 70 °C (158 ºF) ±2 °C (36 °F) Duration: 2 h (See Note 1)	1) Equipment operating during conditioning and testing: 2) Functional test during the last hour of the test temperature; 3) Functional test after recovery.
		IEC 60068-2-2: 1974, Environmental testing—Part 2: Tests. Test Bd, Dry heat for heat-dissipating specimen with gradual change of temperature.	Temperature: 70 °C (158 °F) ±2 °C (36 °F) Duration: 2 h or Temperature: 55 °C (131 °F) ±2 °C (36 °F) Duration: 16 h (See Note 1)	1) Equipment operating during conditioning and testing with cooling system on, if provided; 2) Functional test during the last hour at the test temperature; 3) Functional test after recovery.
3	Damp test	IEC 60068-2-30: 1980, Environmental testing—Part 2: Tests. Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle).	Temperature: 55 °C (131 °F) Humidity: 95 % Duration: 2 cycles/ 12 + 12 h cycle	1) Measurement of insulation resistance before test; 2) Equipment operating during complete 1st cycle, switched off during 2nd cycle except for functional test; 3) Functional test during the first 2 h of the 1st cycle at the test temperature and during the last 2 h of the 2nd cycle at the test temperature; 4) Recovery at standard atmosphere conditions; 5) Insulation resistance measurements and performance test.
4	Cold	IEC 60068-2-1: 1990, Environmental testing—Part 2: Tests. Test A: Cold (Concerns cold tests on both non-heat-dissipating and heat-dissipating specimens).	Temperature: 5 °C (40 °F) ±3 °C (37 °F) Duration: 2 h or Temperature: -25 °C (–13 ºF) ±3 °C (37 °F) Duration: 2 h (See Note 2)	1) Initial measurement of insulation resistance; 2) Equipment not operating during conditioning and testing except for functional test; 3) Functional test during last hour at the test temperature; 4) Insulation resistance measurement and functional test after recovery.
		IEC 60068-2-1: 1990, Environmental testing—Part 2: Tests. Test A: Cold (Concerns cold tests on both non-heat-dissipating and heat-dissipating specimens).	Temperature: -25 ºC (–13 ºF) ±3 ºC (37 ºF) Duration: 2 h or Temperature: 5 ºC (40 ºF) ±3 ºC (37 ºF) Duration: 2 h (See Note 2)	—

Table 37-1—Environmental tests for control and monitoring equipment *(Continued)*

No.	Test	Procedure according to	Test parameters	Other information
5	Salt mist	IEC 60068-2-52: 1996, Environmental testing—Part 2: Test methods—Test Kb Salt mist, cyclic (sodium, chloride solution).	Four spraying periods with a storage of 7 d after each.	1) Initial measurement of insulation resistance and initial function test; 2) Equipment not operated during condition; 3) Functional test on the 7th day of each storage period; 4) Insulation resistance measurement and op test after recovery. (See Note 3.)
6	Insulation resistance	—	Rated supply voltage (V) / Test voltage (V) / Minimum insulation resistance Before (MΩ) / After (MΩ) Un≤65 / 2*Un (min. 24 V) / 10 / 1.0 Un>65 / 500 / 100 / 10	1) Insulation resistance is to be carried out before and after; damp heat test, cold test, and salt mist test; 2) Between all circuits and earth; 3) On the supply terminals, where appropriate.
7	High voltage	—	Rated voltage Un (V) / Test Voltage (ac voltage 50 or 60 Hz) (V) up to 65 / 2*Un+500 66 to 250 / 1500 251 to 500 / 2000	1) Separate circuits are to be tested against each other and all circuits connected with each other tested against earth; 2) Printed circuits with electronic components may be removed during test; 3) Period of application; 1 min.
8	Electro-static discharge	IEC 61000-4-2: 1995, Electromagnetic compatibility (EMC)—Part 4: testing and measurement techniques—Section 2: Electrostatic discharge immunity test. Basic EMC publication.	Test voltage: 8 kV according to level 3 severity standard	1) To simulate electrostatic discharge as may occur when persons touch; 2) Test is to be confined to the points and surfaces that can normally be reached by the operator; 3) The equipment is to operate during testing; 4) As a result of the test, neither permanent or transient effects nor damage to the equipment are allowed.
9	Radiated electro-magnetic field	IEC 61000-4-3: 1995, Electromagnetic compatibility (EMC)—Part 4: testing and measurement techniques—Section 3: Radiated, radio-frequency, electromagnetic field immunity test.	Frequency range: 30 kHz to 500 MHz Field strength; 10 V/m 1) According to severity level 3 2) Field strength to be adopted according to severity.	1) To simulate electromagnetic fields radiated by different transmitter; 2) The test is to be confined to the appliance exposed to direct radiation by transmitters at their place of installation; 3) As a result of the test, neither permanent or transient effects nor damage to the equipment are allowed.
		IEC 61000-4-4: 1995, Electromagnetic compatibility (EMC)—Part 4: testing and measurement techniques—Section 4: Electrical fast transient/burst immunity test. Basic EMC publication.	Test voltage/ ±10%: 1) 2 kV on power supply 2) 1 kV on data and control lines acc. to severity level 3.	1) To simulate interference by electric arcs generated when actuating electrical contacts; 2) Interference effect occurring on the power supply, as well as at the external wiring of the test specimen; 3) As a result of the test, neither permanent or transient effects nor damage to the equipment are allowed.

Table 37-1—Environmental tests for control and monitoring equipment *(Continued)*

No	Test	Procedure according to	Test parameters	Other information
10	Conductance Interference	IEC 61000-4-6: 1996, Electromagnetic compatibility (EMC)—Part 4: testing and measurement techniques—Section 6: Immunity to conducted disturbances, induced by radio-frequency fields.	Testing signal 1.5 V eff. in the range between 10 kHz and 50 MHz Modulation: 30% Modulation frequency: 1 kHz	To simulate electromagnetic fields coupled as high frequency into the test specimen via the connecting lines.
		IEC 61000-4-5: 1995, Electromagnetic compatibility (EMC)—Part 4: testing and measurement techniques—Section 5: Surge immunity test.	Test voltage: 1.0 kV differential mode; 2.0 kV common mode Rise time: 1.2 µs Surge time/50% value/50 µs acc. to severity level 3.	1) To simulate interference generated, for instance, by switching on or off high-power inductive consumers; 2) The test is to be carried out at the power supply.
11	Vibration	IEC 68-2-6: 1995, Environmental testing—Part 2: Tests—Test Fc: Vibration (sinusoidal).	2 ± 3 Hz to 13.2 Hz—amplitude ±1 mm (.039 in) 13.2 Hz to 100 Hz—acceleration ±.7 g For severe vibration conditions such as equipment mounted on diesel engines, air compressors, etc., higher frequency and acceleration values will be considered.	1) Duration in case of no resonance condition 90 min at 30 Hz; 2) Duration at each resonance frequency at which Q>2 is recorded, 90 min; 3) During the vibration test, operational conditions are to be demonstrated; 4) Tests are to be carried out in 3 perpendicular planes; 5) It is recommended, as guidance, that Q does not exceed 5.
12	Inclination	—	Static: 1) Athwartships: 22.5° (see Note 4) 2) Fore and aft: 10° Dynamic 1) Athwartships: 22.5° (see Note 4) 2) Fore and aft: 10° Duration: 10 s	1) This test is to be carried out immediately after the vibration test; 2) For static conditions, the test is to be carried out for a period of sufficient duration to determine the satisfactory operation of the equipment.

NOTE 1—Dry heat at 70 ºC (158 ºF) is to be carried out for equipment located in an non-air-conditioned space.
NOTE 2—For equipment installed in non-weather-protected locations or cold locations, test is to be carried out at –25 ºC (–13 ºF).
NOTE 3—Salt mist test is to be carried out for equipment installed in weather-exposed areas.
For athwartships position, the angle of inclination is to be increased to 45° if switches, levers, or similar are installed on the equipment.

Table 37-2—Performance tests for control and monitoring equipment

No.	Test	Procedure according to	Test parameters	Other information
1	Visual inspection	—	—	1) Conformance to drawings, design data; 2) Quality of workmanship and construction.
2	Functional test	The equipment specification	Standard atmosphere conditions: 1) Temperature: 25 ºC (77 ºF) – 10 ºC (50 ºF) 2) Relative humidity: 60 % ± 30 % 3) Air pressure: 96 bar (.98 kgf/cm², 13.92 lbf/in²) ±.10 bar (.10 kgf/cm², 1.45 lbf/in²)	1) Confirmation that operation is in accordance with the requirements specified for particular automatic systems or equipment; 2) Checking of self-monitoring features; 3) Checking of specified protection against an access to the memory and effects of unerroneous use of control elements in the case of computer systems.
3	Power supply failure	—	1) 3 interruptions during 5 min 2) Switching-off time 30 s each case	Verification of the specified action of the equipment on loss and restoration of supply in accordance with the system design.
4	Power supply (electric)	—	Combination / Voltage variation permanent (%) / Frequency variation permanent (%) 1 / +10 / +5 2 / +10 / –5 3 / –10 / –5 4 / –10 / +5 Combination / Voltage transient 1.5 s (%) / Frequency transient 5 s (%) 5 / +20 / +10 6 / –20 / –10 Electric battery supply: 1) +30% to –25% for equipment connected to battery during charging 2) +20% to –25% for equipment not connected to the battery during charging	—
	Power supply (pneumatic and hydraulic)	—	Pressure: ±20% Duration: 15 min	—

37.23.1 Temperature and humidity

a) Open weather decks and open bridges:
   Temperature range .... –25 °C (–13 °F), +55 °C (131 °F)

b) Machinery spaces:
   1) Temperature range .... 0 °C (32 °F), +65 °C (149 °F)
   2) Relative humidity 10–95%

c) Enclosed areas other than machinery spaces:
   1) Temperature range .... 0 °C (32 °F), +40 °C (104 °F)
   2) Relative humidity 10–95%

d) Storage and transport conditions:
Temperature range... –25 °C (–130 °F), +70 °C (158 °F)

e) Console and stand-alone equipment:

Interior temperatures.. +65 °C (140 °F)

NOTE—Equipment should be suitable for the atmospheric conditions encountered, such as salt air, moisture, and oil vapor.

37.23.2 Power system voltage and frequency

Equipment should be designed for satisfactory operation with a voltage variation of ±10% and possible simultaneous frequency variation of ±5.0%.

37.23.3 Vibration

Frequency range (Hz)	Amplitude
2–13.2	±1.0 mm
13.2–100	±0.7 g

37.23.4 Electromagnetic fields

The generation of electromagnetic fields by the installed equipment should be minimized. However, in recognition that shipboard control equipment will operate in an electromagnetic environment, the equipment should be designed to operate properly when exposed to electromagnetic radiation. The levels of electromagnetic radiation will vary by application and location, and equipment should be designed accordingly.

37.24 Equipment enclosures

The types of protective enclosures used for control apparatus should be governed by the location, unless otherwise specified in these recommendations.

37.25 Control console design—general

All control stations should be placed well inboard from the ship side, in locations where any anticipated structural vibration would be expected to be at a minimum. Control stations should be well ventilated. Control consoles should be self-supporting with the sides and backs suitable protected. Drip covers should be provided over consoles that may be subject to damage by leaks or falling objects. Where antishock or antivibration mounts are used, adequate clearance should be provided between tray and cubicle or rack, allowing full freedom of travel. Cascaded systems of shock or vibration mounts should be avoided. All enclosures should be rodent-proof with openings covered with wire mesh, approximately 6.4 mm by 6.4 mm (0.25 in by 0.25 in). Nonconducting grab rails should be provided along the front of consoles.

Design of chassis and cubicles should be mechanically simple and arranged to avoid the need for special tools in dismantling. Nut and bolt connections should have locking devices. In general, threads should not be tapped directly into molded or synthetic resin board or similar material. The use of blind holes, plain or tapped, should be avoided.

Removable assemblies should be such that one person can handle and maneuver them easily and safely. Check points or connecting points should be accessible without the necessity for complete disassembly of equipment. Components requiring maintenance should be arranged to be clear of or shielded from high voltage, high temperature, and unsafe working areas. Electrical control equipment should not be installed in the same panels as equipment employing a hydraulic medium. Consoles should be constructed to facilitate retrofitting and ease of movement through standard shipboard doors and accesses.

37.25.1 Control console components

Console components should be suitable for use in the marine environment.

Relays of the hermetically sealed type should be used for all circumstances. However, electromagnetic relays of the unsealed type may be used if they are fitted with dust covers. All relays should be arranged to be readily accessible for maintenance. Unsealed relay contacts should not be used for currents less than 2 mA.

Pushbuttons and similar devices should be provided with oiltight enclosures if installed where moisture, oil vapor, or conductive dust may be present. Control pushbuttons for remote-operated valves should have valve position indicators on the control console. Position indicators may be combined with the pushbuttons on the mimic diagrams. Valves that are installed in positions liable to flooding should be capable of operating when submerged. If momentary pushbuttons are used, separate indicators for the state of the pushbutton as well as the status of the controlled device should be provided. Status of the controlled device should be shown for all possible states.

Indicator lights should be fitted with two or more lamps in parallel and enclosed in a diffusing shade, or otherwise shielded to avoid excessive brightness. There should be at least 6.4 mm (0.25 in) clearance through air, and 6.4 mm (0.25 in) creepage clearance between the inside of the enclosure and live parts for 115 V. For systems of 24 V and less, clearances may be reduced to 3.2 mm (0.125 in). Indicator lights should be of rugged construction and not be affected by vibration.

Printed circuit boards should mate with “floating contacts,” enabling the boards to remain fully connected under adverse conditions. Where plug-and-socket connections are used, the plugs and sockets should not carry any mechanical load even when withdrawing or replacing a unit. Guide pins or rails should be provided.

Lugs and connectors should be of the solderless type. These devices should provide adequate contact area and conductive finish, low voltage drop, satisfactory mechanical strength capable of resisting pullout, and the capability to resist vibration. Where lugs are located such that misalignment may result in short circuiting, they should have two holes or be otherwise secured against turning. Connectors should be accessible for cable connections in all units.

Terminal boards for connecting ship cable should have terminal screws not smaller than UNC size 6-32. Terminals should be protected against accidental contact or mechanical damage. Solderless terminal connectors should include a locking device to prevent loosening due to vibration.

37.26 Meters and gauges

Instruments for indicating the plant conditions should be provided and mounted on the control consoles, convenient to the control. Meters and gauges mounted on consoles should be plainly labeled and provided with a distinguishing mark indicating normal maximum load conditions, or ranges as applicable. Scale values should have a logical sequence of operation (e.g., increase from left to right or from bottom to top). Meters and gauges should be located where they can easily be seen.

37.27 Control devices

Control levers or handles should be easy to grasp and manipulate and protected against inadvertent operation. Control movements should be in a logical direction; for example, clockwise movements produce an increase and counterclockwise movements produce a decrease. Also, the forward movements of a lever should cause an increase or a forward motion, the backward motion a decrease or an astern motion, or a similar logical sequence. Controls should be readily identifiable.

All reply pointers should operate in synchronism. Where transmitters are mechanically interlocked to effect synchronous operation, methods of mechanical interlocking should be such that failure of the mechanical interlock will not interrupt or disable the transmitter.

The most important and frequently used controls should have the most favorable position with respect to ease of reaching and right-hand operation, especially rotary controls and those requiring fine settings.

Controls should be selected and distributed so that none of the operator's limbs will be overburdened. Detent controls should be selected to divide adjustments into discrete steps whenever feasible.

37.28 Ergonomics (human factors)

Controls and associated displays should be grouped together so that the effect of control adjustment is readily visible. The relationships of a control to its associated display and the display to the control should be immediately apparent and unambiguous to the operator. Controls should be located adjacent to (normally under or to the right of) their associated displays and positioned so that neither the control nor the hand normally used for setting the control will obscure the display. The guidelines provided in ASTM F1166-95a, as related to controls, displays, audio indicators, labeling, environment and accessibility issues, should be followed where practicable.

Instruments and control panels should be placed normal to the operator's line of sight, or to the mean value if the line of sight varies through an angle. Instruments or displays providing visual information to more than one person should be located for easy viewing by all users concurrently, or if this is not possible, the instruments or displays should be duplicated. Instrument scales that are nonlinear or those requiring elaborate interpolation should be avoided wherever possible. Digital readouts should not be used where the reading changes rapidly. Instruments should be designed and installed to minimize glare or reflection or being obscured by strong light.

Instruments and controls should be labeled in the simplest and most direct manner possible. However, abbreviations should not be used unless they are commonly accepted, for example; use r/min (or rpm) rather than revolutions per minute.

All pushbuttons and control switches should be suitably protected to avoid accidental operation.

Nameplates should be designed to be read easily and accurately at the anticipated operational reading distances and conditions of illumination, considering such factors as contrast, size, method of imprinting, and relative legibility of alternative words. English character type should be News Gothic or similar sans serif.

For general dial and console panel design, character height in millimeters should be not less than three and one half times the reading distance in meters. Character width should be 0.7 times the character height with a minimum character size of 7 mm (0.28 in) by 5 mm (0.2 in).

Controls or combined controls/indicators should be visually and tactually distinguishable from elements that only indicate. The shape of mechanical controls should indicate the method of operation of the control.

Operation and troubleshooting should not be combined in a single display, unless the comparable functions require the information simultaneously.

Displays should indicate a power failure or internal malfunction to an operator.

Display lighting may be accomplished by flood lighting, indirect lighting, edge lighting, or back lighting. Supplementary lighting or other special equipment should not be necessary to read a display. Reflectance of ambient illumination from glass or plastic cover should be avoided. All illumination and lighting of instruments should be adjustable down to zero except the lighting of warning and alarm indicators and the control of the dimmers, which should remain readable.

Color coding of indicator lights and instruments should conform to the requirements of IMO Resolution A.686, Code on Alarms and Indicators. In addition, the following general guidelines for the utility of colors in indicator lights is provided:

Indicator light color/utility	Guideline
Flashing red	1) Corrective action must be taken 2) System or equipment is inoperative 3) Emergency condition exists 4) Potential personnel or equipment disaster.
Steady red	Fault condition exists, but has been acknowledged by the operator.
Amber	Marginal condition exists as far as system or equipment effectiveness is concerned.
Green	Condition is satisfactory.
White	Condition not having “right” or “wrong” implications; for example, power available.
Blue	Advisory light when an additional color is necessary; for example, system is ready for operation.

Mimics and flow diagrams may be provided where clarification of a system would be desirable, for example; fuel oil transfer, condensate systems, etc.

The design and layout of instrumentation should be as simple as possible, consistent with the functions desired. The objective should be to provide an uncomplicated design that

a) Is functional, safe, and reliable;
b) Is easy to operate and maintain;
c) Requires minimum procedural processing;
d) Reduces logistic, personnel, and training problems; and
e) Provides indicator and control lights in the wheel house area with dimmers for use at night.

37.29 Identification and marking

Nameplates should be provided for each piece of apparatus installed on or in the console, clearly indicating its service. All electrical/electronic components should have suitable markings indicating the electrical characteristics of the equipment. Such markings may be by reference to drawings and parts lists.

Fuse holders or circuit breakers in the console should be identified as to rating and circuit. Relays should be identified as to circuit.

LRUs should be clearly identified as such, and the identification should be easily correlated to appropriate technical manual documentation.

37.30 Ventilation

Where control consoles are installed in the machinery space (a separate control room is not provided), a supply of filtered air separate from that of the machinery space should be provided for control consoles. Alternatively, local air conditioning may be provided to the consoles. Consoles fitted with self-contained air conditioning units should be arranged to provide free flow of air to its cooled cubicles.

Air filters to the forced-air cooling system should be readily accessible for removal and cleaning. There should be a warning signal provided for failure of the console integral air conditioning.

37.31 Sealing

Cable and pipe penetrations in the control consoles should be through the bottom and adequately sealed, protecting the enclosure from dust, condensation, and rodents.

37.32 Environmental monitoring

The machinery control system should include a capability of monitoring machinery plant discharges. This monitoring should be accompanied by an alarm and information display providing normal and abnormal ranges. Such information should be provided to the ship's data logging system as part of the ship's permanent record.

38. Ship tests

38.1 General

After the electric installation is complete and before the vessel proceeds on sea trials, the entire electric plant should be thoroughly inspected and tested. Tests are intended to determine general equipment condition and to ensure that the installation of electrical systems and equipment is in a satisfactory and acceptable state at the time of completion. These tests should be in addition to, and not as as substitute for, the tests of individual equipment items at the manufacturer's facility. Satisfactory test results, while providing worthwhile information on general equipment condition, do not always ensure that any particular installation is satisfactory in all respects.

The initial inspection, which may consist of a series of inspections during the construction of the vessel, should include a complete inspection of the electrical installation and electrical equipment. The inspection should ensure that the electrical arrangement, materials, and installations fully comply with each applicable recommendation. The inspection should also ensure that the quality of all equipment and installations is satisfactory.

Electric cable should be checked during installation to ensure it is the size and type shown on the plans. The adequacy of cable supports should be checked. It should be ascertained that no cable is installed in the proximity of steam pipes or other hot objects and that cables have not been damaged during the installation from the excessive pulling force, overbending, or sharp or rough edges. Cable penetrations required to be watertight should be checked for proper packing of the penetrator, terminal, or stuffing tube.

Rotating electrical machinery should be checked to ensure that rotating and uninsulated parts are adequately guarded from accidental contact by personnel.

Electrical equipment should be inspected to ensure that it is accessible for normal inspection and routine maintenance. Inspection should ensure that there is provision for accessing junction boxes behind paneling, and that the access is conspicuously identified. Hinged doors of electrical enclosures should be checked to ensure that they are free of interferences from adjacent structure or equipment.

Metal enclosures for electrical equipment should be inspected to ensure they are grounded, either by the method of mounting or by a separate grounding conductor. Portable equipment should be checked to ensure proper grounding through a conductor of the supply cable. Portable equipment such as power tools, that are identified as "double insulated," need not have a grounding connector in the attachment cord. Refer to Clause 11 for equipment grounding methods.

Cable insulation resistance should be measured by self-contained instruments, such as the direct indicating ohmmeter of the generator type, applying a dc potential of 500 V. Where the normal operating voltage is less than 100 V, a direct reading ohmmeter of the appropriate voltage should be used. Where operating voltage is greater than 500 V, the test instrument should apply a dc potential approximately equal to the operating voltage. Where circuits contain solid-state devices, care should be exercised to ensure that the devices that have a voltage rating less than the test voltage are disconnected or shorted out before the test voltage is applied.

Insulation resistance testing of rotating machinery should be performed in accordance with the recommendations in IEEE Std 43-1974, including the corrections for temperature and humidity. The results obtained from the tests depend not only on the characteristics of the insulation materials and the way they are applied but also on the test conditions. The test values obtained should appropriately adjusted for the test conditions at time of test. The Polarization Index (ratio of 10 min to 1 min insulation resistance value) for the machine windings should be determined. The recommended minimum value of Polarization Index for ac and dc machines is 2.0. The resistance should be measured with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltages should be tested separately. This test should be made at a dc voltage of 500 V for a

minimum
1 min. The recommended minimum insulation resistance *Rm* for ac and dc armature windings and for field windings of ac and dc machines can be determined as follows:

$$Rm = \text{kV} + 1$$

where

Rm = recommended minimum insulation resistance in MΩ at 40 °C of the entire machine winding
kV = rated machine terminal to terminal potential, in rms kilovolts

The actual winding insulation resistance to be used for comparison with the recommended minimum value *Rm* is the observed insulation resistance, corrected to 40 °C (104 °F), obtained by applying direct potential to the entire winding for 1 min to obtain the initial value and for 10 min to obtain the value for the polarization index. The minimum insulation resistance of the field windings of machines separately excited, with voltage less than the rated voltage of the machine, should be not less than one MΩ.

38.2 New installations

38.2.1 Circuits

Each power and lighting circuit should be tested for insulation resistance between all insulated poles and ground, and, where practicable, between poles. Each power and lighting circuit should have an insulation resistance between conductors and ground of not less than the following:

Up to 5 A load ....2 MΩ

Up to 10 A load ....1 MΩ

Up to 25 A load ....400 000 Ω

Up to 50 A load ....250 000 Ω

Over 50 A load ....100 000 Ω

If necessary to obtain the desired resistance, appliances may be disconnected from the circuit.

Each interior communication circuit of 115 V and above should have an insulation resistance between conductors and between each conductor and ground of not less than 1 MΩ. For circuits below 115 V, the insulation resistance should be at least 1/3 MΩ. If necessary to obtain the desired resistance, appliances may be disconnected from the circuit.

38.2.2 Generating sets

The commutation, electrical characteristics, overspeed trips, governing, range of excitation control, lubrication, and absence of vibration should be satisfactorily demonstrated. Tests should be made to demonstrate compliance with 5.6 and 5.7. Each generating set should be run at full rated (kW) load until constant temperature has been reached and in no case for less than 4 h. If generating sets are intended to operate in parallel, they should be tested in all combinations over a range of loading sufficient to demonstrate that load sharing and parallel operation are satisfactory. Voltage and speed regulation, when load is suddenly applied and removed, should comply with 5.6 and 5.9. The insulation resistance of all generators should be measured both in the cold condition and in the hot condition immediately before and after running at normal full load. Automatic, local, and remote starting and stopping systems should be tested.

38.2.3 Switchboards

Before switchboards, motor control centers, and distribution panels are put into service, they should be tested to ensure the insulation resistance is not less than 1 MΩ when measured between each bus-bar and ground and between each bus-bar. This test shall be made with all circuit breakers and switches open, all fuses for pilot lamps, ground indicating lamps, voltmeters, etc., removed and all voltage coils disconnected. All switches, circuit breakers, and associated equipment should be operated to demonstrate suitability and compliance with recommendations in Clause 7 (except for short-circuit withstand, circuit-breaker-interrupting rating, and instantaneous trip settings).

All switchboards should be fully loaded (or as close as practicable) and no overheating should occur.

Reverse power relays, reverse current and overcurrent relays, preferential tripping relays, and all electrical and electromechanical interlocks should be satisfactorily operated. Generator, bus tie, and main propulsion feeder circuit breakers should be test-tripped to ensure that adjustable settings comply with the system design values.

Switchboards should be checked for handrails, guardrails, insulating floor covering, drip covers, and backs and sides on the enclosure. Adequate working space around the switchboard should be verified. Switchboard-mounted apparatus should be checked for identifying nameplates. Circuit nameplates should be compared with the rating or setting of the overcurrent devices and with the plans. The accessibility of items requiring maintenance or adjustment should be checked. Meters should be checked for proper operation. The operation of automatic paralleling devices and mechanical and electrical interlocks should be observed.

38.2.4 Motors and controllers

Each motor and all associated control equipment should be run under operating conditions for a sufficient length of time to demonstrate correct alignment, wiring, capacity, speed, and satisfactory operation. Motors driving pumps, ventilation fans, and similar loads should be operated as nearly as practicable under their individual service conditions. Motors driving cargo winches should hoist and lower their specified loads. Motors for which it is difficult to obtain actual operating loads, such as motors driving warping capstans, machine tools, and other similar load characteristics, should be run to demonstrate suitability.

Motor controllers should be checked to ensure proper starting of the motor under service conditions and that properly rated overcurrent devices are installed. Each motor starter not completely disconnected from all sources of potential when the disconnect switch is opened (due to electrically interlocked circuits necessary for proper operation of the apparatus or for other valid reasons) should be checked to ensure that attention is directed to such conditions by a suitable warning label.

The remote control units for stopping ventilation fans, oil pumps, and pumps discharging overboard in way of survival craft should be satisfactorily operated.

38.2.5 Lighting

Circuits should be tested to ensure that all lighting fixtures, receptacles, and other connected fittings are in satisfactory operating condition. A photometric survey should be conducted to ensure that illumination levels are satisfactory and meet the specified requirements.

38.2.6 Communication systems

Each interior communications system and alarm system should be tested to verify that they perform their required function. Particular attention should be paid to testing all essential electrical communication systems including electric engine order telegraphs, electric docking telegraphs, automatic fire alarm and detection systems, general announcing and public address systems, the general emergency alarm system, sound-powered telephone systems, and dial telephone systems.

38.2.7 Steering system

The operation of electric and electrohydraulic steering gear and associated steering controls should be tested. Particular attention should be paid to the motor overload alarm, motor stopped indication, and supply circuit-breaker tripped alarm.

38.2.8 Control systems

All propulsion, auxiliary machinery, and electric plant control and safety systems installed to comply with the requirements for an automated machinery system or a periodically unattended machinery space should be checked for correct installation and material condition and be performance-tested to verify satisfactory operation.

38.2.9 Emergency electrical systems

The complete emergency electrical supply and distribution system should be tested to verify proper performance. This should include the following tests (where applicable):

- Operation of the emergency generator automatic starting system
- Operation of the transitional emergency battery automatic transfer system
- Capacity test of the emergency storage battery
- Operation of the emergency lighting system
- Operation of emergency power driven equipment

38.2.10 Storage batteries

Storage batteries used for ship service diesel generator set starting and main propulsion diesel engine starting should be checked for capacity. The batteries should have sufficient capacity (without recourse to charging) to provide not less than 12 consecutive starts of each main engine, if of the reversible type, and not less than six consecutive starts if of the nonreversible type. For ship service diesel generator sets, battery capacity should provide not less than six consecutive starts.

Emergency diesel generator set batteries should be checked to ensure that they have sufficient capacity to provide three consecutive starts from each energy source within 30 min.

38.2.11 Electric heating systems

Electric heating and reheat systems should be checked for proper functioning. Overheat cut-outs should be checked for proper operation and temperature rating. Electrical connections should be checked to ensure that they are tight. The interior of reheat boxes should be checked to ensure that they are free from excessive amounts of combustible dust.

38.2.12 Voltage drop

One lighting circuit from each distribution panel and switchboard should be selected for voltage drop testing. With all lamps burning and all other permanently connected loads on that circuit operating, the current in the feeder and the voltage at the most remote branch outlet should be measured. The voltage drop in these circuits should meet the recommendations of 11.6. If the voltage drop on this sample circuit does not meet the recommendations, all lighting circuits should be tested, and corrective action taken.

For power circuits, the voltage drop in branch circuits fed from distribution panels should be measured. Equipment should be loaded to approximately full rating, and voltage drop should be determined by measuring the current in the circuit and the voltage at the device’s terminals. For auxiliaries fed from switchboards, the voltage drop and feeder current should be measured at the maximum load imposed during scheduled dockside tests. Voltage measurement should be made at the motor output terminals of the motor controller.

The voltage at the generator switchboard should be maintained at rated value. Voltage drop should not exceed the recommended values.

38.3 Existing installations

Electric equipment and systems should be continually maintained to ensure that the installation is kept as close as practicable to the original physical condition. Insulation maintenance for rotating electrical machinery should be conducted in accordance with IEEE Std 432-1992. Electrical equipment and systems should be periodically inspected and tested for the purpose of observing the possible development of physical changes or deterioration. These inspections and tests, at the intervals required by classification societies or national authorities, should include the following items:

a) The equipment and installation should be generally inspected and tested under working conditions and electric cables inspected as far as practicable without dismantling equipment.
b) Generators and all motors driving essential auxiliary machinery should be inspected as far as may be practicable without dismantling equipment unless such dismantling is deemed necessary as a result of test or observation.
c) An insulation resistance test should be made on generators, motors, cables, heaters, and fittings using a direct indicating ohmmeter of the generator type, applying a dc voltage of 500 V; the insulation resistance measured should not be less than the values given in 38.1.
d) All generators should be run individually or simultaneously and all main switches and circuit breakers operated under load and their reverse power, overcurrent, undervoltage, and underfrequency trip circuits tested.
e) The functioning of the complete emergency electrical supply system should be tested. This should include the following:
    - Operation of the emergency generator automatic starting system
    - Operation of the transitional emergency battery automatic transfer system
    - Where the emergency source of power is supplied by batteries, operation under the specified load conditions
    - Operation of the emergency lighting system
f) All essential electrical communication systems should be tested to verify proper operation.
g) Where the control of the propulsion machinery or the propeller is provided by electric or electronic means, a general inspection of the complete control system should be conducted.
h) The operation of electric and electrohydraulic steering gear should be tested. Particular attention should be paid to the functioning of the motor overload alarm, motor stopped indication, and supply circuit-breaker tripped alarm.

It is further recommended that, in addition to required inspections, periodic measurements of resistance of the insulation be made between conductors and the frame or ground of rotating equipment and in circuits between conductors and between conductors and ground. The value of insulation resistance will afford a useful indication as to whether or not the equipment or system is in a suitable condition for continued service. This data can be used to detect deterioration conditions and to allow for corrective action prior to equipment or system failure.

The best indication of the magnitude of current leakage from a winding or circuit is given by a comparison of the observed insulation resistance with previously measured values. The change from the last measured value of resistance is far more significant than the absolute value of the resistance. It is recommended that a log of successive readings be kept for each important machine and circuit on board ship. In addition, remarks should be entered into the log to describe properly the observed condition of the machine and circuit for future comparison. Log entries should typically include the following:

— For machines: Supply cable connected or disconnected; machine blown out, machine dried out, dusty, oily or wet; condition of connecting leads, brush rigging, brushes, commutator; clearances between pole pieces and armature; temperature; humidity; repairs made.
— For circuits: Equipment and appliances connected or disconnected to the supply cables; cable and connection boxes dirty, oily or wet; condition of connected equipment and appliances; temperature; humidity; repairs made.

Any large and abrupt decrease in insulation resistance should be investigated immediately. The insulation resistance is subject to variation with temperature, humidity, and cleanliness of parts. When the insulation resistance falls, it can, in most cases when no defect or ground exists, be brought up to a proper value by cleaning and drying. The insulation resistance of rotating machines can generally be improved by cleaning in accordance with IEEE Std 432-1992. It is difficult to prescribe definite recommendations for the actual value of insulation resistance of a machine or circuit since their values vary with type, size, voltage rating, kind and condition of insulating material used, method of construction, and the insulation record of the machine and circuit. Considerable judgment based upon the results of previous measurements should be exercised to determine whether or not the machine or circuit is suitable for continued service or should be repaired or replaced.

The frequency of periodic inspections and insulation resistance tests is dependent upon the magnitude and importance of the electric installation on board the vessel as well as the service and climatic conditions to which such installations are subjected.

The use of logs or records covering these recommendations, which will also show other pertinent information contingent on the vessel's individual service conditions, is recommended.

Annex A

(informative)

General information on hazardous location classification and equipment

This informative annex is intended to provide basic hazardous location information and a comparison of the traditional requirements of the National Electrical Code (NEC) (ANSI/NFPA 70-1996), as addressed in articles 500 through 504, to the standards, techniques and practices outlined in the standards of the International Electrotechnical Commission (IEC). The IEC approach can also be found in the 1996 edition of the NEC, article 505.

The International Electrotechnical Commission consists of the National Committees of over 40 participating countries, and it cooperates in international standardization with organizations like the International Standards Organization (ISO) and the IEEE. Today, IEC member nations represent more than 80% of the global population and more than 95% of the consumers of the world's electrical energy.

The IEC has developed hazardous location standards that have been adopted in many countries. These standards are largely based upon European practice. United States and Canadian standards are similar but have evolved separately based upon the requirements of the (U.S.) National Electrical Code and the Canadian Electrical Code (CEC). The IEC's standards for hazardous location equipment and installations represent only one area of their concern in a wide array of electrical issues.

While NEC/CEC and IEC requirements are similar in certain respects, the differences are significant enough to not permit interchangeability of components in many instances. The appropriate regulatory bodies and classification societies should be consulted to determine the acceptability of any hazardous location electrical equipment or system.

A.1 IEC (and NEC article 505) and NEC (articles 500 to 504)

Both the IEC and the NEC/CEC classification schemes define the hazard that is present and likelihood that the hazard will be present.

The traditional NEC approach uses a system of three classes to define the hazard:

- Class I: Flammable gases
- Class II: Combustible dusts
- Class III: Ignitable fibers or flyings

The NEC identifies Class I "groups" based upon the characteristics of the gas of vapor that may be present, including maximum experimental spark gap (MESG), explosion pressure, and ignition temperature. A Group A gas is the easiest to ignite, and a Group D gas the most difficult. Gases are grouped as follows (other gases with similar characteristics are included in the same group):

- Group A: Acetylene
- Group B: Hydrogen
- Group C: Ethylene
- Group D: Propane

The IEC classification uses two main group designations:

— Group I: Mining
— Group II: Surface industries (including offshore)

Group II contains subgroups A, B, and C. Similar to the NEC, the subgroups represent the different categories of flammable gases and vapors based on their MESG, explosion pressure, and ignition temperature. “A” represents the most difficult to ignite, “C” the easiest, as shown below.

— Group IIC: Acetylene/Hydrogen
— Group IIB: Ethylene
— Group IIA: Propane

To represent the likelihood of the hazard being present, the NEC uses two location classifications based upon the hazard probabilities during normal and abnormal operations:

— Division 1: Locations where material can exist under normal operating conditions, or frequently because of repair, maintenance, or leakage.
— Division 2: Locations where material can exist under abnormal conditions (accidental rupture, breakdown, abnormal operations, etc.), or locations adjacent to a Division 1 location where material may occasionally be present.

Although not described in NEC (articles 500 through 504) location classifications, a third hazardous location classification has traditionally existed on tank vessels that is comparable to the IEC Zone 0 location. In this location (e.g., cargo tanks and cargo pumprooms) North American regulatory bodies have electrical equipment requirements that are more stringent than those for Division 1 locations.

The IEC uses a three “Zone” method of hazardous location classification:

— Zone 0: Explosive gas (vapor)/air mixture is always present or present for extended periods during normal operations. (Zone 0 is a location were explosive vapors are continually present, such as the air space in a closed tank containing a flammable liquid.)
— Zone 1: An explosive gas/air mixture is likely to occur in normal operation.
— Zone 2: An explosive gas/air mixture is not likely to occur in normal operation and, if it occurs, only exists for a short time.

To address the hazards associated with combustible dust, the IEC uses the designations:

— Zone 10: An explosive dust atmosphere is present continuously or for extended periods of time.
— Zone 11: An explosive dust atmosphere may exist for a short period of time due to unsettled dust layers.

The groups and classes/zones are compared in Table A.1.

Table A.1—Groups and class/zones comparisons approximate

IEC	NEC
Group I	Gaseous mines
Group II-A	Group I, Group D
Group II-B	Class I, Group C
Group II-C	Class I, Groups A and B
Zone 0	Division 1
Zone 1	Division 1
Zone 2	Division 2
Zone 10	Class II, Division 1
Zone 11	Class II, Division 2

A.2. Hazardous location equipment

The methods of protection for traditional electrical installations in NEC Division 1 and Division 2 hazardous locations are: explosionproof enclosures, intrinsically safety apparatus, purged/pressurized systems, and nonincendive devices (Division 2 only).

For Zone 1 and Zone 2 locations, the IEC permits flameproof (similar to NEC explosionproof) enclosures, intrinsically safe apparatus (types i_a and i_b; i_a intrinsically safe apparatus is the only electrical equipment permitted in a Zone 0 location) and purged/pressurized enclosures. The IEC also recognizes the following Zone 1 and Zone 2 protection techniques: increased safety, encapsulation, special protection, sand/powder filling, and oil filling.

The information below refers to only to NEC articles 500 through 504, which reflect traditional North American practice. It does not reflect the installations in accordance with the recently approved article 505, which is based upon the IEC zone concept of classification.

A.2.1 Explosionproof/flameproof enclosures

Explosionproof/flameproof equipment is designed and constructed to contain an explosion that occurs within the enclosure. Mated surfaces are fashioned with a flame path (threaded connections or machined surfaces) to ensure that the hot gases escaping the enclosure as a result of an internal explosion are sufficiently “cooled” to prevent ignition of the surrounding atmosphere. The fundamental difference between NEC explosionproof and IEC flameproof equipment is the dimensional differences of flame path and surface gaps “MESG.” The smaller values established for MESGs in explosionproof enclosures take “pressure piling” (pressure increases in the enclosure due to the ignition of turbulent mixtures and the enclosure being connected to a rigid conduit) into account and are based on slightly different test conditions.

A.2.2 Intrinsic safety (IS) apparatus

By limiting the amount of energy in a given circuit to a value below the minimum energy required to cause the ignition of a specific explosive atmosphere, a circuit is considered to be intrinsically safe. Because of their low power ratings, intrinsically safe circuits are typically limited to instrumentation circuits. Two ratings are given to IS circuits, i_a and i_b. Of the two protections, the NEC (in article 504) recognizes only i_a intrinsically safe circuits for Division 1 and 2 locations (the IEC recognizes type i_a for Zone 0, Zone 1, and Zone 2 applications, and i_b for

Zone 1 and 2 applications). IS i_a circuits are tested with a two-fault criteria applied. IS i_b circuits are tested with a single-fault criteria applied.

A.2.3 Purged/pressurized systems

Purged/pressurized systems pressurize the atmosphere within an enclosure with a nonhazardous gas, typically air, supplied from a nonhazardous location. This action prevents a hazardous atmosphere from coming in contact with the electrical equipment within the enclosure. The NEC recognizes two types of system purging for Class I, Division 1 location. Type X purging reduces the classification from Class I, Division 1 to nonhazardous, and type Y reduces the classification from Class I, Division 1 to Class I, Division 2. In the event of loss of pressure within a type X purged enclosure, power must be automatically disconnected from the electrical equipment. However, an alarm must be provided warning of the pressure loss. Type Y purging does not require the disconnection of power upon loss of pressure. The IEC requirements are similar to those of the NEC. However, purged/pressurized systems are limited to Zone 1 and Zone 2 locations only.

A.2.4 Increased safety

This method of protection is not recognized in articles 500 through 504 of the NEC. By applying additional design factors to normally non-arcing or sparking equipment, such as increased creepage distances between live parts and high-integrity insulating materials, increased safety equipment prevents the ignition of surrounding vapors by preventing hot spots. The IEC permits increased safety equipment in Zone 1 and Zone 2 locations.

A.2.5 Encapsulation

This type of protection is not recognized in articles 500 through 504 of the NEC. By the encapsulation of small electrical components in resins or similar materials, components are effectively isolated from the surrounding atmosphere. The encapsulated component is then tested under fault conditions that assure that the surface temperature does not rise above its given “T” rating. The IEC permits encapsulation for Zone 1 and Zone 2 applications.

A.2.6 Sand/oil filled

This type of protection is not recognized in articles 500 through 504 of the NEC. This protection technique is very similar to encapsulation type protection. The IEC permits sand/oil filled components for Zone 1 and Zone 2 applications.

A.2.7 Special protection

The NEC does not recognize special protection in articles 500 through 504. Special protection recognizes certification of approval by a responsible agency after thorough review and testing of apparatus and equipment that does not comply with any of the recognized protection methods. This method of protection is typically applied to Zone 1 equipment.

A.2.8 IEC protection technique designations

IEC equipment designations are provided in Table A.2.

Table A.2—IEC protection technique designations

Letter	Protection technique
d	Flameproof: similar to explosionproof
e	Increased safety
i_a	Intrinsic safe for Zones 0, 1, and 2: similar to two-fault criteria used in North America
i_b	Intrinsic safety for Zones 1 and 2: one-fault criteria not generally accepted in North America
m	Encapsulation: not generally accepted in North America
n	Nonsparking: for Zone 2 use only
o	Oil immersion: not generally accepted in North America
p	Pressurization: similar to North America purged and pressurized technique
q	Sand filling: not generally accepted in North America
s	Special protection: nonstandard techniques or combinations of techniques (not generally accepted in North America)

A.3 IEC/NEC temperature codes

The equipment temperature code shows the maximum surface temperature of the apparatus, based on a 40 °C (104 °F) ambient. An actual temperature number may be listed in lieu of, or in addition to, one of the "T-codes" listed in Table A.3.

Table A.3—IEC/NEC temperature codes

IEC Temperature code	Max. surface temperature	NEC temperature Code
T1	450 °C	T1
T2	300 °C	T2
280 T2	280 °C	T2-A
260 T2	260 °C	T2-B
230 T2	230 °C	T2-C
215 T2	215 °C	T2-D
T3	200 °C	T3
180 T3	180 °C	T3-A
165 T3	165 °C	T3-B
160 T3	160 °C	T3-C
T4	135 °C	T4
120 T4	120 °C	T4-A
T5	100 °C	T5
T6	85 °C	T6

A.4. IEC ingress protection codes

While not a direct part of the hazardous location certification, the ingress protection code is typically provided as part of the equipment hazardous locations marking. This code is very useful in determining the equipment's suitability for marine use. Enclosures are certified using the two-digit ingress protection (IP) codes defined in IEC 60529: 1989. The first number describes the level of protection against solid object entry and the second number indicates the level of protection against liquid entry, as shown in Table A.4.

Table A.4—IEC ingress protection codes

First digit	Definition	Second digit	Definition
0	no protection	0	no protection
1	objects > 50 mm	1	vertically dripping water
2	objects > 12 mm	2	75–90 angled diving water
3	objects > 2.5 mm	3	sprayed water (60 from vertical)
4	objects > 1.0 mm	4	splashed rules
5	dust protected	5	water jets
6	dusttight	6	heavy seas
		7	effects of immersion
		8	indefinite immersion

A.5 IEC hazardous location equipment designations

The IEC equipment designation consists of six parts:

a) The symbol **Ex**, the IEC designation for electrical apparatus suitable for use in explosive atmospheres. **EEx** is the old symbol for apparatus certified to meet the CENELEC (harmonized European Community) standards for electrical equipment in hazardous areas. The letters “**Ex**” in Greek script (epsilon chi, **Ex**) within a hexagon form the new CENELEC symbol.
b) A lowercase letter (or letters), identifying the protection technique(s) employed to make the apparatus safe for use in hazardous areas. Where multiple protection techniques are used, several letters may appear.
c) A Roman numeral for gas or vapor hazards that shows the intended application of the apparatus:
   1) I: Below ground mining.
   2) II: Above ground installations. This designation includes shipboard installations.
d) For Group II apparatus, an uppercase letter that identifies a gas as representative of the flammability properties of the relevant gas group.
e) The temperature code “T” rating.
f) The ingress protection provided by the equipment.

Example: “EEx d IIC T4 IP56” on a lighting fixture can be interpreted as follows:

EEx Certified to meet CENELEC standards for hazardous areas
d Protection by flameproof enclosure, for Zones 1 and 2
II Intended for above-ground application
C For gas groups represented by hydrogen and acetylene
T4 Maximum surface temperature limit of 135
IP56 Protected against dirt, dust, and heavy seas

A.6. IEC reference standards

The following is a list of standards and requirements for IEC hazardous locations equipment and installations (as of August 1998):

IEC 60079-0: 1998, Electrical apparatus for explosive gas atmospheres—Part 0: General requirements.

IEC 60079-1: 1990, Electrical apparatus for explosive gas atmospheres— Part 1: Construction and verification test of flameproof enclosures of electrical apparatus (Amendment 1: 1993 and Amendment 2: 1998).

IEC 60079-2: 1983, Electrical aparatus for explosive gas atmospheres—Part 2: Electrical apparatus—Type of protection “p.”

IEC 60079-3: 1990, Electrical apparatus for explosive gas atmospheres—Part 3: Spark test apparatus for intrinsically-safe circuits.

IEC 60079-4: 1975, Electrical apparatus for explosive gas atmospheres—Part 4: Method of test for ignition temperature (Amendment 1: 1995 and IEC 60079-4A: 1970, First supplement).

IEC 60079-5: 1997, Electrical apparatus for explosive gas atmospheres—Part 5: Powder filling “q.”

IEC 60079-6: 1995, Electrical apparatus for explosive gas atmospheres—Part 6: Oil-immersion “o.”

IEC 60079-7: 1990, Electrical apparatus for explosive gas atmospheres—Part 7: Increased safety “e” (Consolidated edition incorporating Amendment 1: 1991 and Amendment 2: 1993).

IEC 60079-10: 1995, Electrical apparatus for explosive gas atmospheres—Part 10: Classification of hazardous areas.

IEC 60079-11: 1991, Electrical apparatus for explosive gas atmospheres—Part 11: Intrinsic safety “i.”

IEC 60079-12: 1978, Electrical apparatus for explosive gas atmospheres—Part 12: Classification of mixtures of gases or vapours with air according to their maximum experimental safe gaps and minimum igniting currents.

IEC 60079-13: 1982, Electrical apparatus for explosive gas atmospheres—Part 13: Construction and use of rooms or buildings protected by pressurization.

IEC 60079-14: 1996, Electrical apparatus for explosive gas atmospheres—Part 14: Electrical installations in hazardous areas (other than mines).

IEC 60079-15: 1987, Electrical apparatus for explosive gas atmospheres—Part 15: Electrical apparatus with type of protection “n.”

IEC 60079-16: 1990, Electrical apparatus for explosive gas atmospheres—Part 16: Artificial ventilation for the protection of analyser(s).

IEC 60079-17: 1996, Electrical apparatus for explosive gas atmospheres—Part 17: Recommendations for inspection and maintenance of electrical installations in hazardous areas (other than mines).

IEC 60079-18: 1992, Electrical apparatus for explosive gas atmospheres—Part 18: Encapsulation “m.”

IEC 60079-19: 1993, Electrical apparatus for explosive gas atmospheres—Part 19: Repair and overhaul for apparatus used in explosive atmospheres (other than mines or explosives).

IEC 60529: 1989, Degrees of protection provided by enclosures (IP code).

IEC 60654-1: 1993, Industrial-process measurement and control equipment—Operating conditions—Part 1: Climatic conditions.

IEC 60947-1: 1996, Low voltage switchgear and controlgear—Part 1: General rules (Amendment 1 : 1997 and Amendment 2: 1998).

Annex B

(informative)

Circuit designations

All electrical circuits, including those for power, lighting, interior communications, control, and electronics, are typically identified in the appropriate documentation and on equipment labeling, such as nameplates, cable tags, wire markers, etc., by a traditional system designation. These designations use a designation prefix, as follows:

Type	Designation Prefix
Cathodic protection	CPS
Control	K
Degaussing	D
Electronics	R
Emergency lighting	EL
Emergency power	EP
Interior communication	C
Lighting	L
Propulsion power	PP
Ship service power	P
Shore power	SP
Special frequency power	SFP

The following list of systems and system designations should be used, and may be modified to suit particular applications:

System	Designation
Announcing—Docking	C-8MC
Announcing—General	C-1MC
Announcing—Integrated	C-MC
Announcing—Loudhailer	C-6MC
Announcing—Talk Back	C-9MC

Auxiliary Machinery Remote Control	K-AC
Boiler Combustion Control	K-SX
Boiler Water Level Alarm	C-1TD
Boiler Water Level Control	K-BL
Call Bells	C-A
Central Alarm and Monitoring	C-AM
CO_2 Release Alarm	C-CO
Cooling Water High Temperature Alarm	C-EW
Echo Depth Sounder	R-SS
Electric Clocks	C-CE
Electric Door Control (other than for watertight doors)	C-DE
Electric Plant Control and Monitoring	K-EC
Emergency Generator Set Control and Indication	K-EG
Engine Order Telegraph	C-MB
Feed Water Low Level Alarm	C-2TD
Fire Detection and Alarm	C-F
Fire Door Release	C-FR
Flooding Alarm	C-FD
Fog Alarm	C-FB
Fuel Oil Filling Alarm	C-3TD
Fuel Oil Tank High-Level Alarm	C-4TD
General Alarm	C-G
Gyro Compass	C-LC
Helm Angle Indicator	C-LH
Hospital and Nursing Call	C-AN
Integrated Navigation	C-IN
Lubricating Oil Low-Level Alarm	C-EL

Lubricating Oil Low-Pressure Alarm	C-EC
Main Generator Set Local Control and Indication	K-PG
Propulsion Diesel Local Control and Indication	K-PD
Propulsion Motor Local Control and Indication	K-PM
Propulsion System Remote Control	K-PC
Propulsion Turbine Local Control and Indication	K-PT
Pyrometer	C-PB
Radar, Navigation	R-RN
Radio Antenna	R-RA
Radio Direction Finder	R-RD
Radio GMDSS	R-GA
Radio Receiver	R-RR
Radio Receiving Antenna Distribution	R-RB
Radio Receiving Entertainment Distribution	R-RE
Radio Satellite Communication	R-RS
Radio Transceiver	R-RQ
Radio Transmitter	R-RT
Refrigerator Alarm Cargo	C-RH
Refrigerator Alarm Ship Stores	C-RA
Resistance Temperature Indication	C-FT
Rudder Angle Indicator	C-N
Salinity Indicator	C-SB
Security Alarm	C-FZ
Sewage Tank High-Level Alarm	C-5TD
Shaft Revolution Indication	C-K
Ship Service Generator Local Control and Indication	K-SG
Smoke Indicator	C-SM

Sprinkler Alarm	C-FS
Steering Control	C-L
Steering Gear Alarm	C-LA
Tank Level Alarm	C-TD
Tank Level Indicator	C-TK
Telephone—Automatic Dial	C-J
Telephone—Sound Powered—Call	C-E
Telephone—Sound Powered—Cargo and Ballast Control	C-6JV
Telephone—Sound Powered—Damage Control	C-JZ
Telephone—Sound powered—Engineers (Electrical)	C-5JV
Telephone—Sound Powered—Engineers (Fueling)	C-3JV
Telephone—Sound Powered—Engineers (Machinery Control)	C-2JV
Telephone—Sound Powered—Engineers (Maintenance)	C-4JV
Telephone—Sound Powered—Miscellaneous	C-7JV
Telephone—Sound Powered—Ship Control and Maneuvering	C-1JV
Television—Closed Circuit	R-TC
Television—Entertainment	R-TV
Television—Monitoring	R-TM
Underwater Log	C-Y
Watertight Door Control	C-WD
Wet and Dry Bulb Temperature Indication	C-T
Whistle Operator	C-W
Wind Direction Indicator	C-HD
Wind Intensity Indicator	C-HE