

IEEE Recommended Practice for Electrical Installations on Shipboard— Design

IEEE Industry Applications Society

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3 Park Avenue
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USA

IEEE Std 45.1™-2017

IEEE Recommended Practice for Electrical Installations on Shipboard— Design

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Petroleum & Chemical Industry Committee
of the
IEEE Industry Applications Society

Approved 23 March 2017

IEEE-SA Standards Board

Recognized as an American National Standard

Abstract: Recommendations for the design of electrical power generation, distribution, propulsion, loads systems, and equipment on merchant, commercial, and naval vessels are covered in this document.

Keywords: IEEE 45.1™, marine electrical engineering, marine vessels, naval vessels, ship, shipboard electrical systems

The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 978-1-5044-4142-1 STD22656
Print: ISBN 978-1-5044-4143-8 STDPD22656

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Introduction

This introduction is not part of IEEE Std 45.1-2017, IEEE Recommended Practice for Electrical Installations on Shipboard—Design.

The IEEE Std 45™ series comprises nine recommended practices addressing electrical installations on ships and marine platforms. IEEE Std 45.1 provides recommended practice for design recommendations for ac power systems, dc power systems, emergency power systems, shore power, power quality and harmonics, electric propulsion and maneuvering systems, motors and drives, thrusters, and steering systems installed shipboard and is intended for use with the IEEE Std 45 series of documents. The topics covered in this document should be considered from the beginning of the project and throughout the design and construction processes, and thereby should facilitate the integration of electrical systems at the shipyard level. Adherence to the IEEE 45.1 design process provides an effective set of integration requirements and identifies key issues and recommended solutions or options.

Previous editions of IEEE Std 45 were developed as single documents addressing all areas. On 9 June 2005, PAR 45 for the Revision of IEEE Std 45-2002 was approved and the revision of IEEE Std 45 as a single document began. It soon became apparent that attempting to cover all issues in a single document would produce a document that was very large and, therefore, difficult to ballot due to the wide range of issues needing to be addressed. In September 2008 it was decided that the revision of IEEE Std 45™ should be developed as a base document with separate documents addressing specific areas.

On 10 December 2008 separate Project Authorization Requests (PARs) were approved for seven separate recommended practices. Additional PARs were approved on 11 September 2009 for Switchboards and 9 December 2009 for Cable Systems bringing the total number of standards in the IEEE Std 45 series to nine, including:

- IEEE Std 45™, IEEE Recommended Practice for Electrical Installations on Shipboard
- IEEE Std 45.1™-2016, IEEE Recommended Practice for Electrical Installations on Shipboard—Design
- IEEE Std 45.2™-2011, IEEE Recommended Practice for Electrical Installations on Shipboard—Controls and Automation
- IEEE Std 45.3™-2015, IEEE Recommended Practice for Shipboard Electrical Installations—Systems Engineering
- IEEE P45.4™, Recommended Practice for Electrical Installations on Shipboard—Marine Sectors and Mission Systems
- IEEE Std 45.5™-2014, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations
- IEEE Std 45.6™-2016, IEEE Recommended Practice for Electrical Installations on Shipboard—Electrical Testing
- IEEE Std 45.7™-2012, IEEE Recommended Practice for Electrical Installations on Shipboard—AC Switchboards
- IEEE Std 45.8™-2016, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems

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IEEE Recommended Practice for Electrical Installations on Shipboard—Design

1. Overview

1.1 Introduction

These recommendations establish the minimally acceptable guidelines for the design, selection, and installation of systems and equipment aboard both Navy combatant and commercial marine vessels applying electrical apparatus for power, propulsion, steering, automation, navigation, lighting, and communications. These recommendations describe present-day acceptable marine electrical engineering methods and practices. The primary focus of these IEEE Std 45.1™ guidelines is overall electrical power system and subsystem design. Guidelines for some key electrical power system components (including electrical power switchboards, cable systems, and control systems), safety considerations, and system testing are discussed elsewhere in this IEEE Std 45™ series, which comprises nine recommended practices addressing electrical installations on ships and marine platforms.

It is recognized that changes and improvements in shipboard requirements may develop that are not specifically covered herein; such changes, if incorporated in the design, should be equal to the safety and reliability levels established herein and generally in accord with the intent of these standards.

In developing these recommendations, consideration was given to the electrical and engineering requirements promulgated by various regulatory agencies, classification societies, and by the International Maritime Organization's International Convention for the Safety of Life at Sea (IMO SOLAS), as amended.

This recommended practice was developed by a voluntary consensus body to provide assistance and guidance to regulatory agencies governing electrical engineering requirements.

1.2 Scope

The recommendations for electrical power generation, distribution, and electric propulsion system design for use on shipboard are established by this document. These recommendations reflect the present-day technologies, engineering methods, and engineering practices.

This document is intended to be used in conjunction with the IEEE Std 45 series.

1.3 Purpose

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

1.4 Application of various national and international standards

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

Special precautions must be exercised when mixing equipment designed to different national and international standards. Coordination of different equipment design and testing standards, construction ratings, installation methods, and performance must be carefully analyzed.

1.5 Equipment construction, testing, and certification

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

2. Normative references

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

ANSI C63.12™, American National Standard Recommended Practice for Electromagnetic Compatibility Limits and Test Levels.¹

ANSI/EIA 709, Control Network Protocol Specification.²

ANSI/ISA 60079-0, Explosive Atmospheres—Part 0: Equipment—General Requirements.

ANSI/NEMA MG 1, Motors and Generators.³

API RP 14F, Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1 and Division 2 Locations.⁴

¹ ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

² EIA publications are available from the U.S. Energy Information Administration (<http://www.eia.gov/>).

³ NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

⁴ API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA (<http://www.api.org/>).

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

API RP 500, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2.

API RP 505, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2.

ASTM B117, Standard Practice for Operating Salt Spray (FOG) Apparatus.⁵

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

ASTM F1003, Standard Specification for Searchlights on Motor Lifeboats.

ETSI EN 300 132-3-1, Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V; Sub-part 1: Direct current source up to 400 V.^{6, 7}

IACS UR M59, Control and Safety Systems for Dual Fuel Diesel Engines.⁸

IEC 60034, Rotating electrical machinery.⁹

IEC 60038, IEC standard voltages.

IEC 60076-1, Power transformers—Part 1: General.

IEC 60092 Series, Electrical installations in ships.

IEC 60146 Series, Semiconductor converters.

IEC 60726, Dry-type power transformers.

IEC 60947-6-1, Low voltage switchgear and controlgear—Part 6-1: Multiple function equipment—Transfer switching equipment.

IEC 61000 Series, Electromagnetic compatibility (EMC).

IEC/IEEE 60079-30-1, Explosive atmospheres—Part 30-1: Electrical resistance trace heating—General and testing requirements.

IEC/ISO/IEEE 80005-1, Utility connections in port—Part 1: High Voltage Shore Connection (HVSC) Systems—General requirements.¹⁰

IEEE Std C50™ Series, Standards for large steam and combustion turbine generators.^{11, 12}

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IEEE Std C57™, Series on transformers.

IEEE Std C57.12.00™, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.90™, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std 45.2™, IEEE Recommended Practice for Electrical Installations on Shipboard—Controls and Automation.

IEEE Std 45.3™, IEEE Recommended Practice for Shipboard Electrical Installations—Systems Engineering.

IEEE Std 45.5™, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations.

IEEE Std 45.7™, IEEE Recommended Practice for Electrical Installations on Shipboard—AC Switchboards.

IEEE Std 45.8™, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems.

IEEE Std 142™, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

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

IEEE Std 444™, Standard Practices and Requirements for Thyristor Converters for Motor Drives, Part 1—Converters for DC Motor Armature Supplies.

IEEE Std 519™, IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems.

IEEE Std 802.3™, IEEE Standard for Ethernet.

IEEE Std 841™, IEEE Standard for Petroleum and Chemical Industry—Premium-Efficiency, Severe-Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 kW (500 hp).

IEEE Std 1100™, IEEE Recommended Practice for Powering and Grounding Electronic Equipment.

IEEE Std 1566™, IEEE Standard for Performance of Adjustable-Speed AC Drives Rated 375 kW and Larger.

IEEE Std 1584™, IEEE Guide for Performing Arc Flash Hazard Calculations.

IEEE Std 1662™, IEEE Guide for the Design and Application of Power Electronics in Electrical Power Systems on Ships.

¹² IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

IEEE Std 1709™, IEEE Recommended Practice for 1 kV to 35 kV Medium-Voltage DC Power Systems on Ships.

IEEE Std 1815™, IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3).

IEEE Std 1826™, IEEE Standard for Power Electronics Open System Interfaces in Zonal Electrical Distribution Systems Rated Above 100 kW.

IEEE Std 3003.2™, IEEE Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems.

IEEE Std 15288.1™, IEEE Standard for Application of Systems Engineering on Defense Programs.

ISA TR12.24.01 (IEC 79-10 Mod), Recommended Practice for Classification of Locations for Electrical Installations Classified as Class I, Zone 0, Zone 1, or Zone 2.¹³

MIL-STD-461E-1999, Department of Defense Interface Standard: Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.¹⁴

MIL-STD-704F, Department of Defense Interface Standard: Aircraft Electric Power Characteristics.

MIL-STD-1399-300B, Department of Defense Interface Standard: Section 300b, Electric Power, Alternating Current.

MIL-STD-1399-680, Department of Defense Interface Standard: Section 680, High Voltage Electric Power, Alternating Current.

NFPA 70, National Electrical Code® (NEC®).^{15, 16}

NFPA 70E, Standard for Electrical Safety in the Workplace.®

NFPA 77, Recommended Practice on Static Electricity.

NFPA 780, Standard for the Installation of Lightning Protection Systems.

SOLAS Consolidated Edition, 1997, Consolidated text of the International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1978: articles, annex and certificates: incorporating all amendments in effect from 1 July 1997.¹⁷

UL 73, Standard for Safety Motor-Operated Appliances.¹⁸

UL 153, Standard for Safety Portable Electric Luminaires.

UL 197, Standard for Safety Commercial Electric Cooking Appliances.

¹³ ISA publications are available from the International Society of Automation (<http://www.isa.org/>).

¹⁴ MIL publications are available from the U.S. Department of Defense (<http://quicksearch.dla.mil/>).

¹⁵ The NEC is published by the National Fire Protection Association (<http://www.nfpa.org/>). Copies are also available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

¹⁶ NFPA publications are published by the National Fire Protection Association (<http://www.nfpa.org/>).

¹⁷ SOLAS publications are available from the International Maritime Organization, 4 Albert Embankment, London SE1 7SR, United Kingdom.

¹⁸ UL publications are available from Underwriters Laboratories (<http://www.ul.com/>).

UL 399, Standard for Safety Drinking-Water Coolers.

UL 471, Standard for Safety Commercial Refrigerators and Freezers.

UL 486A, Standard for Safety Wire Connectors and Soldering Lugs for Use with Copper Conductors.

UL 595, Standard for Safety Marine-Type Electric Lighting Fixtures.

UL 921, Standard for Safety Commercial Dishwashers.

UL 924, Standard for Safety Emergency Lighting and Power Equipment.

UL 1008, Standard for Safety Transfer Switch Equipment.

UL 1042, Standard for Safety Electric Baseboard Heating Equipment.

UL 1278, Standard for Safety Moveable and Wall- or Ceiling-Hung Electric Room Heaters.

UL 1570, Standard for Safety Fluorescent Lighting Fixtures.¹⁹

UL 1571, Standard for Safety Incandescent Lighting Fixtures.²⁰

UL 1572, Standard for Safety High Intensity Discharge Lighting Fixtures.²¹

UL 1598, Standard for Safety Luminaires.

UL 2021, Standard for Safety Fixed and Location-Dedicated Electric Room Heaters.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.²²

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

adjustable speed drive (ASD): 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.

¹⁹ UL 1570-1995 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

²⁰ UL 1571-1995 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

²¹ UL 1572-1995 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

²² *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>

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.

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.

amortisseur winding: A permanently short-circuited winding used for inductively starting synchronous 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.

automatic bus transfer (ABT) system: Self-acting equipment for transferring one or more load conductor connections from one power source to another.

auxiliary machinery space: Spaces containing ship-service or mission machinery, but located outside of the main machinery casing.

base speed of an adjustable-speed motor: The lowest speed obtained at rated load and rated voltage at the specified temperature rise.

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

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.

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, and so on.

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.

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.

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

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.

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 non-pulsating current.

duplex receptacle: Two electrical receptacles housed in the same outlet box.

electric generator: A machine that transforms mechanical power into electric power.

electric motor: A machine that transforms electric power into mechanical power.

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.

enclosed self-ventilated: 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.

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

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

frequency converter: A converter using semiconductor devices to vary the output waveform and frequency to a motor as a means of controlling motor speed and or torque.

Hertz (Hz): The unit of frequency, one cycle per second.

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

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.

intermittent duty: A requirement of service that demands operation for alternate periods: load and no load, load and rest, or load, no load, and rest, as specified.

lighters: Short-range cargo-transfer vessels or barges used for ferrying cargo or personnel.

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

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

main machinery space: A space generally confined by the fireproof boundary of the machinery casing, and normally containing major ships' equipment and prime moving equipment, including propulsion services equipment.

manual bus transfer (MBT) switch: Non-self-acting equipment for transferring one or more load conductor connections from one power source to another.

mobile offshore drilling units: Mobile platforms including self-elevating drilling units (SEDUs or jackups), column-stabilized drilling units (CSDUs) or semisubmersibles, and drillships.

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.

multi-cable 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.

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

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

reactance: The imaginary component ($\pm j$, or $\pm 90^\circ$ phase angle) of impedance, where resistance is the real component with a zero-phase angle. Reactance appears in two forms, one as a capacitive reactance (X_C) 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:

$$X_C = \frac{1}{2\pi fC}$$

and

$$X_L = 2\pi fL$$

where:

f is the excitation frequency

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.

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

self-ventilated machine: A machine that has its ventilating air circulated by means integral with the machine.

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.

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.

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.

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.²³

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

- As a percent of synchronous speed
- As a decimal fraction of synchronous speed

²³ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

— Directly in revolutions per minute

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.

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.

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.

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.

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

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.

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) = $120f/p$). 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.

tank vessel: A vessel that carries liquid or gaseous cargo in bulk.

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.

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.

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.

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.

3.2 Acronyms and abbreviations

ABS	American Bureau of Shipping
ABT	automatic bus transfer
AFE	active front-end
AHF	active harmonic filter
ASD	adjustable speed drive
AVR	automatic voltage regulator
BOP	blow out preventer
CEC	Canadian Electrical Code
CENELEC	European Committee for Electrotechnical Standardization
CFR	Code of Federal Regulations
COLREGS	International Regulations for Preventing Collisions at Sea
CSDU	column-stabilized drilling unit
DNV GL	Det Norske Veritas & Germanischer Lloyd, an international accredited registrar and classification society headquartered near Oslo, Norway.
dPF	displacement power factor
EEDI	Energy Efficiency Design Index
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPS-CONOPS	electrical power system concept of operations
ESWBS	Expanded Ship Work Breakdown Structure
FMEA	failure mode and effects analysis
FMECA	failure modes, effects, and criticality analysis
FOG	salt spray apparatus
GDI	ground detector indicator
GL	part of the DNV GL (see above)
hPF	distortion power factor
ICD	interface control document
IGBT	insulated gate bipolar transistor
IMO	International Maritime Organization
IPS	integrated power system
ITHD	current total harmonic distortion
IVHD	individual voltage harmonic distortion
LCI	load commutated inverter
LCL	inductor-capacitor-inductor filter, typically either a 'T' for 'pi' configuration.
LF	load factor
LVP	low voltage protection
MBT	manual bus transfer
MESG	maximum experimental safe gap
MIC	minimum igniting current
MODU	mobile offshore drilling unit
MTBF	mean time between failures
MTBSI	mean time between service interruption
MTTR	mean time to repair

NRTL	Nationally Recognized Testing Laboratory
PDC	protective device coordination
PDSS	propulsion derived ship service
PSID	power system interface device
PTI	power take-in
PTO	power take-off
PWM	pulse width modulated
QoS	quality of service
RFI	radio frequency interference
RM&A	reliability, maintainability, and availability
RMS	need definition for acronym
RTD	resistance temperature detection
SCR	silicon control rectifier
SEDU	self-elevating drilling unit
SLI	starting, lighting, and ignition
SMPS	switching mode power supply
SNVT	standard network variable type
SOLAS	International Convention for the Safety of Life at Sea
SSL	solid state lighting
TEAAC	totally enclosed air to air cooled
TEFC	totally enclosed fan cooled
TEWAC	totally enclosed water/air cooled
THD	total harmonic distortion
TPF	true power factor
UCPT	user-defined configuration property type
UPS	uninterruptible power supply
VPI	vacuum-pressure-impregnation
VSCF	variable speed constant frequency
VSD	variable speed drive
VTHD	voltage total harmonic distortion

4. System engineering

4.1 Introduction

Figure 1 shows the design process from concept design to product baseline and the relationship between IEEE Std 45.1-2017 and IEEE Std 45.3. This document (IEEE Std 45.1) provides recommended practices for the Product Design Phase based on the Design Baseline and leading to the establishment of the Product Baseline.

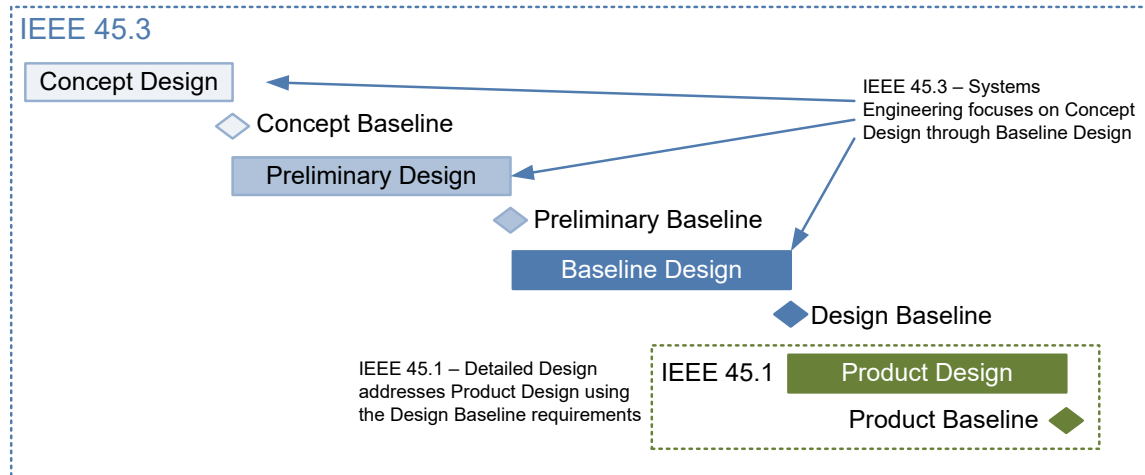


Figure 1—Design process

4.2 Design baseline

A design baseline is an agreement between an owner and a builder that defines the desired product in sufficient detail to allow proceeding with the product design phase.

The electrical power system design baseline should be established at the conclusion of baseline design and maintained using configuration management throughout product design.

The design baseline should consist of the following elements:

- Cover sheet
- Drawing index
- Drawing tree/document index*
- Electrical power system top-level requirements
- Systems list
- Power system design (single line diagram)
- Primary power system parameters
- Electrical power system concept of operations (EPS-CONOPS)*
- Electrical power system control design
- Master equipment list*
- Interface control document (ICD)
- Computer software
- Electric load analysis
- Reliability, maintainability, and availability (RM&A) analysis*
- Quality of service (QoS) analysis*
- Electrical power system corrosion control description*
- Failure modes, effects, and criticality analysis (FMECA)

- Models list*
- Simulation results*
- Cost considerations
- Electrical power system specification
- Long-lead electrical procurements
- Studies and other reference documents*
- Testing and acceptance criteria
- Bibliography

*These items are recommended for more complex vessels such as naval combatants.

4.3 Product design

Product design is the final phase in the design process and should build on the design baseline from the baseline design phase. The long-lead items will have been specified and procurements initiated during baseline design. All remaining electrical power system components should be specified, design issue questions should be answered, and no undefined elements should be left in the design. Some additional equipment/material will be procured during this phase to support the construction schedule. The product baseline is the design product from the product design phase.

4.4 Product baseline

The product baseline consists of the following components:²⁴

- Describes the detailed design, including necessary physical (form, fit, and function) characteristics and selected functional characteristics designated for production, acceptance testing, and production test requirements
- Identifies the verifications necessary for accepting product deliveries (first article and acceptance instructions)
- Identifies and documents the design of any special tooling, software, equipment, and facilities required to manufacture, operate, maintain, calibrate, or inspect items contained in the design
- Includes any quality assurance provisions required for first article or acceptance inspection
- Includes any unique process specifications required to manufacture, operate, maintain, or calibrate items contained in the design
- Identifies any specialized software and documents the operating environment used to author the detailed design
- Includes technical data that provides instructions for the installation, operation, maintenance, training, and support of a system or equipment

²⁴ Adapted from IEEE Std 15288.1™.

5. Power system characteristics

5.1 Electrical power systems architectures

5.1.1 Radial architecture

A radial architecture is implemented by interconnecting switchboards with distribution cabling, and then powering loads and load centers/power panels feeding multiple smaller loads via feeder cables from the switchboards. Generators and energy storage typically connect to switchboards. Emergency loads are normally provided power from an emergency switchboard. Mission-critical loads are connected to multiple load centers (typically geographically dispersed) via manual bus transfer (MBT) or automatic bus transfer (ABT) devices. Figure 2 is an example of a radial architecture for a commercial marine vessel, while Figure 3 shows a typical naval vessel.

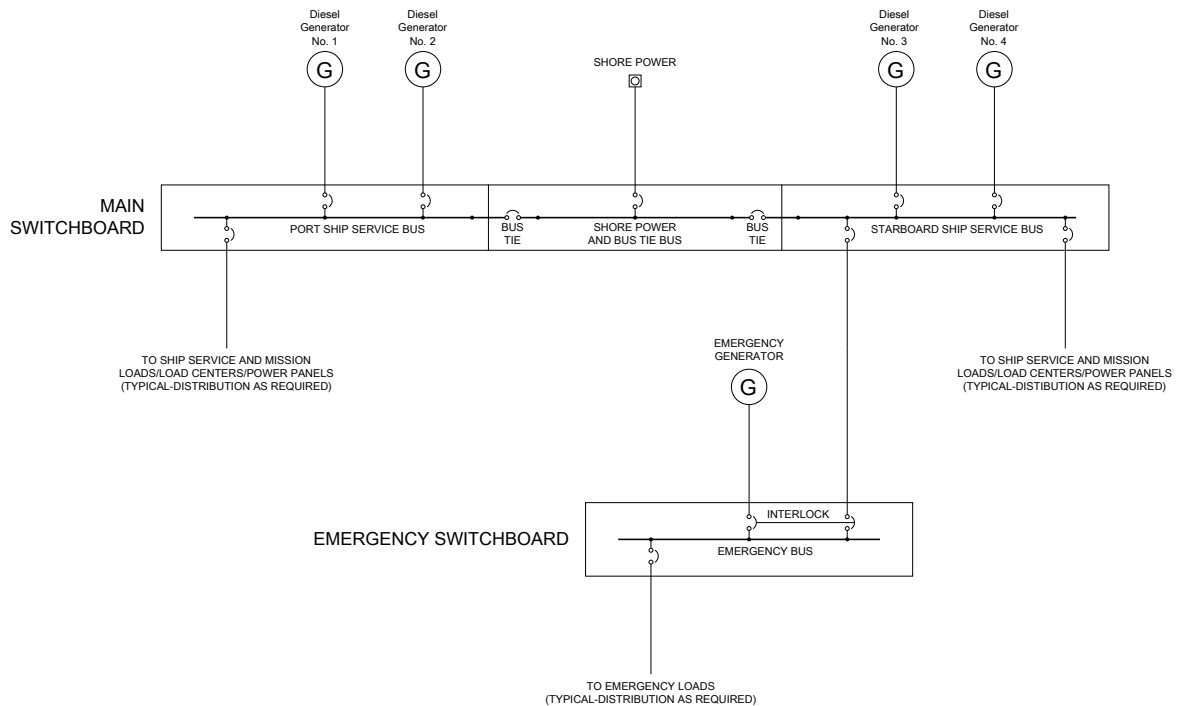


Figure 2—Typical commercial marine single-line diagram

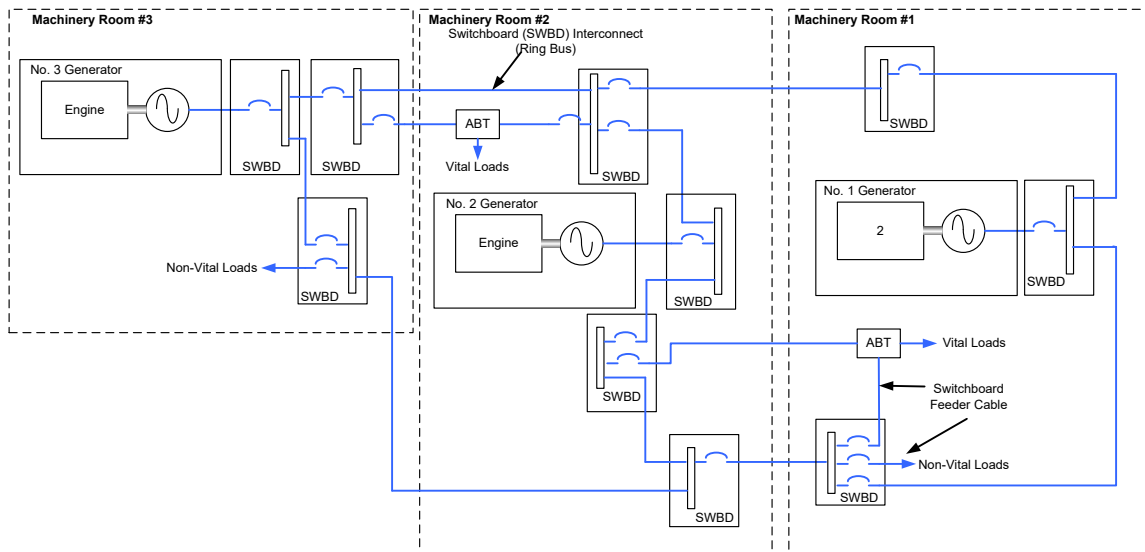


Figure 3—Notational radial distribution architecture typically found on a naval warship

5.1.2 Zonal architecture

For complex vessels with stringent power system power continuity requirements, a zonal architecture is recommended. This architecture is implemented by dividing the ship into multiple zones, designing a zonal electrical distribution system (ZEDS) for each zone, and integrating the zones with a primary bus/interzonal distribution bus, power generation, and possibly energy storage as shown in Figure 4. Note that power system equipment that is not part of the ZEDS may reside within the boundaries of the zone. Likewise, not all loads (electric propulsion, for example) within the geographic boundaries of the zone are necessarily part of the zone.

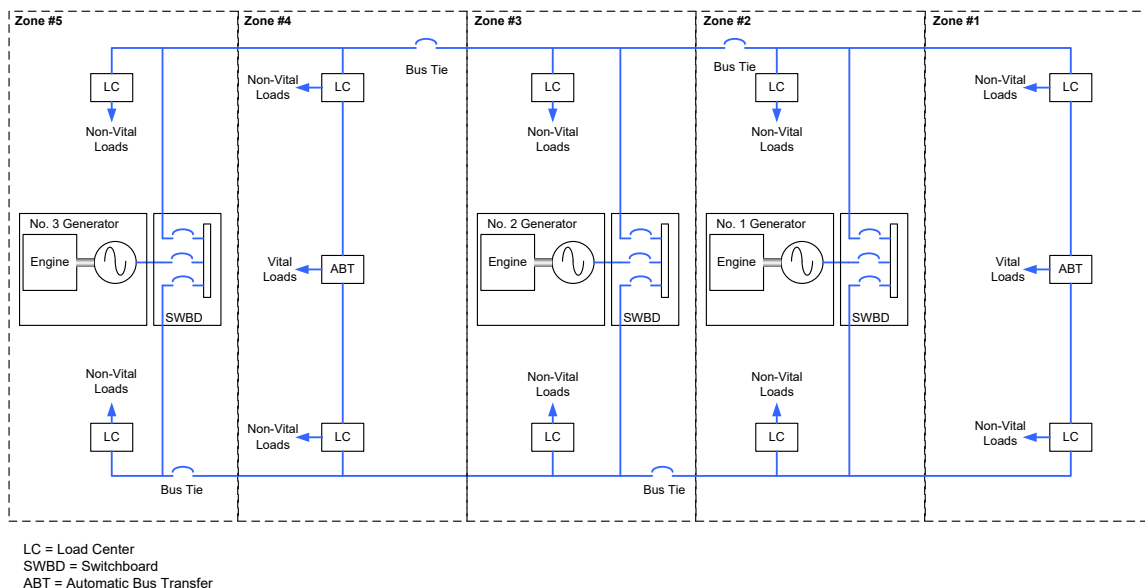


Figure 4—Notational zonal electrical power system architecture for a naval warship

For a ship, a zone is typically a longitudinal section of the ship with boundaries at water-tight bulkheads. The number of zones within a ship is a function of the complexity of the ship, its missions, and

survivability requirements. A naval warship, for example, would typically have between four and seven zones.

A ZEDS consists of power system elements serving a group of loads and is part of a larger power system. ZEDS plus the loads it serves comprise a zone. A ZEDS has a limited number of power and control interfaces with the larger encompassing system and has the property that faults within the zone do not propagate outside the zonal boundaries. Furthermore, a design objective of ZEDS and the larger system containing the ZEDS is that loads served by the ZEDS are provided with the type of power, quality of power, and QoS specified by a customer-supplier agreement. Loads served by the ZEDS receive power only via the ZEDS. The power systems elements composing a ZEDS include power conversion equipment, controls, switchgear, cabling, and, optionally, energy storage and generation.

If specified by the customer, a ZEDS isolated from the rest of the power system may be required to operate either for a limited time or on a continuous basis. In either case, the ZEDS will have energy storage and/or generation.

Requirements for a power electronics-based ZEDS are provided by IEEE Std 1826.

5.1.3 Hybrid architectures

Special circumstances can result in hybrid power system architectures that do not cleanly fit the definition of either a radial or zonal architecture. If employing a hybrid architecture, analysis is required to verify the system will operate in a satisfactory and stable manner under all operating conditions, achieve QoS and power quality requirements, and meet all other customer requirements.

An example of a hybrid architecture would be power generation and large loads in a ring-bus configuration connected to a ZEDS supplying all other loads.

5.2 Standard systems

The following distribution systems are recognized as standard:

- Two-wire with single-phase ac or dc
- Three-wire with single-phase ac or dc
- Three-phase, three-wire ac
- Three-phase, four-wire ac

5.3 Standard voltage

The following voltages are recognized as standard, as shown in Table 1.

Table 1—Standard voltages

Standard	AC (V)	DC (V)
Power utilization	115, 200, 220, 230, 350, 440, 460, 575, 660, 2300, 3150, 4000, 6300, 10 600, 13 200	12, 24, 28, 115, 230, 270, 380 See IEEE Std 1709
Power generation	120, 208, 230, 240, 380, 450, 480, 600, 690, 2400, 3300, 4160, 6600, 11 000, 13 800	120, 240 See IEEE Std 1709

Standard voltages and associated power quality are also provided by IEC 60038 (does not provide power quality requirements), IEEE Std 1709, IEEE Std 1826, IEC/ISO/IEEE 80005-1, MIL-STD-1399-300, and MIL-STD-1399-680.

5.4 Standard frequency

For ac lighting and power systems, 50 Hz and 60 Hz are standard frequencies. For some military and special service applications, 400 Hz is standard, usually required by ship mission system equipment.

5.5 Selection of voltage and system type

In general, voltage selection should take into consideration maximum anticipated load, total power generation capacity, distribution cable weight/volume allocation, available switchgear rated continuous current capability, and any other special considerations unique to the vessel. The following guidelines may be useful in selecting both the system 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 120/208 V three-phase, four-wire. Power and lighting utilization should be at 115/200 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 ac power at 13 800 V, 11 000 V, 6600 V, 4160 V, 3300 V, or 2400 V with some power utilization at 13 200 V, 10 600 V, 6300 V, 4000 V, 3150 V, or 2300 V, three-phase, respectively, with lower utilization voltages to be derived from transformers. Where dc generation is desired, consideration should be given to employing rated voltages defined in IEEE Std 1709.

For vessels requiring dc power generation, and having little power apparatus, 120 V dc generators are recommended with a 115 V dc lighting and power distribution system. Where an appreciable amount of dc power apparatus is provided, 120/240 V dc, three-wire generators and 230 V dc power distribution system

and 115/230 V dc three-conductor lighting feeders may be selected. Branch circuits from lighting panelboards should be 115 V dc two-wire.

Ships with loads requiring 28, 270, or 380 V dc are recommended to provide these loads with power from point-of-use power conversion.

User equipment shall be designed to operate normally when supplied power with a nominal voltage between the nominal power utilization and nominal generation voltages. The difference between the nominal generation voltage and the power utilization voltage accounts for voltage drop due to cables and other distribution system equipment.

5.6 AC power system characteristics

Ac power distribution systems should maintain the system characteristics described in MIL-STD-1399-300, MIL-STD-1399-680, or Table 2 under all operating conditions. Power-consuming equipment should operate satisfactorily under the conditions described in MIL-STD-1399-300, MIL-STD-1399-680, or Table 2, and it should be designed to withstand the power interruption, transient, electromagnetic interference (EMI), radio frequency interference (RFI), and insulation resistance test conditions inherent in the system. Power-consuming equipment requiring a nonstandard voltage or frequency for successful operation should have integral power conversion capability. Power-consuming equipment should not have inherent characteristics that degrade power quality.

Table 2—Alternating current (ac) power characteristics

Characteristics	Limits
Frequency	
a) Nominal frequency	50/60 Hz
b) Frequency tolerances	± 3%
c) Frequency modulation	0.5%
d) Frequency transient:	
1) Tolerances	4%
2) Recovery time	2 s
e) The worst-case frequency excursion from nominal frequency resulting from item b), item c), and item d) 1) combined, except under emergency conditions.	5.5%
Voltage	
a) User voltage tolerance:	
1) Average of the three line-to-line voltages	± 5%
2) Any one line-to-line voltage, including item a) 1) and line voltage unbalances item 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 item a) 1) and item d) combined, except under transient or emergency conditions	± 6%
g) The worst-case voltage excursion from nominal user	± 20%

Characteristics	Limits
voltage resulting from item a) 1), item a) 2), and item d) 1) combined, except under emergency conditions	
Emergency conditions a) Frequency excursion b) Duration of frequency excursion c) Voltage excursion d) Duration of voltage excursion: 1) Lower limit (– 100%) 2) Upper limit (+ 35%)	– 100% to + 12% Up to 2 min – 100% to + 35% Up to 2 min 2 min
Definitions: a) Frequency 1) Nominal frequency: The designated frequency (f_{nominal}) in Hz. 2) 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. 3) 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. $\text{Frequency Modulation (\%)} = \left[\frac{f_{\text{max}} - f_{\text{min}}}{2 \times f_{\text{nominal}}} \right] \times 100$ 4) 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. 5) Frequency transient recovery time: The time period from the start of the disturbance until the frequency recovers and remains within frequency tolerance limits.	
b) Voltage 1) 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. 2) Line voltage unbalance tolerance (three-phase system): The difference between the highest and lowest line-to-line voltages. $\text{Line Voltage Unbalance Tolerance (\%)} = \left[\frac{E_{\text{max}} - E_{\text{min}}}{E_{\text{nominal}}} \right] \times 100$	

Characteristics	Limits
3) 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: $\text{Voltage Modulation (\%)} = \left[\frac{E_{\max} - E_{\min}}{2 \times E_{\text{nominal}}} \right] \times 100$ 4) Voltage transient i) 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. ii) Voltage transient recovery time: The time elapsed from initiation of the disturbance until the voltage recovers and remains within the user voltage tolerance limits. 5) Voltage spike: A voltage change of very short duration (less than 1 ms).	
c) Waveform 1) 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. 2) Single harmonic (of a sine wave): The ratio in percentage of the rms value of that harmonic to the rms value of the fundamental. 3) 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. $\text{Deviation Factor (\%)} = \left[\frac{\text{Maximum Deviation}}{\text{Maximum ordinate of the equivalent sine wave}} \right] \times 100$	
d) Emergency conditions 1) 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 online.	

^aFor ships with electric propulsion or other adjustable speed drive (ASD) loads, higher voltage distortion can be accepted on a dedicated power bus if the equipment connected to the dedicated power bus is designed and tested for the actual conditions.

5.7 DC power systems characteristics

For vessels utilizing a dc power distribution system or subsystem, Table 3 provides recommended requirements.

Table 3—DC power systems recommended power quality requirements

DC voltage level	Recommended power quality requirements
28 V or 270 V	MIL-STD-704F
380 V	ETSI EN 300 132-3-1
≥ 1000 V	IEEE Std 1709

5.8 Key electrical power system design inputs

5.8.1 Electric load analysis

The electric load analysis developed in previous design phases documents the basis for estimating the operating load for different ship operating conditions. The electric load analysis is updated as part of product design (See 4.3). The electric load analysis is used to size major electrical equipment and is updated during this phase to provide confidence that the equipment will meet the demand load. It is also used to ensure extra capacity is provided at ship delivery as required by the customer. See 22.2 for additional information.

5.8.2 Ship consumer equipment locations

The locations of electric power consumer loads have a direct bearing on configuration of the electrical distribution system. This information is needed to determine locations, quantities, and sizes of load centers, power panels, transformers, etc. that will be required to efficiently supply power to the loads. In early design phases, compartment names on the ship general arrangements are used to estimate equipment locations. As the ship design progresses, specific locations of consumer loads will be defined and adjustments to the electrical distribution system will need to be made.

5.9 Quality of service (QoS)²⁵

5.9.1 Introduction

QoS is a metric of how reliably the power system provides power to the loads. It is calculated as a mean time between service interruptions (MTBSI). QoS is a reliability metric; as such the calculation of QoS metrics does not take into account survivability events such as collisions, fires, or flooding. QoS does take into account equipment failures and normal system operation transients.

Equipment designers or manufacturers should provide QoS information to the electric system designer.

Loads should be categorized into four QoS categories: uninterruptible, short-term interrupt, long-term interrupt, and exempt.

5.9.2 Service interruption

A service interruption is any interruption in service or power quality degradation outside of acceptable parameters for a period of time that results in the load's parent system not being capable of meeting its requirements. The duration of service interruption is measured relative to two system dependent times: t_1

²⁵ Quality of Service (QoS) is a concept developed by the U.S. Navy to drive electrical power system reliability into the system design. The concept is recommended for other vessels where power system reliability is a key requirement.

and t_2 . Different electrical power system-load interfaces may have different values for t_1 and t_2 based on the choice of power system components.

System times are system dependent quantities that can have a major impact on cost and should, therefore, be selected very carefully and include mission functionality.

5.9.3 Reconfiguration time (t_1)

Reconfiguration time (t_1) is defined as the maximum time to reconfigure the distribution system without bringing on additional generation capacity.

The t_1 is defined by the time delays in the system protection coordination and system reconfiguration. For systems with traditional switchgear, historic values of 0.5 s, 1 s, 2 s, and 3 s should be used. For designs with fast power electronics, t_1 of 0.0001 s, 0.001 s, 0.01 s, 0.05 s, 0.1 s, and 0.2 s should be used.

Reconfiguration time should be specified and included as part of the EPS-CONOPS.

5.9.4 Generator start time (t_2)

Generator start time (t_2) is defined as the maximum time to bring the slowest power generation module online. The t_2 is typically on the order of 1 to 5 min for naval vessels. Commercial vessels must bring the generator module online within 30 s or seek regulatory relief.

5.9.5 Mean time between service interruptions

Different operating conditions of the ship may have different requirements for the MTBSI. These different operating conditions are generally defined and the MTBSI calculated over an operating cycle or, alternately, a design reference mission. Associated with each operating condition is a machinery concept of operation that details the expected policies for redundancy, rolling reserve, etc. needed to achieve the customer specified MTBSI.

MTBSI should be specified and included as part of the EPS-CONOPS.

5.9.6 QoS categories

5.9.6.1 Uninterruptible load

Loads that cannot tolerate service interruptions greater than time t_1 are categorized as uninterruptible loads.

The power system should be designed to provide each uninterruptible load the minimum achievable service interruption (or lower than the longest duration that a load can tolerate an interruption) with a reliability in excess of the specified MTBSI.

5.9.6.2 Short-term interrupt load

Loads that can tolerate service interruptions of duration t_1 and cannot tolerate service interruptions of duration t_2 are categorized as short-term interrupt loads, which are common on complex vessels such as naval combatants.

The power system should be designed to limit service interruptions to short-term interrupt loads to less than t_1 in duration. Service interruptions greater than t_1 in duration for a given load should not occur on average more frequently than the specified MTBSI.

5.9.6.3 Long-term interrupt loads

Loads that can tolerate service interruptions of duration t_2 are categorized as long-term interrupt, which are common on complex vessels such as naval combatants.

With the exception of exempt loads, the power system should be designed to limit service interruptions to long-term interrupt loads to less than t_2 in duration. Service interruptions greater than t_2 in duration to long-term interrupt loads (except exempt loads) should not occur on average more frequently than the specified MTBSI.

5.9.6.4 Exempt loads

Exempt loads are a special case of long-term interrupt loads that do not require restoration within t_2 , which are common on complex vessels such as naval combatants.

For integrated power system (IPS) configurations where propulsion and ship service power are provided by the same set of power generation modules and prime movers, sufficient redundancy in generation is not provided to enable the ship to achieve its maximum speed with any one generator out of service. Propulsion power for IPS ships may thus be split into three categories: short-term interrupt load, long-term interrupt load, and exempt load. The installed generation capacity of the ship must be capable of supporting all categories of load for all loads for every operating condition with all generators online, and must support all loads except the exempt load with one generator out of service. Unless otherwise specified by the customer, that portion of propulsion load needed to exceed the minimum mission speed is exempt load.

The concept of the exempt load is only used in sizing the installed generation capacity of the ship. In operation of the power system, exempt load is treated as long-term interrupt load.

5.10 Electrical power system concept of operation (EPS-CONOPS)

An EPS-CONOPS should either be updated from previous stages of design or prepared to document the expected manner of operation during different operational cases. IEEE Std 45.3 provides details for the content of an EPS-CONOPS.

The EPS-CONOPS includes scenarios that all ships encounter as well as scenarios unique to the particular vessel's marine sector. Common scenarios include in port, normal transit, anchored, recovery from casualty. Sector-unique scenarios include container off load and on load, underway lightering of petroleum, combat, and humanitarian relief.

The EPS-CONOPS articulates power system attributes that should be optimized for each of the expected scenarios. Typical attributes include QoS, energy efficiency, safety, emissions, and safety of life at sea to meet the ship's mission and business needs. It should also include margin policy and provisions for future changes, and should foster a design that meets or exceeds the requirements and expectations for the vessel. The EPS-CONOPS address the human systems interface; an important aspect is the interaction between humans and the electric power system equipment.

5.11 Marine environmental conditions

5.11.1 Normal environmental conditions

Systems and equipment should be suitable for continuous operation under the following shipboard conditions:

- Exposure to moisture-laden and salt-laden atmosphere, weather, sun, high wind velocities, and ice.
- Equipment and systems shall be designed for temperature extremes and conditions expected. Typically, the following conditions can be used: ambient temperature values of 40 °C in accommodation areas and similar spaces; 45 °C in main and auxiliary machinery spaces; 50 °C for rotating machinery and propulsion equipment in main and auxiliary machinery spaces containing significant heat sources such as prime movers and boilers; and 65 °C in the uptakes of machinery spaces containing prime movers and boilers; all at relative humidity values up to 95%. The design value for seawater cooling temperature should be 32 °C.
- Roll and pitch of a vessel underway, as shown in Table 4.

Table 4—Roll and pitch requirements

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

^a In vessels designed for carriage of liquefied gases and of chemicals, the emergency power installation is to remain operable with the vessel flooded to its permissible athwartship inclination up to a maximum of 30°.

- Vibration of a vessel underway: Electrical equipment should be constructed to withstand at least the following:
 - Vibration frequency range of 5 Hz to 50 Hz with a velocity amplitude of 20 mm/s
 - Peak accelerations due to ship motion in a seaway of $\pm 5.9 \text{ m/s}^2$ for ships exceeding 90 m in length, and $\pm 9.8 \text{ m/s}^2$ for smaller ships, with a duration of 5 s to 10 s

5.11.2 Abnormal environmental conditions

Special conditions for a specific ship design or operating arrangement may require special consideration – typical for complex ships such as naval combatants. Examples of such conditions include, but are not necessarily limited to the following:

- Exposure to damaging fumes or vapors, excessive or abrasive dust, steam, salt-spray, ice, sunlight, physical damage, and so on
- Exposure to high levels of shock and vibration
- Exposure to high or low temperatures
- Operation in flammable atmospheres
- 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, and so on

6. Electrical power system elements

6.1 Introduction

An electrical power system, in general, can be decomposed into up to six different types of elements based on functionality: power generation, power distribution, power conversion, energy storage, electrical power system supervisory control, and loads. These elements are described in this clause. The equipment implementing each element may include power electronics to convert and condition the electrical power. Guidance for the design and application of power electronics in electrical power systems on ships is provided in IEEE Std 1662.

6.2 Power generation

Power generation consists of equipment that converts an energy source (such as fuel) into electrical power for use by loads via one or more power distribution systems. Power generation equipment exchanges control and information signals with the electrical power system supervisory control and may interface with other distributed systems such as a seawater system, steam generation system, fuel service system, intakes, and exhaust.

Power generation equipment using rotating electrical generator sets generally includes a steam turbine, gas turbine, or a diesel engine prime mover; a generator; possibly power electronics; auxiliary support submodules; and module controls. Other possible power generation technologies include rotating generators directly connected to the propulsion train, direct conversion (e.g., solar cells, fuel cells), and wind-driven turbines.

Power generation equipment should regulate its output voltage and frequency (for ac systems). Additionally, if multiple generator sets are intended to operate in parallel, provisions should be made for the stable sharing or apportioning of real power and reactive power (for ac systems). For ac systems, real power sharing is generally implemented through frequency droop or other signals between paralleled units' speed governors. For ac systems, reactive power sharing is generally implemented through voltage droop or other signals between paralleled units' voltage regulators. For dc systems, real power sharing is generally implemented through voltage droop or other signals between paralleled units' voltage regulators. If power generation equipment and/or the output of power conversion equipment of different types or ratings is intended to operate in parallel, the dynamic performance of the power system should be verified for stable operation and adherence to transient power quality requirements.

The design of the fault current capability of power generation equipment should be coordinated with the fault protection equipment in the distribution system. The differing fault current characteristics of rotating machines and power electronics should be considered when designing the protection system.

See Clause 8 for additional requirements for power generation.

6.3 Power distribution

6.3.1 General

Power distribution systems transfer electrical power between other power system elements. They also provide fault current protection as well as implement different power system architectures. Power distribution systems typically consist of cables, switchgear, load centers, power panels, load monitoring

equipment, and fault protection equipment. Power distribution equipment communicates with the electrical power system supervisory control and may communicate with other distributed systems. Power distribution may include power electronics and distribution transformers to directly provide the type and quality of power required by specific loads or a small grouping of loads.

A power system may have one or several power distribution systems, each with its own bus of potentially different voltage and power type. A bus of one type should be galvanically isolated from buses of all other types. Historically, mechanical drive ships have had one power distribution system that distributed 450 V to 480 V, three-phase, 50 Hz to 60 Hz power. More recently, large ships and those with electric propulsion have employed a medium voltage ac power distribution system interconnected via transformers with a low voltage (450 V to 480 V) ac power distribution system. A ship may have a single medium voltage power distribution system that feeds multiple electrical zones via power conversion equipment (e.g., transformers, solid-state power converters). Under such conditions, each electrical zone will have its own zonal power distribution system.

Switchgear consists of the equipment, such as electrical disconnect switches, fuses, and circuit breakers, used to control power to, protect, and isolate electrical equipment. Recommendations for ac switchgear are provided by IEEE Std 45.7. Recommendations for cable systems are provided in IEEE Std 45.8.

Requirements for connecting to shore utility power are provided by IEC/ISO/IEEE 80005-1.

See Clause 9 for additional requirements for power distribution.

6.3.2 Primary bus

A primary bus is a term reserved for a medium voltage ac or dc bus and applies only to vessels with a medium voltage bus. A primary bus may be implemented as multiple buses for redundancy, criticality, or safety. A primary bus usually is only directly connected to a few large loads; the majority of the loads are powered from other buses that connect to the primary bus via power conversion equipment (e.g., transformers, solid-state power converters).

In selecting the voltage for the primary bus, consideration should be given to using the standard voltages in IEC/ISO/IEEE 80005-1 to simplify connections to shore utility power while in port.

6.3.3 Distribution bus

A distribution bus provides power to loads throughout a ship or a zone. Multiple distribution buses may be utilized as necessary for the vessel design. Distribution buses typically support voltages between 400 V and 1000 V.

6.3.4 Secondary low voltage bus

A secondary low voltage bus provides low voltage directly to equipment, appliances, or appliance outlets.

6.3.5 Special bus

A special bus provides power for unique purposes such as medical use, control system power, special control, or propulsion.

6.4 Power conversion

Power conversion equipment converts electrical power from the type and quality required by one power distribution system to the type and quality required by another power distribution system. Power conversion equipment technologies include power electronics, transformers, and rotating motor-generator sets. Note that power electronics and transformers are not unique to power conversion equipment and may be part of other power system elements. Power conversion equipment exchanges control and information signals with the electrical power system supervisory control. Power conversion equipment may interface with other distributed systems such as a cooling water system and ventilation systems.

The simultaneous paralleling of the primaries and the secondaries of two or more transformers is not recommended unless provisions are provided to limit circulating currents. These circulating currents must be included in load flow analyses and in calculating the required current ratings of switchgear and cables.

See Clause 10 for additional requirements for power conversion.

6.5 Energy storage

An energy storage element stores electrical energy received from a distribution system that later may be used to provide power back to the distribution system or to a dedicated load. Energy storage is typically employed to achieve QoS requirements but may also fulfill power quality and other system requirements, including high energy loads with unique power profiles. An energy storage element should protect the distribution system to which it connects from faults internal to the energy storage element. Additional requirements for energy storage are provided by IEEE Std 1826 and Clause 11.

6.6 Electrical power system supervisory control

6.6.1 General

An electrical power system supervisory control monitors, controls, reconfigures, protects, and coordinates the operation of an integrated electrical power system. The supervisory control may be centralized or distributed. Recommendations for the overall machinery control system, including the electrical power system supervisory control, are provided in IEEE Std 45.2 and Clause 12.

Typical electrical power system supervisory control functions could include the following processes as appropriate for the vessel type:

- Remote monitoring and control of electrical power system equipment
- Resource planning and system configuration to support the EPS-CONOPS
- Mission priority load shedding
- Coordination of fault detection, fault isolation, and reconfiguration
- Optimization of QoS and QoS load shedding
- Interfacing with the overall machinery control system
- Performance analysis, parameter trending, and logging

Additionally, the electrical power system supervisory control design should facilitate the following processes:

- Maintenance support (such as special modes, electrical isolation, and tag-outs)
- Training

The electrical power system supervisory control software may reside in hardware contained in other power system elements or may reside in an external distributed computer system. The software should interact with the human operators through a human-computer interface. Incorporating this human-computer interface as part of a ship wide monitoring and control system is recommended.

6.6.2 Power system interface device (PSID)

A PSID is equipment that communicates control and monitoring signals with the integrated electrical power system supervisory controller to monitor and control individual loads, in accordance with the EPS-CONOPS. A PSID may also provide custom power to a specific load. PSIDs may be part of the power system or may be part of an external system. A PSID should be used for equipment that requires a connection to the machinery control system but does not have the inherent ability to make such a connection.

6.7 Loads

6.7.1 General

Loads may simultaneously be part of multiple systems and may therefore communicate with multiple supervisory controllers for different systems. For example, cargo cooling systems may communicate with the chill-water system, electrical power system, etc. For the electrical power system, loads are categorized by their ability to directly communicate with the power system control.

Additional requirements for loads are provided in Clause 13 through Clause 20.

6.7.2 Uncontrolled load

Uncontrolled loads interface only to the power system for electrical power and do not communicate directly with the power system control. An uncontrolled load may communicate indirectly with the power system control via a PSID. Unless a simple load can be commanded to shut down via a PSID, an uncontrolled load is typically shed by switching off the power feed to the load without prior notification.

6.7.3 Controlled load

Controlled loads interface to the power system control through a control interface. Controlled loads may have the capability to have their operational state changed by the power system control. For example, the power system control may command a controlled load to reduce load or switch off instead of simply switching off the power. Controlled loads may also communicate with other system supervisory controllers.

6.7.4 Large loads

Any single load that may require more than 20% of the online power generation capacity supplying that load in any operating condition is considered a large load. A propulsion motor and associated drive is a good example of a large load. For power systems incorporating large loads, the dynamic performance of the power system should be verified for stable operation and adherence to transient power quality requirements.

7. Power system design

7.1 Power generation and energy storage capacities

7.1.1 General requirements

For any ship operating condition, 95% of the total power generation capacity of all online generator sets and energy storage minus 95% of the rating of the largest online generator set must be greater than the sum of the online uninterruptible and short-term interruptible loads. For zonal architectures, if the power from energy storage or a generator set can serve only in-zone loads, then any energy storage or generator set power capacity in excess of the sum of that zone's uninterruptible and short-term interruptible load should not be counted in the total power generation capacity. The 95% factor is an allowance for variation in load due to equipment cycling on and off.

7.1.2 Nonintegrated ship service power and propulsion power systems

In designs where the majority of the ship's propulsion power is not provided via the electrical power system, the loss of use of the generating unit with the highest power rating for any reason (e.g., failure, maintenance) shall not impact the ability of the electrical power generation plant to supply maximum end-of-service-life ship service electric load for any ship operating condition with the remaining generators at 95% rated power.²⁶

7.1.3 Integrated power systems (IPSs)

IPSs are systems where the majority of propulsion power and ship service power are supplied from a common electrical power generating plant. The power generating plant shall be designed to provide the maximum margined electric load with service life allowance (including design propulsion load) for any ship operating condition at the design rating of the generating plant. The loss of use of the generating unit with the highest power rating for any reason (e.g., failure, maintenance) shall not impact the ability of the electrical power generation plant to provide the maximum of the margined electric load with service life allowance (including design propulsion load) less exempt load for any ship operating condition. Unless otherwise specified, propulsion load above the minimum of that required to achieve one half of the design speed or 7 knots (whichever is less) is exempt load. When paralleled, each generator shall maintain paralleled loading within $\pm 5\%$ of its rated portion of the operating load. The generator sets shall be designed for a 110% continuous overload rating.

Additionally, at least one of the two following criteria shall be met:

²⁶ This requirement is often called the "N-1" rule.

- The IPS control system shall prevent overloading of the generators. When sufficient power is being provided to the propulsion motor(s), the IPS control system shall have the ability to prevent overloading of the generators by managing the power provided to the propulsion motor(s).
- The power generating plant shall be designed to provide the maximum margined electric load with service life allowance (including design propulsion load) at 95% of the design rating of the generating plant.

7.1.4 Special cases

A power take-in (PTI) (also known as a hybrid electric drive) incorporates an electric auxiliary propulsion motor and augments a mechanical drive system. If a hybrid electric drive is installed essentially for fuel economy and is not required to achieve the ship's design maximum speed, the customer should specify whether the hybrid electric drive load is considered for establishing generator or energy storage module power capacity.

A power take-off (PTO) (also known as propulsion derived ship service (PDSS)) consists of an electrical generator connected to the drive shaft of a mechanical drive system. (It may also include power electronics to convert the power produced by the generator to the frequency and voltage of the power distribution system.) If a PDSS PTO is installed, its capacity may be included in the total generating capacity of the ship if the electrical power generation capacity is independent of the propulsion power at all times.

A bidirectional hybrid electric drive system performs both functions (PTO and PTI) with a single set of equipment. The electric machine mechanically attached to the propulsion system acts as either a motor or a generator depending on operating mode. A power converter acts as either a motor drive or inverter synthesizing distribution bus voltage and frequency depending on the operating mode. In this arrangement, the power capacity and power draw should be included in the electric load analysis as appropriate for the operational conditions. The EPS-CONOPS should detail the intended operating mode for each operating condition.

Some ships with large maneuvering thrusters may have operational conditions where the propulsion loads are mostly electric and a significant fraction of the electric load. For these operational conditions, the criteria of 7.1.3 apply.

7.2 Power conversion and transformer ratings

Power conversion equipment and transformers should have a power rating sufficient to satisfy the worst-case anticipated load including margin and service life allowance. If the power conversion equipment is modular and extra capacity can be easily added at a later date, then the power conversion equipment and associated cabling should be designed to incorporate sufficient capacity to satisfy the worst-case anticipated load including margin and service life allowance, but need provide only sufficient modules at delivery to satisfy the worst-case anticipated load without service life allowance.

Single-phase transformers are normally rated in kilovolt-amperes (megavolt-amperes) by multiplying the open-circuit voltage of the secondary by the full-load current, even though these two conditions do not happen at the same time. Hence, the actual amount of kilovolt-amperes delivered by the transformer has to take into account the regulation of the transformer. Similarly, three-phase transformers are normally rated in kilovolt-amperes (megavolt-amperes) by multiplying the open-circuit line-to-line voltage by the full-load current and the square root of 3.

The calculation of the worst-case anticipated load should account for the impact of cycling loads. Additionally, the ability of the power conversion and transformers to provide in-rush current to load equipment and to provide adequate, but not too much, fault current to enable proper coordination of circuit breakers must be evaluated.

7.3 Emergency power

7.3.1 General

Emergency power is required by regulatory authorities and classification societies depending on vessel type, tonnage, and voyage. The recommendations in this document are general. For specific requirements, consult the appropriate regulatory authorities and classification societies.

Every vessel should be provided with a self-contained emergency source of electric power, generally a diesel-engine generator, gas turbine-driven generator, or storage batteries (for integrated power systems see 15.5.1). These emergency sources of power and an emergency switchboard should be located in a space separate and remote from the main switchboard, that is above the uppermost continuous deck, aft of the collision bulkhead, outside the main machinery compartment, and readily accessible from the open deck. The emergency switchboard should be in the same compartment as the emergency generator set and in a compartment adjacent to the storage battery room.

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 fire boundaries (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.

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.

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.

7.3.2 Emergency generators

Emergency generator(s) should be sized to supply 100% of connected loads that are essential for safety in an emergency condition. Where redundant equipment is installed so that not all loads operate simultaneously, these redundant loads need not be considered in the calculation.

The prime movers of generators should be provided with all accessories necessary for operation and protection of the prime mover, including a self-contained cooling system that ensures continuous operation in an ambient temperature of 50 °C, or as required by local or regional codes and regulations.

Any liquid fuels used should have a flash point of 43 °C minimum.

Emergency generators should be capable of carrying a full rated load within 45 s after loss of the normal power source with the intake air, room ambient temperature, and starting equipment at a minimum temperature specified for the application.

Except for a thermostatically controlled, electric water-jacket heater connected to the emergency bus, emergency generator prime movers should not require a starting aid to meet this requirement.

Prime movers of emergency generator sets should start by hydraulic, compressed air, or electrical means.

Hydraulic starting systems should be automatically maintained within the predetermined pressure limits and be electrically energized from the emergency bus. Provision for manual recharge should be provided.

The starting air receiver for compressed air starting systems should be supplied from one of the following sources of air:

- The main or auxiliary compressed air receivers with a check valve in the emergency generator room to prevent backflow of compressed air to the ship service system; there should be a handcranked, diesel-powered air compressor for recharging the air receiver.
- An electrically driven air compressor that is automatically operated and is powered from the emergency power source. If this compressor supplies other auxiliaries, there should be a check valve at the inlet of the starting air receiver to prevent backflow of compressed air to the other auxiliaries, and there should be a hand-cranked, diesel-powered air compressor for recharging the air receiver.

When an emergency generator is operated in emergency mode, 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 $\pm 3.5\%$ of rated generator voltage between reactive load change from 0% to 60% of the continuous kVA rating. For emergency sets under transient conditions, the values may be increased to $\pm 4\%$ in not more than 5 s.

Emergency generators should maintain proper lubrication and not spill oil when subjected to the marine environmental conditions of 5.11.

Emergency generator sets should shut down automatically upon loss of lubricating oil pressure, overspeed, or operation of a fixed fire extinguishing system in the emergency generator room.

Diesel engine prime movers should be provided with an audible alarm that sounds on low oil pressure and high cooling water temperature.

An independent fuel supply should be provided for prime movers. A fuel tank should be sized for the number of hours of full load operation as determined for the specific application.

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.

7.3.3 Emergency energy storage

Where the emergency source of power is energy storage (such as a storage battery), it should be capable of carrying the emergency load without recharging while maintaining the voltage of the energy storage throughout the discharge period within $+5\%$ and -12% of its nominal voltage. If the energy storage is not normally connected to the emergency switchboard, it should be automatically connected in the event of failure of the main power supply.

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

When energy storage is used as the source of emergency lighting and power, transfer to the energy storage should be automatic upon failure of the ship service source. Upon restoration of ship service power and an

appropriate time delay, the emergency system should be automatically reconnected to the ship service source.

See Clause 11 for general requirements applicable to energy storage installation.

7.3.4 Emergency power distribution system

The emergency, interior communication and electronics switchboards must meet all requirements as detailed in IEEE Std 45.7.

The emergency switchboard should be supplied during normal operation from the main switchboard by an interconnecting feeder. This interconnecting feeder should be protected against short-circuit and overload at the main switchboard and, where arranged for feedback, protected for short-circuit at the emergency switchboard. The interconnecting feeder should be disconnected automatically at the emergency switchboard upon failure of the main source of electrical power. Means shall be provided to prevent auto closing of the emergency generator circuit breaker should a fault occur on the emergency switchboard.

Normal power from the ship's generating plant for the emergency loads should be supplied to the emergency loads by an automatic transfer device (i.e., circuit breaker, contactor, automatic transfer switch, and so on) and located remotely from the main switchboard. When installed in switchboards, the automatic transfer device should use electrically operated circuit breakers when installed in switchboards. When independently enclosed, the automatic transfer device should be of the equipment type with coils energized only during the transfer operation. Automatic transfer switches should conform to the requirements of UL 1008 or IEC 60947-6-1.

Upon interruption of normal power, the prime mover driving the emergency power source should start automatically. When the voltage of the emergency source reaches 85% to 95% of nominal value, the emergency loads should transfer automatically to the emergency power source. The transfer to emergency power should be accomplished within 45 s after failure of the normal power source. If the system is arranged for automatic retransfer, the return to normal supply should be accomplished when the available voltage is 85% to 95% of the nominal value and the expiration of an appropriate time delay. The emergency generator should continue to run without load until shut down either manually or automatically by use of a timing device.

If fast transfer schemes (less than 15 cycles) are used, the ABT devices feeding motor loads should be equipped with an adjustable time delay to permit low voltage protection (LVP) motor controllers to open.

Regulatory requirements typically do not allow non-emergency loads to be connected to an emergency switchboard. However, for some complex designs such as naval combatants where an "emergency" generator provides back-up power for a limited amount of ship's loads, then:

- For ready availability of the emergency source of electrical power to emergency loads, arrangements should be made, where necessary, to automatically disconnect non-emergency loads from the emergency power source upon loss of ship's normal power.
- If any non-emergency loads are connected to the emergency switchboard and if the system is arranged for feedback operation (through the interconnection feeder), they should automatically be disconnected at the emergency power source upon detection of 95% of full load current of the emergency generator to prevent an overload condition.
- Protective devices and circuitry shall be provided to automatically disconnect the interconnection feeder and any non-emergency loads should a main power failure occur while the emergency generator is running (i.e., exercising or testing).

The emergency switchboard should be arranged to prevent parallel operation of an emergency power source with any other source of electrical power (i.e., main power), except where suitable means are taken for safeguarding independent emergency operation under all circumstances. This will allow for the emergency generator to be used to supply non-emergency loads. This is useful when exercising and testing the emergency generator(s).

Where parallel operation is possible and allowable by regulatory rules, the emergency generator shall be equipped with the appropriate synchronizing controls in accordance with IEEE Std 45.7.

7.3.5 Emergency switchboard configuration

If two (or more) ship service generating plants are provided, with paralleled or automatic 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 service switchboard connected to an ABT device on the emergency switchboard.

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.

7.3.6 Temporary emergency power

A temporary power source provides emergency power in the interim period between the loss of main power and the establishment of emergency generator power.

Where a temporary source of emergency power is required, it should consist of energy storage suitably located for use in an emergency. Energy storage shall be in accordance with Clause 11. A converter may be used for supplying the temporary emergency bus for ac loads. The energy storage should have sufficient capacity and should be arranged to automatically supply the services listed in the following paragraphs of this subclause for 30 min (if they depend on an electrical source for their operation) in the event of failure of either the main or emergency source of power.

Where temporary emergency power is required, it shall be in accordance with this subclause. It shall feed the following designated loads:

- The lighting required in 7.3.7.
- All essential internal communication equipment, fire detection, and associated alarm equipment.
- All internal communication equipment required in an emergency.
- 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.

The temporary emergency bus should be supplied from the final emergency bus through an ABT device.

7.3.7 Temporary emergency circuits

The emergency generator supplied power source should be supplemented by a temporary emergency source in accordance with 7.3.6. The capacity of the temporary emergency source should be determined by the connected load of all emergency circuits listed as follows:

- Navigation lights
- 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
- Radio room lighting
- 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.
- At least one light in each berthing compartment accommodating 20 or more persons
- 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
- Boat and embarkation deck lighting
- Essential communication circuits among the navigating bridge, machinery spaces, and the steering gear room
- Watertight door operating gear (if electric) and indicating system
- Emergency loudspeaker or public address system
- General or emergency alarm and the fire alarm systems
- Gyro compass
- 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.

7.3.8 Final emergency circuits

The following circuits should be connected to the final emergency bus:

- Navigation lights