



IEEE Recommended Practice for Electrical Installations on Shipboard— Design

IEEE Industry Applications Society

Developed by the
Petroleum & Chemical Industry Committee

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Petroleum & Chemical Industry Committee
of the
IEEE Industry Applications Society

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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

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Introduction

This introduction is not part of IEEE Std 45.1-2023, IEEE Recommended Practice for Electrical Installations on Shipboard—Design.

The IEEE 45™ series of standards comprises eight 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 at that time. Subsequently, the base document was dropped, resulting in the eight standards currently in the IEEE Std 45 series, including:

- IEEE Std 45.1™-2023, IEEE Recommended Practice for Electrical Installations on Shipboard—Design
- IEEE Std 45.2™-2023, 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 Std 45.4™-2018, IEEE 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

IEEE Std 45.1 provides recommendations for the design, selection, and installation of systems and equipment aboard both naval 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 recommendations is overall electrical power system and subsystem design. Recommendations 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 eight recommended practices addressing electrical installations on ships and marine platforms.

The terms high voltage, medium voltage, and low voltage are often encountered, but depending on the application, the ranges of voltages to which they apply can differ substantially. If these terms are encountered, their definition in the context of their use should be understood. To avoid ambiguity, the terms high voltage, medium voltage, and low voltage are not used in this recommended practice.

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 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

1.5 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.

1.6 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

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

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.

ABS Guidance Notes on Cathodic Protection of Ships.⁸

ABS Guidance Notes on Control of Harmonics in Electrical Power Systems.

ABS Guide for Crew Habitability on Ships.

ABS Guide for Fuel Cell Power Systems for Marine and Offshore Applications.

ABS Guide for Use of Lithium-ion Batteries in the Marine and Offshore Industries.

ABS Guide for Use of Supercapacitors in the Marine and Offshore Industries.

ABS Requirements for Autonomous and Remote Control Functions.

ANSI C63.12, American National Standard Recommended Practice for Electromagnetic Compatibility Limits and Test Levels.⁹

ANSI/NEMA MG 1, Motors and Generators.¹⁰

API RP 14F, Recommended Practice for 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.¹¹

API RP 14FZ, Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, 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.¹²

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

⁸ABS publications are available from the American Bureau of Shipping (<https://ww2.eagle.org>).

⁹ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

¹⁰NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

¹¹API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA (<http://www.api.org/>).

¹²ASTM publications are available from the American Society for Testing and Materials (<http://www.astm.org/>).

ASTM F1003, Standard Specification for Searchlights on Motor Lifeboats.

IACS UR E11, Unified requirements for systems with voltages above 1 kV up to 15 kV.

IEC 60034, Rotating electrical machinery.¹³

IEC 60038, IEC standard voltages.

IEC 60060-1, High-voltage test techniques—Part 1: General Definitions and Test Requirements.

IEC 60076 Series, Power transformers.

IEC 60092 Series, Electrical installations in ships.

IEC 60146 Series, Semiconductor converters.

IEC 60529, Degrees of protection provided by enclosures (IP Code).

IEC 60664-1, Insulation coordination for equipment within low-voltage supply systems.

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 62368-1, Audio/video, information and communication technology equipment—Part 1: Safety requirements.

IEC TS 60815-Series, Selection And Dimensioning Of High-Voltage Insulators Intended For Use In Polluted Conditions.

IEC/EN/UL 61800-5-1, Adjustable speed electrical power drive systems—Part 5-1: Safety requirements—Electrical, thermal and energy.

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

IEC/IEEE 80005-1, Utility connections in port—Part 1: High voltage shore connection (HVSC) systems—General requirements.¹⁴

IEC/IEEE 80005-2, Utility connections in port—Part 2: High and low voltage shore connection systems—Data communication for monitoring and control.

IEEE Std C50.13™, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.^{15, 16}

IEEE Std C57™, Series on transformers.

¹³IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>) and the American National Standards Institute (<http://www.ansi.org/>).

¹⁴ISO publications are available from the International Organization for Standardization (<http://www.iso.org/>) and the American National Standards Institute (<http://www.ansi.org/>).

¹⁵The IEEE standards or products referred to in this clause are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

¹⁶ IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

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 C57.18.10™, IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers.

IEEE Std C62.11™, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV).

IEEE Std C62.21™, IEEE Guide for the Application of Surge Voltage Protective Equipment on AC Rotating Machinery 1000 V and Greater.

IEEE Std C62.22™, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

IEEE Std C62.37.1™, IEEE Guide for the Application of Thyristor Surge Protective Device Components.

IEEE Std C62.41.1™, IEEE Guide on the Surge Environment in Low-Voltage (1000 V and less) AC Power Circuits.

IEEE Std C62.41.2™, IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.

IEEE Std C62.41.3™, IEEE Guide for Interactions between Power System Disturbances and Surge-Protective Devices.

IEEE Std C62.42.0™, IEEE Guide for the Application of Surge-Protective Components in Surge-Protective Devices and Equipment Ports—Overview.

IEEE Std C62.44™, IEEE Guide for the Application of Low-Voltage (1000 V rms or Less) Surge Protective Devices Used on Secondary Distribution Systems (Between the Transformer Low-Voltage Terminals and the Line Side of the Service Equipment).

IEEE Std C62.72™, IEEE Guide for the Application of Surge-Protective Devices for Use on the Load Side of Service Equipment in Low-Voltage (1000 V or Less, 50 Hz or 60 Hz) AC Power Circuits.

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 45.4™, IEEE Recommended Practice for Electrical Installations on Shipboard—Marine Sectors and Mission Systems.

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

IEEE Std 45.6™, IEEE Recommended Practice for Electrical Installations on Shipboard—Electrical Testing.

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

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 1349™, IEEE Guide for the Application of Electric Machines in Zone 2 and Class I, Division 2 Hazardous (Classified) Locations.

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 Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems on Ships.

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

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

IEEE Std 3002.8™, IEEE Recommended Practice for Conducting Harmonic Studies and Analysis of Industrial and Commercial Power Systems.

IEEE Std 3003.1™, IEEE Recommended Practice for System Grounding of Industrial and Commercial Power Systems.

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 2.¹⁷

MIL-DTL-917, Detail Specification: Electric Power Equipment, Basic Requirements For.

MIL-STD-461, Department of Defense Interface Standard: Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.¹⁸

MIL-STD-1399-300-1, Department of Defense Interface Standard: Section 300, Part 1, Low Voltage Electric Power, Alternating Current.

¹⁷ ISA publications are available from the International Society of Automation (<http://www.isa.org/>).

¹⁸ MIL publications are available from the U.S. Department of Defense (<http://quicksearch.dla.mil/>).

MIL-STD-1399-300-2, Department of Defense Interface Standard: Section 300, Part 2, Medium Voltage Electric Power, Alternating Current.

NAVSEA Technical Publication T9070-A3-DPC-010/310-1 Electrical Power Load Analysis (EPLA) for Surface Ships.¹⁹

NFPA 70, National Electrical Code® (NEC®).^{20, 21}

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.

SAND2015-10759, Sandia Report, Recommended Practices for the Safe Design and Operation of Flywheels.²²

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 1997.²³

UL 73, Standard for Motor-Operated Appliances.²⁴

UL 153, Standard for Portable Electric Luminaires.

UL 197, Standard for Commercial Electric Cooking Appliances.

UL 399, Standard for Drinking-Water Coolers.

UL 471, Standard for Commercial Refrigerators and Freezers.

UL 486A–486B, Standard for Safety Wire Connectors.

UL 840, Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment.

UL 921, Standard for Commercial Dishwashers.

UL 924, Standard for Emergency Lighting and Power Equipment.

UL 1008, Standard for Transfer Switch Equipment.

UL 1042, Standard for Electric Baseboard Heating Equipment.

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

UL 1598, Standard for Luminaires.

¹⁹ T9070-A3-DPC-010/310-1 is available upon email request to CommandStandards.fct@navy.mil

²⁰ 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/>).

²¹ NFPA publications are published by the National Fire Protection Association (<http://www.nfpa.org/>).

²² Sandia publications are published by Sandia National Laboratories(<https://www.sandia.gov>)

²³ SOLAS publications are available from the International Maritime Organization, 4 Albert Embankment, London SE1 7SR, United Kingdom.

²⁴ UL publications are available from Underwriters Laboratories (<http://www.ul.com/>).

UL 1598A, Supplemental Requirements for Luminaires for installation on Marine Vessels.

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

UL 60079 series, Standard for Explosive Atmospheres.

U.S. DOE Energy Storage Handbook.²⁵

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.²⁶

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 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.

black start: Energizing the ship's electrical system from a blackout condition such as a dark ship or dead ship state.

blackout: Aboard ship, a power outage (also power cut or power failure) of electrical power to an entire ship. A blackout may be characterized as either a dark ship or a dead ship. Dark ship is when there is no power generation online, but energy storage is available for control system and startup. Dead ship is when there is no generation online and all the energy storage is depleted.

²⁵ U.S. DOE Energy Storage Handbook is published by Sandia National Laboratories (<https://www.sandia.gov/ess/publications/doe-oe-resources/eshb>).

²⁶ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

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

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.

choke: An in-line transformer or a set of inductors with a large impedance to common-mode current and/or non-fundamental frequency differential-mode currents, and a low impedance to differential-mode current at the fundamental frequency (or dc). Chokes are used to control common-mode currents and/or differential-mode harmonic and interharmonic currents.

clearance: The shortest distance between two exposed conductors through an air gap.

common-mode current: The instantaneous sum of the conductor currents in the same direction for a set of conductors.

common-mode voltage: The voltage between a neutral point and another voltage reference (such as ground or another neutral point).

comparative tracking index: The maximum voltage, measured in volts, at which a material withstands 50 drops of contaminated water without tracking.

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.

conductor: a component made out of a material with low electrical resistivity. Often, but not always, conductor is used to refer specifically in an electrical distribution system to the conductors in which current is intended to flow.

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

creepage: The shortest distance between two exposed conductors along the surface of insulating material.

dark ship: *See:* **blackout.**

dead ship: *See:* **blackout.**

decisive voltage class: classification of the working voltage into one of 4 classes (A, B, C, or D) for the purpose of determining the protective measures against electrical shock. The classes are defined in IEC/EN/UL 61800-5-1.

design electrical load: For a particular application, the electrical load for which an electrical source should at least be capable of supplying continuously. Design electrical load includes applicable margins and service life allowances.

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.

displacement power factor: Displacement power factor (dPF) is equal to $\cos\Phi$, with Φ being the angle between the fundamental current and voltage. Displacement PF can be either leading or lagging. Inductive loads are lagging while capacitive loads are leading.

distortion power factor: Distortion power factor (hPF) is the reduction in the power factor due to distortion of the voltage and current waveforms. The distortion power factor is equal to the (true) power factor divided by the displacement power factor (dPF). Distortion PF is neither leading nor lagging. For typical nonlinear loads, the dPF will be near unity. PF, however, can be very low because of the distortion component. For example, the dPF of a variable speed drive will be near unity but its PF and hPF are often in the 0.7 to 0.8 range unless current waveform distortion mitigation is applied.

drip proof: An enclosure with an IP rating of 22 to 26, 32 to 36, 42 to 46, 52 to 56, or 62 to 66.

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.

emergency conditions: A situation or occurrence of a serious nature that may result in electrical power system interruptions or deviations, such as the occurrence of ship service generator failure and the emergency generator coming online. Frequency excursions under emergency conditions are measured as a percentage of nominal frequency. Voltage excursions under emergency conditions are measured as a percentage of nominal system voltage.

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.

excitation: The means for providing regulated dc to the field windings of a synchronous generator or motor for the purpose of establishing a magnetic field.

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

frequency converter: A converter used to vary the output waveform and frequency to that needed by load equipment.

frequency modulation: The permitted recurring variation in frequency during normal operation over a period up to 10 s. Frequency modulation may be caused by regularly and randomly repeated loading. Frequency modulation is measured as a percentage of nominal frequency.

$$\text{Frequency modulation (\%)} = \left[\frac{f_{\max} - f_{\min}}{2 \times f_{\text{nominal}}} \right] \times 100$$

frequency tolerance: The maximum permitted departure from nominal frequency of the fundamental waveform during normal operation, excluding transients. 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.

frequency transient: A sudden change in frequency (f_{system}) of the fundamental waveform from an initial frequency of operation (f_{initial}) that goes outside the frequency tolerance limits, returns to, and remains inside these limits within the frequency transient recovery time after initiation of the disturbance. Frequency transient tolerance is in addition to frequency tolerance limits and measured as percentage of nominal frequency.

$$\text{Frequency transient tolerance (\%)} = \left[\frac{f_{\text{system}} - f_{\text{initial}}}{f_{\text{nominal}}} \right] \times 100$$

frequency transient recovery time: The time period from the start of the disturbance until the frequency recovers and remains within frequency tolerance limits.

galvanic isolation: (A) A method of electrical isolation where neither the signal nor the common of the output of the isolator is dc coupled to the signal or common of the input of the isolator, except for low-level leakage associated with non-ideal components. (B) A principle of isolating functional sections of electrical power systems, thus preventing the movement of charge-carrying particles from one section to another, i.e., no direct current flows between the sections. Energy or information can still be exchanged between the sections by other means, e.g., by capacitance, induction, or electromagnetic waves or by optical, acoustic, or mechanical means.

Galvanic isolation is used in situations where two or more electric circuits must transfer energy among them, but their neutrals may be at different potentials. It is an effective method of breaking ground loops by preventing unwanted current from flowing between two units sharing a ground conductor. Galvanic isolation can also be used for safety.

generator differential protection: A protection scheme where the current measurements at both ends of each generator stator winding are compared; if the current measurements differ more than a prescribed amount, then a protection action, such as generator shutdown, is activated.

hazardous (classified) location: A location (area) where fire or explosion hazards can exist due to flammable gases, flammable liquid-produced vapors, combustible liquid-produced vapors, combustible dusts, or combustible fibers or flyings, or ignitable fibers or flyings.

imbalance: A measure of how the rms phase current magnitude differs in a three-phase set of conductors. Imbalance is calculated by:

$$\% \text{ Imbalance} = \frac{I_{\text{max}} - I_{\text{min}}}{\frac{1}{3}(I_a + I_b + I_c)} \times 100$$

where: I_a , I_b , and I_c are the rms phase current magnitudes, I_{max} is the maximum of the rms phase currents, and I_{min} is the minimum of the rms phase currents.

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.

ingress protection: Rating of the degree of protection or sealing effectiveness in electrical enclosures against intrusion of objects, water, dust or accidental contact, defined by IEC 60529.

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.

interface control document: A document that describes physical and functional interfaces of equipment with a shared interface. An interface control document's purposes are to establish and maintain compatibility between the equipment with a shared interface and to communicate design decisions with respect to the interface to the designers and providers of the equipment with the shared interface. An interface control document may describe interfaces such as (but not limited to) mechanical, electrical, fluid, monitoring signals, sensor signals, and control signals.

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

line voltage unbalance (three-phase system): The difference between the highest and lowest line-to-line voltages (rms) measured as a percentage of nominal system voltage.

$$\text{Line voltage unbalance (\%)} = \left[\frac{V_{\text{line to line max}} - V_{\text{line to line min}}}{V_{\text{nominal}}} \right] \times 100$$

locked rotor: Test condition of a motor where the rotor is held stationary for the purpose of taking measurements such as current, torque, or kVA.

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.

neutral point: voltage reference for a set of conductors where the sum of the instantaneous conductor voltages with respect to the neutral point is zero. *See:* **common-mode voltage**.

nominal frequency: The designated frequency (f_{nominal}) in Hz for a power system used as a reference value for establishing other power quality measures.

nominal system voltage: The designated voltage for a power system used as a reference value for establishing other power quality measures. For direct current, single phase ac, and three-phase ac systems, the nominal system voltage is measured line-to-line.

nonhazardous location: *See:* **unclassified location**.

ordinary location: *See:* **unclassified location**.

partitioning or segregation: The separation of higher and lower voltage rated components and sub-components into enclosures within the same equipment.

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

power factor: power factor (PF), also known as true power factor (tPF) is the ratio of the real power to the product of the rms values for the current and voltage waveforms. The power factor for the power system reflects frequency and all of the non-fundamental (distortion) frequencies. Non-linear loads, such as rectifier circuits, do not typically shift the current waveform, rather they distort it. These distorted waveforms contain frequency components that do no useful work and, therefore, are reactive in nature.

proof tracking index: The numerical value of the proof voltage expressed in volts which a material can withstand without tracking under specified test conditions.

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:

$$X_C = \frac{1}{2\pi fC} \text{ and } X_L = 2\pi fL$$

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.

sectionalization: Division of separately earthed systems within the same ship electrical distribution system through transformer isolation.

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 frequency component: The ratio in percentage of the rms value of a single frequency (not the fundamental) to the rms value of the fundamental.

single-phase circuit: A circuit consisting of two-phase conductors and optionally a neutral conductor. The voltage between the phase conductors is ac. The voltages of the phase conductors with respect to the neutral conductor (if provided) are equal in magnitude and 180 electrical degrees apart.

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
- Directly in revolutions per minute

steady-state voltage range: Voltage range over which the system voltage setpoint can be set.

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.

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) = $120 f/p$). Thus, the speed of the motor can be varied by varying the frequency of the power source. The synchronous motor generally operates at unity power factor and can be used to improve the system power factor. It is generally the motor of choice for ac propulsion systems.

system voltage: The average of the rms line-to-line voltages for all phases of a power system.

system voltage setpoint: Voltage to which the generator (or other power source) controls are regulating the system voltage.

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

three-phase circuit: A circuit consisting of three-phase conductors and optionally a neutral conductor. The voltages between each pair of phase conductors are ac with the same fundamental frequency; the phase angles of these voltages are 120 electrical degrees apart. The currents through the phase conductors are ac, have the same fundamental frequency, and the phase angles of these currents are 120 electrical degrees apart when the loads are balanced.

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.

total waveform distortion (TWD): The ratio in percentage of the rms value of the residue (after elimination of the fundamental) to the rms value of the fundamental.

totally enclosed water-to-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.

unclassified location (nonhazardous location or ordinary location): A location determined to not be a hazardous (classified) location. *See:* **hazardous (classified) location**.

variable frequency drive (VFD): A converter using controlled rectifier or transistor devices that has the capability of varying the frequency and proportional voltage of the output waveform to provide speed control of motors.

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.

voltage tolerance: The maximum permitted departure of the system voltage from nominal system voltage during normal operation, excluding transient variations. It includes variations such as those caused by load changes, environment (temperature, humidity, vibration, inclination), switchboard meter error, and drift. The voltage tolerance is measured as a percentage of nominal system voltage.

voltage transient: A sudden change (excluding spikes) in system voltage that goes outside the user voltage tolerance limits and returns to and remains within these limits within the time period between 1 ms and the voltage transient recovery time after the initiation of the disturbance. The voltage transient (percent) is the difference between the instantaneous system voltage ($V_{\text{transient}}$) during the disturbance and the instantaneous value of the fundamental voltage waveform (V_{system}) extrapolated from immediately prior to the disturbance, expressed as a percentage of nominal system voltage.

$$\text{Voltage transient (\%)} = \left[\frac{V_{\text{transient}} - V_{\text{system}}}{V_{\text{nominal}}} \right] \times 100$$

voltage transient recovery time: The time elapsed from initiation of the disturbance until the system voltage recovers and remains within voltage tolerance limits.

watertight: In the context of an enclosure, an enclosure with an IP rating of 57, 58, 67, or 68. In other contexts, impervious to the flow of water.

working voltage: The maximum rms and recurring peak ac voltage, or mean dc voltage, exclusive of transient overvoltages, an insulation system (including air) between two conductors is subjected to under normal conditions, and for faulted conditions (i.e., ground faults) that may exist for extended periods of time. In some standards, working voltage is referred to as “system voltage” or “rated voltage”.

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
AIT	autoignition temperature
ALISN	active line impedance stabilizing network
AVR	automatic voltage regulator
BOP	blow out preventer
C&C	creepage and clearance
CE Code	Canadian Electrical Code
CENELEC	European Committee for Electrotechnical Standardization
CFR	code of federal regulations
CM	common mode
CODLAD	combined diesel electric and diesel
CODLOD	combined diesel electric or diesel
CODLAG	combined diesel electric and gas turbine
CODLOG	combined diesel electric or gas turbine
COGLAG	combined gas turbine electric and gas turbine
COGLOG	combined gas turbine electric or gas turbine
COLREGS	International Regulations for Preventing Collisions at Sea
CSDU	column-stabilized drilling unit
CTI	comparative tracking index
DM	differential mode
DNV GL	Det Norske Veritas & Germanischer Lloyd
DUT	device under test
DVC	decisive voltage class
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
FFT	fast Fourier transform
FMEA	failure mode and effects analysis
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
IP	ingress protection
IPS	integrated power system
ITHD	current total harmonic distortion
LF	load factor

LISN	line impedance stabilization network
LTi	linear and time invariant
LTV	linear time-varying
LVP	low voltage protection
MBT	manual bus transfer
MESG	maximum experimental safe gap
MIC	minimum igniting current
MODU	mobile offshore drilling unit
MTBSI	mean time between service interruption
NEC	National Electrical Code
NRTL	nationally recognized testing laboratory
PARD	periodic and random deviations
PDC	protective device coordination
PDSS	propulsion derived ship service
PSD	power spectral density
PSID	power system interface device
PTI	power take-in
PTI	proof tracking index
PTO	power take-off
PWM	pulse width modulated
QoS	quality of service
RFI	radio frequency interference
RM&A	reliability, maintainability, and availability
RMS	root mean square
RTD	resistance temperature detection
SCR	silicon controlled rectifier
SEDU	self-elevating drilling unit
SLI	starting, lighting, and ignition
SOLAS	international convention for the safety of life at sea
SSL	solid state lighting
t1	reconfiguration time
t2	generator start time
TEAAC	totally enclosed air-to-air cooled
TEC	Thévenin equivalent circuit
TEFC	totally enclosed fan-cooled
TEWAC	totally enclosed water-to-air cooled
THD	total harmonic distortion
TPF	true power factor
UPS	uninterruptible power supply
VFD	variable frequency drive
VPI	vacuum-pressure-impregnation
VSCF	variable speed constant frequency

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.

The applicability of the IEEE 45 series of standards to particular vessel types is described in IEEE Std 45.4.

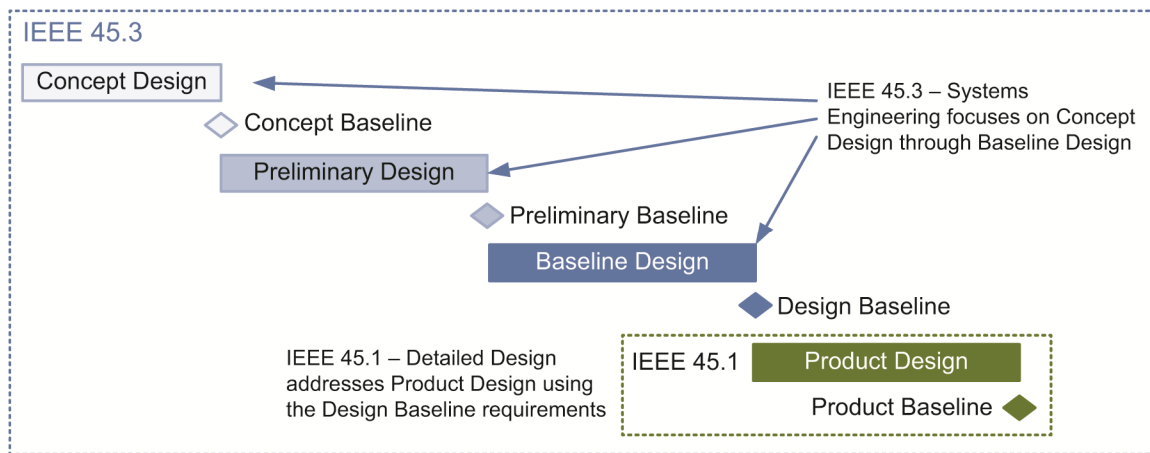


Figure 1—Design process

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 bill of material
- Electric plant load analysis
- Reliability, maintainability, and availability (RM&A) analysis*
- Quality of service (QoS) analysis*
- Electrical power system corrosion control description*
- Failure modes and effects analysis (FMEA)
- Model Description Documents (MDD)*
- Simulation and analyses 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:²⁷

- 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

²⁷ Adapted from IEEE Std 15288.1.

- 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

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.

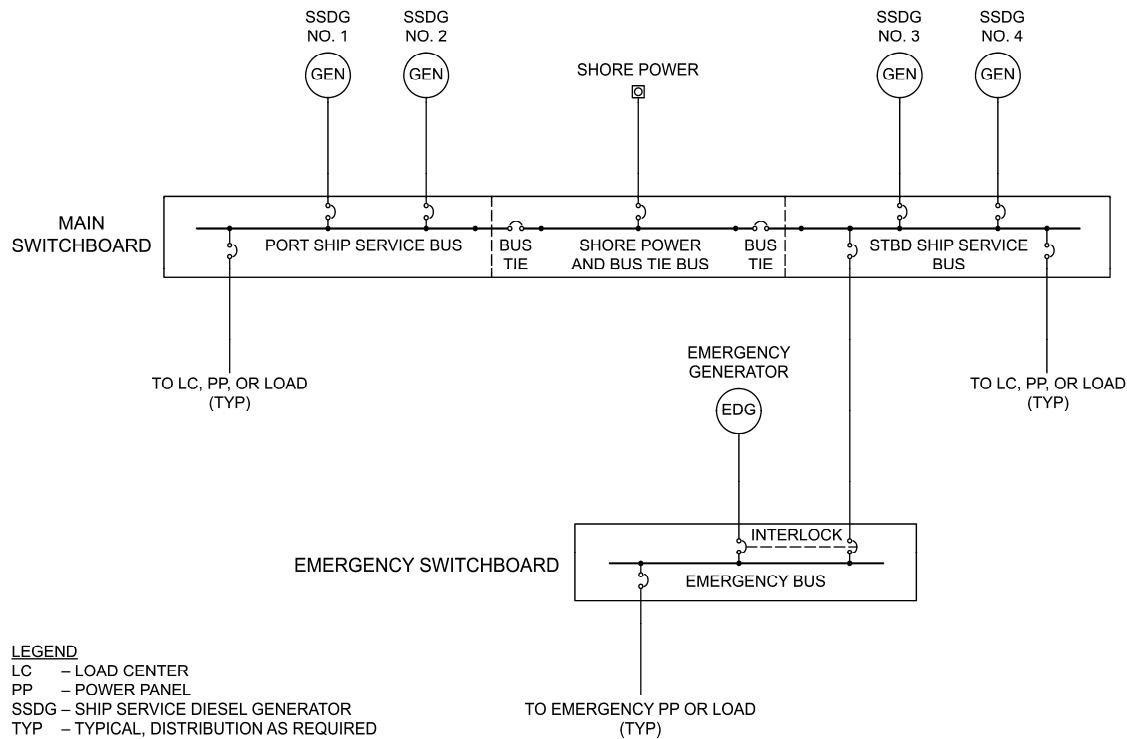


Figure 2—Notional radial architecture for commercial marine ships

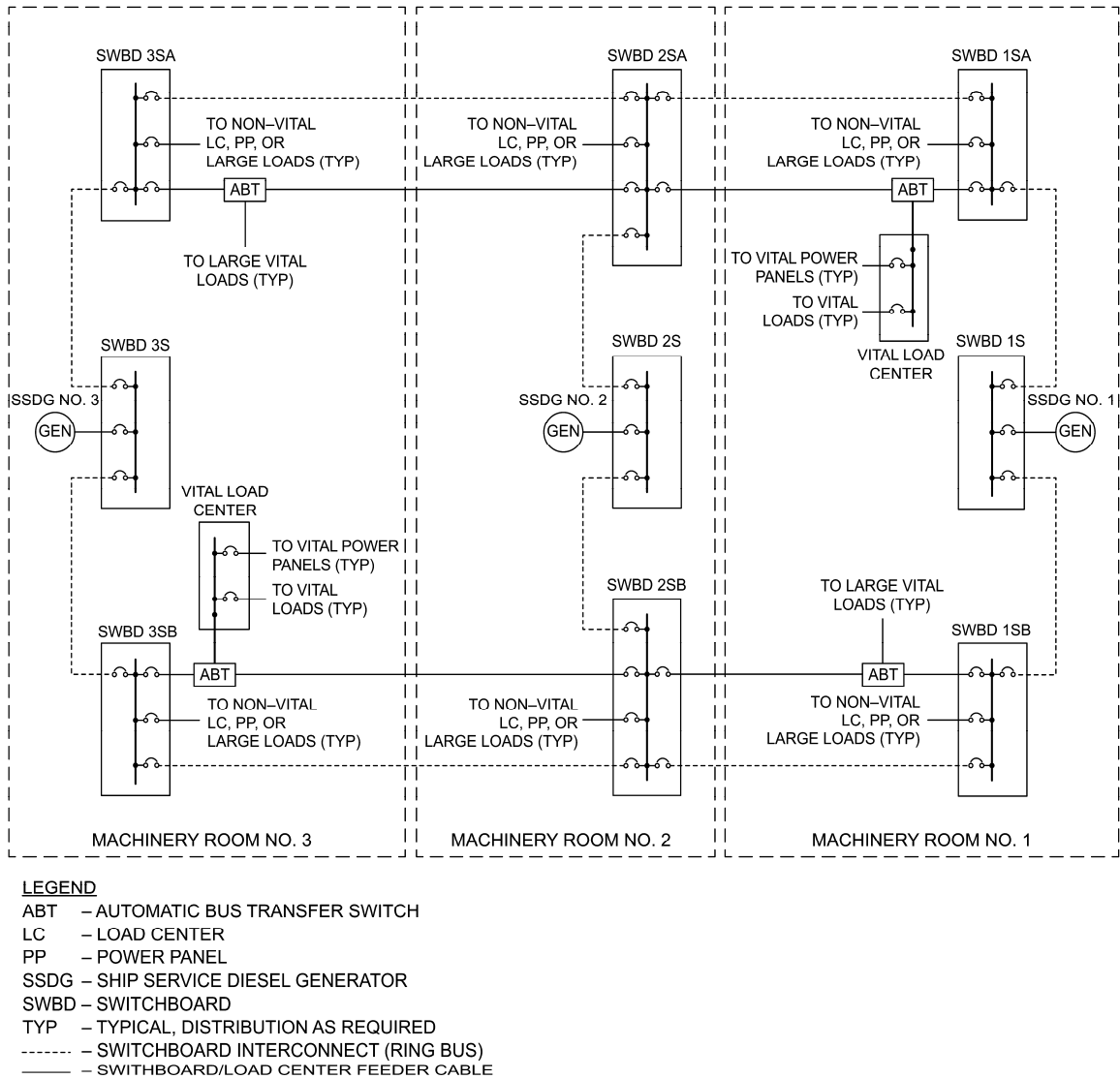


Figure 3—Notional radial architecture for naval warships

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.

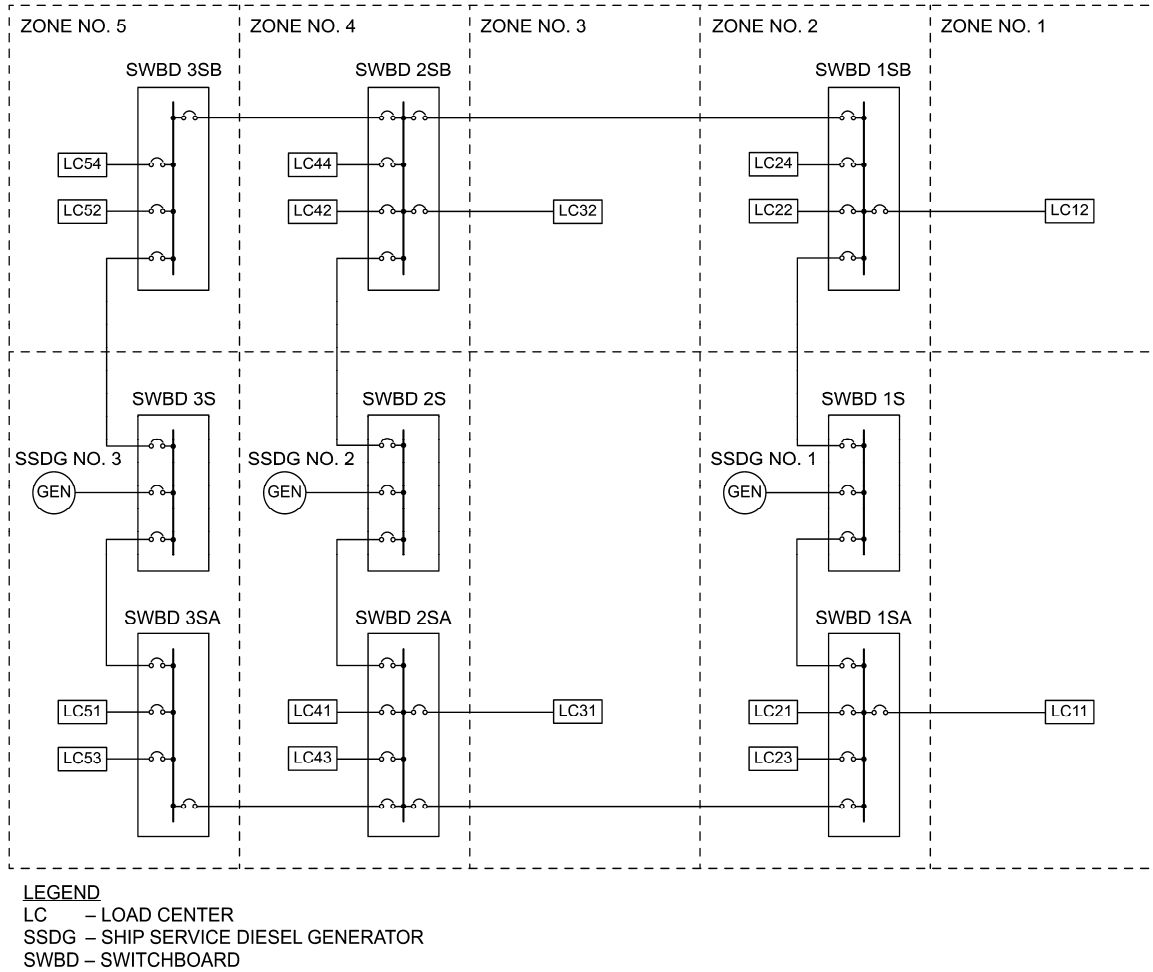


Figure 4—Notational zonal architecture for naval warships

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 recommended 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 distribution system types

The following distribution system types are recognized as standard for ac distribution:

- Two-wire with single-phase: Loads connect to the two wires
- Three-wire with single-phase: Third wire (middle wire) has voltage midway between other wires. Loads connect to any two wires with the proper voltage.
- Three-phase, three-wire: Three-phase loads connect to all three wires. Single phase loads connect to any two wires.
- Three-phase, four-wire: Fourth wire is a neutral conductor. Three-phase loads connect to the first three wires and may connect to the fourth wire. Single phase loads connect to any two wires with the proper voltage.

The following distribution system types are recognized as standard for dc distribution:

- Two-wire: Loads connect to the two wires.
- Three-wire: Third wire (middle wire) has voltage midway between other wires. Loads connect to any two wires with the proper voltage.

5.3 Nominal system voltage

The standard ac nominal system voltages and associated power utilization voltages shown in Table 1 are recommended:

Table 1—Standard ac nominal system voltages and power utilization voltages

Nominal system voltage (Volts rms)	Power utilization voltage (Volts rms)	1 phase	3 phase	Notes
120	115	Yes	Yes	
208	200	Loads only	Yes	120 volts line to neutral with three-phase four-wire ac
230	220	Yes	Yes	
240	230	Yes	No	Three-wire with single-phase ac 120 volts line to voltage
400	380	Loads only	Yes	230 volts line to neutral with three-phase four-wire ac
450	440	No	Yes	
480	460	No	Yes	
600	575	No	Yes	
690	660	No	Yes	
3300	3300	No	Yes	
4160	4160	No	Yes	

Nominal system voltage (Volts rms)	Power utilization voltage (Volts rms)	1 phase	3 phase	Notes
6600	600	No	Yes	
11000	11000	No	Yes	
13800	13800	No	Yes	

For three-phase systems, the nominal system voltage and power utilization voltage are measured line-to-line. The nominal system voltage may also be referred to as the power generation voltage.

For nominal system voltages greater than 1000 V, the percentage voltage drop between generators and loads can be expected to be less than for voltages no greater than 1000 V. For systems with nominal system voltages greater than 1000 V, the user voltage tolerance (see 5.6) and the generator voltage regulation adjustability (see 8.4.7) are usually sufficient to accommodate voltage drops in the distribution system; the nominal system voltage and the power utilization voltage have the same value.

AC power consuming equipment (loads) should be chosen based on the power utilization voltage and the power characteristics recommended in 5.6.

Standard voltages and associated power quality are also provided by IEC 60038 (does not provide power quality requirements), IEEE Std 1826, IEC/ISO/IEEE 80005-1, MIL-STD-1399-300-1, and MIL-STD-1399-300-2.

The following legacy ac voltages are no longer recommended for new installations:

- 380 volts nominal system voltage and 350 volts power utilization voltage
- 2400 volts nominal system voltage and 2300 volts power utilization voltage

The standard dc nominal system voltages up to 1000 volts and associated power utilization voltages shown in Table 2 are recommended:

Table 2—Standard dc nominal system voltages and power utilization voltages

Nominal system voltage (Volts)	Power utilization voltage (Volts)	2 wire	3 wire
110	105	Yes	No
220	210	Yes	Yes
375	360	Yes	Yes
600	570	Yes	Yes
650	620	Yes	Yes
700	670	Yes	Yes
750	720	Yes	Yes
1000	950	Yes	Yes

The voltages in Table 2 are line to line. For three wire systems, the nominal system voltage and power utilization voltage are measured line-to-line; line-to-middle wire voltage shall not be considered as the nominal system voltage. The nominal system voltage may also be referred to as the power generation voltage.

The following dc voltages above 1000 volts are recommended as standard nominal system voltages:

— 1.5 kV, 3 kV, 6 kV, 12 kV, 18 kV, 24 kV, 30 kV

See IEEE Std 1709 for additional guidance.

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 and aircraft support 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.

A nominal frequency of 60 Hz is preferred to maintain compatibility with shore power connections. If the use of shore power is not anticipated, or if 50 Hz shore power is available at the anticipated ports served by the ship, then 50 Hz nominal frequency may be desirable.

For small vessels having minimal power apparatus (up to 15 kW), 120 V nominal system voltage, three-phase (three wire) or single-phase, 120/240 V nominal system voltage single-phase (three wire), or 120/208 V nominal system voltage three-phase (four wire) generation and distribution is recommended, with three-phase or single-phase distribution for power and lighting. If 50 Hz power is employed, 230 V or 240 V nominal system voltage, three-phase (three wire) or single-phase power is recommended.

For intermediate-size vessels with power apparatus (up to 100 kW), three-phase (four wire) 120/208 V power generation and distribution with three-phase (four wire) or single-phase distribution for power and lighting is recommended. If 50 Hz power is employed, three-phase (three wire) 230 V or 240 V nominal system voltage, or three-phase (four wire) 230/400 V nominal system voltage is recommended.

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 using nominal system voltages of 450 V, 480 V, or 690 V and lighting distribution using a nominal system voltage of 120 V single-phase or three-phase (three wire) or 120/208 V, three-phase (four-wire). If 50 Hz power is employed, three-phase power with a nominal system voltage of 400 V, 600 V, or 690 V is recommended with lighting distribution employing 230 V or 240 V three-phase (three wire) or single-phase distribution, or three-phase (four wire) 230/400 V distribution.

For vessels having a very large electrical system requiring higher voltage power generation, consideration should be given to generating three-phase, three-wire ac power with a nominal system voltage of 13–800 V, 11 000 V, 6600 V, 4160 V, or 3300 V, with lower nominal system voltages to be derived from transformers or power converters.

For systems that provide single-phase lighting feeders from three-phase distribution systems, single-phase lighting feeders should be balanced at the switchboard to provide approximately equal load on the three-phase system. Imbalance should not exceed the recommendation of 9.8.6.

For vessels requiring dc power generation, and having little power apparatus (up to 11 kW), a nominal system voltage of 110 V is recommended. Where a greater amount of dc power apparatus is provided (up to 22 kW), 110/220 V dc, three-wire generators and distribution is recommended. Ships with loads requiring 28 V, 270 V, or 380 V dc are recommended to provide these loads with power from point-of-use power conversion.

For vessels requiring dc power generation with power apparatus greater than 22 kW, the selection of nominal system voltage should be based in part on the availability of power apparatus and appropriate switchgear.

Ships with loads requiring dc voltages or ac voltages or frequencies not provided in a distribution system are recommended to provide these loads with power from point-of-use power conversion.

5.6 AC power system characteristics

AC power distribution systems should maintain the system characteristics described in MIL-STD-1399-300-1, MIL-STD-1399-300-2, or Table 3 under all operating conditions.

Power-consuming equipment should operate satisfactorily under the conditions described in MIL-STD-1399-300-1, MIL-STD-1399-300-2, or Table 3, and 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 voltage or frequency for successful operation not provided by the distribution system should incorporate power conversion equipment to convert power from the power distribution system.

Power consuming equipment should operate satisfactorily when supplied with power that has a nominal voltage between the nominal power utilization and nominal system voltages. The difference between the nominal system voltage and the power utilization voltage accounts for voltage drop due to cables and other distribution system equipment.

Table 3—Alternating current (ac) power characteristics

Characteristics	Limits
Frequency (reference system frequency)	
a) Frequency tolerance	±5%
b) Frequency transient	
1) Frequency transient tolerance	±10%
2) Frequency transient recovery time	5 s
c) Frequency modulation	0.5%
Voltage (reference nominal system voltage)	
a) Voltage tolerance	+6%/−10%
b) Voltage transient	
1) Voltage transient tolerance	±20%
2) Voltage transient recovery time	1.5 s
c) Line voltage unbalance (three-phase systems only)	3%
Combined	
a) Sum of frequency tolerance (%) and voltage tolerance (%)	+6%/−10

Power equipment and power consuming equipment should operate normally following successful completion of pulse impulse voltage tests in accordance with IEC/EN/UL 61800-5-1 or IEC 60950. Pulse impulse voltage tests should be conducted on at least one production unit (typically first article) of a particular design.

Power equipment and power consuming equipment should not be damaged under emergency conditions where the voltage can range from 0% to 112% of nominal system voltage and the frequency can range from 0% to 135% of nominal frequency for up to 2 minutes. Power equipment and power consuming equipment should be capable of operating normally after emergency conditions when voltages and frequency return to within tolerance limits. Emergency power consuming equipment running prior to the emergency condition shall either continue running or automatically restart and resume functionality within 30 seconds once the emergency condition ends. Other equipment may shut down in a fail-safe manner during emergency conditions and be manually restarted once voltages and frequencies return to within tolerance limits.

The total waveform distortion (TWD) of the voltage at the switchboard, load center, or power panel directly connected to a load should not exceed 8% and any single frequency component of the voltage waveform should not exceed 5%. If these values are exceeded, distribution equipment and load equipment should be designed to operate at the higher values. The impacts of higher voltage waveform distortion (above the levels specified previously) such as increased heat losses, instrumentation errors, and possible system instability should be evaluated to ensure system performance is not degraded. If economical, consideration should be given to limiting the TWD of the voltage waveform to no more than 5% and limiting any single frequency component to no more than 3%. If the TWD of the voltage waveform exceeds 5% or any single frequency component exceeds 3%, equipment specifications should include the expected maximum values for TWD and the equipment vendors should be made aware of this requirement.

Load equipment should limit current distortion in accordance with IEEE Std 519 under all operating conditions from standby to full load. For the purpose of applying IEEE Std 519, the point of common coupling should be considered the load connection to a switchboard, load center, or power panel. In cases where the current waveform distortion is above that specified in IEEE Std 519, the impacts of the higher current waveform distortion such as increased heat losses, instrumentation errors, and possible system instability should be evaluated, and current waveform distortion mitigation means should be incorporated as they are needed to help ensure adequate system performance. IEEE Std 519 provides guidance for mitigation means.

In power systems with multiple voltage levels connected through transformers, the voltage regulation at the power generation voltage level may require tighter regulation to achieve the power quality requirements at the other voltage levels due to transformer regulation.

5.7 DC power systems characteristics

DC power distribution systems with nominal voltage below 1000 volts should maintain the system characteristics described in Table 4 under all operating conditions.

Power-consuming equipment should operate satisfactorily under the conditions described in Table 4, and should be designed to withstand the power interruption, transient, EMI, RFI, and insulation resistance test conditions inherent in the system. Power-consuming equipment directly connected to the dc source requiring a dc or ac voltage for successful operation not provided by the distribution system should incorporate power conversion equipment to convert power from the power distribution system.

Power consuming equipment should operate satisfactorily when supplied with power that has a voltage between the nominal power utilization and nominal system voltages. The difference between the nominal system voltage and the power utilization voltage accounts for voltage drop due to cables and other distribution system equipment.

Table 4—Direct current (dc) power characteristics

Characteristics	Limits
Voltage (references nominal system voltage)	
a) Steady state	
1) Steady-state voltage tolerance (rms)	$\pm 1.5\%$
2) Steady-state voltage range (rms) (0 to rated power)	$\pm 4\%$
3) Steady-state voltage ripple (rms)	4%
4) Steady-state peak-to-peak voltage deviation	18%
b) Transient	
1) Voltage transient tolerance	$\pm 20\%$
2) Voltage transient recovery time	1.5 s

Voltage limits are expressed as a percentage of the nominal system voltage value. Steady-state voltage tolerance, steady-state voltage range and steady-state voltage ripple are in root mean square (rms). Steady-state peak-to-peak voltage deviation and voltage transient tolerance are instantaneous values.

Steady-state voltage ripple is the rms value of the non-dc periodic component of the voltage.

Steady-state peak-to-peak voltage deviation is the magnitude of the difference between the maximum and the minimum instantaneous voltage in steady-state conditions. It includes both periodic and random deviations, often referred to as PARD.

Power conversion equipment may permit closer control of voltages. Lower limits may be agreed by owners and builders.

Power system characteristics for equipment internal buses where only one manufacturer is responsible for the integration of all the connected equipment and control systems should not be restricted by the system characteristics described in Table 4.

For special applications where dc sources supply the main distribution system without power conversion interfaces, the steady-state voltage range may be extended to up to $-30/+10\%$. Special precautions should be considered to help ensure that, at the lower voltage limit, currents do not exceed the power and distribution systems equipment rating values. Power limitation should not be considered as a means to limit the currents within the power and distribution systems equipment rating values.

For steady-state voltage ripple associated with frequency in the range of kHz or greater, provisions should be made to evaluate and mitigate radiated emissions.

Power equipment and power consuming equipment should operate normally following successful completion of pulse impulse voltage tests in accordance with IEC/EN/UL 61800-5-1 or IEC 62368-1. Pulse impulse voltage tests should be conducted on at least one production unit (typically first article) of a particular design.

Power equipment and power consuming equipment should not be damaged under emergency conditions where the voltage can range from 0% to 112% of nominal system voltage for up to 2 minutes. Power equipment and power consuming equipment should be capable of operating normally after emergency conditions when the voltages return to within tolerance limits. Emergency power consuming equipment running prior to the emergency condition shall either continue running or automatically restart and resume functionality within 30 seconds once the emergency condition ends. Other equipment may shut down in a fail-safe manner during emergency conditions and be manually restarted once voltages return to within tolerance limits.

For vessels utilizing a dc power distribution system with nominal voltage above 1000 volts, IEEE Std 1709 provides the recommended requirements.

5.8 Key electrical power system design inputs

5.8.1 Electric plant load analysis

The EPLA developed in previous design phases documents the basis for estimating the operating load for different ship operating conditions. The EPLA is updated as part of product design (see 4.3). The EPLA 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 make sure that 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)²⁸

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 consider 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 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.

²⁸ 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. Consideration of QoS is otherwise optional.

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 min to 5 min for naval vessels. Commercial vessels should 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 should be capable of supporting all categories of load for all loads for every operating condition with all generators online, and should support all loads except the exempt load with one generator out of service. Unless otherwise specified by the customer, that portion of propulsion load in excess of the power required to achieve 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, the exempt load is treated as a 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 should be designed for temperature extremes and conditions expected. Typically, the following conditions can be used: ambient temperature values of 5 °C to 40 °C in accommodation areas and similar spaces; 0 °C to 45 °C in main and auxiliary machinery spaces; 0 °C to 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 –25 °C to 65 °C on the exterior of the ship and 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 5.

Table 5—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:
 - 1) Vibration frequency range of 5 Hz to 50 Hz with a velocity amplitude of 20 mm/s
 - 2) 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.

A droop characteristic is the steady-state behavior of generator sets where the y-axis is a quantity that is essentially the same for paralleled generator sets (such as frequency and voltage) and the x-axis is a quantity that sums for the paralleled generator sets to the load demands (such as real and reactive power). Figure 5 displays example droop generator set characteristics for three paralleled generator sets; Figure 5(a) and 5(b) refer to ac systems and Figure 5(c) refers to dc systems. The operating point for frequency or voltage is where the corresponding real or reactive power of the generator sets sum to the load. Droop characteristics are typically linear, but need not always be. The system controls may adjust the droop characteristics of the generator sets such that the operating point for frequency or voltage is at or near the nominal frequency or nominal system voltage.

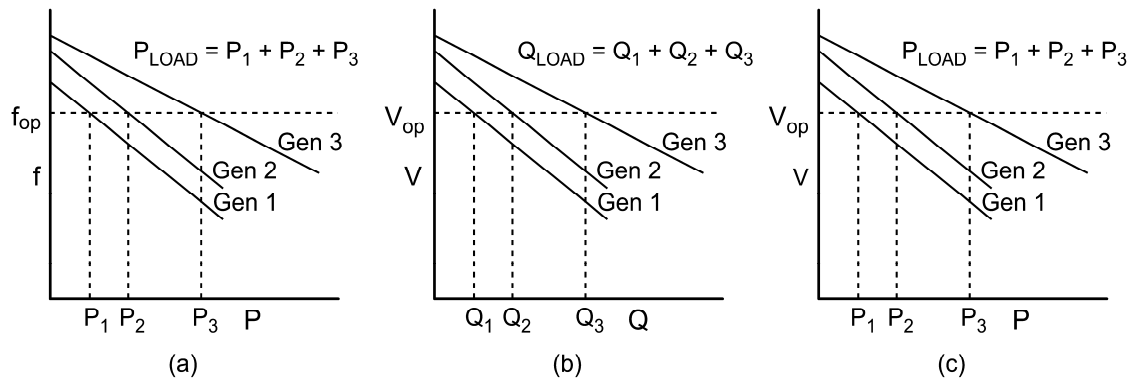


Figure 5—Droop characteristic

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 recommendations 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 an ac power distribution system with a nominal system voltage greater than 1000 V interconnected via transformers with an ac power distribution system having a nominal system voltage less than 1000 V (typically 450 V to 480 V). A ship may have a single ac power distribution system with a nominal system voltage greater than 1000 V 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 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 recommendations for power distribution.

6.3.2 Primary bus

A primary bus is a term reserved for an ac or dc bus with a nominal system voltage greater than 1000 V and applies only to vessels with a primary 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 nominal system voltages between 400 V and 1000 V.

6.3.4 Secondary bus

A secondary bus provides electrical power with a nominal system voltage typically no greater than 400 V 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 should be included in load flow analyses and in calculating the required current ratings of switchgear and cables.

See Clause 10 for additional recommendations 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