



IEEE Recommended Practice for Electrical Installations on Shipboard—Controls and Automation

STANDARDS

IEEE Industry Applications Society

Developed by the
Petroleum and Chemical Industry Committee

IEEE Std 45.2™-2023
(Revision of IEEE Std 45.2-2011)



IEEE Recommended Practice for Electrical Installations on Shipboard—Controls and Automation

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Petroleum and Chemical Industry Committee
of the
IEEE Industry Applications Society

Approved 8 November 2023

IEEE SA Standards Board

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Abstract: The recommendations for controls, control applications, control apparatus, and automation on shipboards are established by this document. Present-day technologies, engineering methods, and engineering practices are reflected by these recommendations. This document is intended to be used in conjunction with IEEE Std 45™.

Keywords: automation, computer-based system, control system, IEEE 45.2™, interior communication system, monitoring, navigation system, remote control, safety system

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Norbert Doerry

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Steve Swindler
Amit Trivedi
Tuyen Vu
Nikolas Xiros
Mehdi Zadeh

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Mihaela Albu
Dwight Alexander
John Amy
Donald Ankele
Peter Baen
Michael Basler
Paul Becker
Mohamed Belkhatay
Steven Bezner
Kenneth Bow
Bill Brown
Gustavo Brunello
Koti Reddy Butukuri
William Byrd
Paul Cardinal
Norbert Doerry
Marcus Durham
Robert Durham
A. Ferraro
Keith Flowers
Carl Fredericks
Kamal Garg
Shubhanker Garg
J. Travis Griffith

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Guy Hardwick
Christopher Harper
Chris Heron
Werner Hoelzl
John Houdek
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Piotr Karocki
John Kay
Yuri Khersonsky
Robert Konnik
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Wei-Jen Lee
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Steven Liggio
Geoff Lowe
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Rajendra Mistry
Jeff Mizener
Mfanasibili Nkonyane
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Introduction

This introduction is not part of IEEE Std 45.2-2023, IEEE Recommended Practice for Electrical Installations on Shipboard—Controls and Automation.

The IEEE Std 45™ series 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 the following:

- 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 [B21]⁶
- 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 [B22]
- IEEE Std 45.7™-2012, IEEE Recommended Practice for Electrical Installations on Shipboard—AC Switchboards [B23]
- IEEE Std 45.8™-2016, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems

⁶The numbers in brackets correspond to those of the bibliography in [Annex A](#).

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IEEE Recommended Practice for Electrical Installations on Shipboard— Controls and Automation

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1. Overview

These recommendations establish the minimally acceptable guidelines for the design, selection, and installation of systems and equipment aboard marine vessels applying electrical apparatus for power, propulsion, steering, automation, navigation, lighting, and communications. These recommendations describe present-day acceptable electrical engineering methods and practices. The primary focus of these IEEE Std 45.2 guidelines is on the deliverability of [shipboard controls and automation](#) ~~control~~ systems and the equipment, conditions and documentations that should be required. Guidelines for the design and integration of ship electrical systems are discussed elsewhere in this IEEE Std 45™ series, which comprises [eight](#) ~~nine~~ recommended practices addressing electrical installations on ships and marine platforms.

It is recognized that changes and improvements in shipboard requirements may develop that are not specifically covered herein; such changes, if incorporated in the design, should be equal to [or greater than](#) 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 [shipbuilders, ship owners, system providers, and](#) regulatory agencies governing electrical engineering requirements.

Corrosion due to improper or inadvertent grounding of control systems is a significant problem in marine platforms. Corrosion is not addressed in this standard; however, it [should](#) ~~must~~ be considered in the overall design of [shipboard controls and automation](#) ~~the platform's control~~ systems.

1.1 Scope

The recommendations for controls, control applications, control apparatus, and automation on shipboards 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 [other standards in the](#) IEEE Std 45:¹ [series](#).

1.2 Purpose

[As](#) an extension of the baseline technology and methods covered in IEEE Std [45.1TM](#) ~~45~~ and IEEE Std [45.3TM](#),⁷ [this document](#) ~~45.2~~ provides a consensus of recommended practices for control applications and automation in marine electrical engineering as applied specifically to ships, shipboard systems,² and equipment.

1.3 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 \(*shall* equals *is required to*\).](#)^{8,9}

¹ Information on ~~normative~~ references can be found in Clause 2.

⁸ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁹ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

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*).

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 Control of Harmonics in Electrical Power Systems.¹⁰](#)

[ABS, Rules for Building and Classing Marine Vessels.](#)

~~[API RP 14F, Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1 and Division 2 Locations, Fifth Edition.²](#)~~

ASTM F1166-95a(2006), Standard Practice for Human Engineering Design for Marine Systems, Equipment and Facilities.^{11 3}

¹⁰ABS publications are available from American Bureau of Shipping (<https://www.eagle.org>).

~~²API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA (<http://www.api.org/>).~~

^{11 3}ASTM publications are available from the American Society for Testing and Materials, ~~100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA~~ (<https://www.astm.org/> ~~<http://www.astm.org/>~~).

Code of Federal Regulations Title 46 Part 111 (46 CFR 111), Electric Systems—General Requirements.^{12 4}

Code of Federal Regulations Title 46 Part 113.25-25 (46 CFR 113.25-25), Communication and Alarm Systems and Equipment.

Code of Federal Regulations Title 46 Part 113.25-30 (46 CFR 113.25-30), Communication and Alarm Systems and Equipment.

IEC 60068-2-1, Environmental Testing—Part 2-1: Tests— ~~Test~~ Test A: Cold.^{13 5}

IEC 60068-2-2, Environmental Testing—Part 2-2: Tests— ~~Test~~ Test B: Dry heat.

IEC 60068-2-6, Environmental Testing—Part 2-6: Tests— ~~Test~~ Fc: Vibration (sinusoidal).

IEC 60068-2-30, Environmental Testing—Part 2-30: Tests— Test Db: Damp heat, cyclic (12 h + 12 h cycle).

IEC 60068-2-52, Environmental Testing—Part 2-52: Tests— Test Kb: Salt mist, cyclic (sodium, chloride solution).

IEC 60309-5, Plugs, socket-outlets and couplers for industrial purposes—Part 5: Dimensional compatibility and interchangeability requirements for plugs, socket-outlets, ship connectors and ship inlets for low-voltage shore connection systems (LVSC).

~~IEC 60079, Explosive Atmospheres—Part 0: Equipment—General requirements.~~

IEC 60947-1, Low-voltage switchgear and controlgear—Part 1: General rules.

IEC 61000-4-2, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.

¹²Code of Federal Regulations publication are available from <https://www.govinfo.gov/app/collection/cfr>.

⁴~~CFR publications are available from the U.S. Government Printing Office, 732 N. Capitol Street, Washington, DC 20401, USA (<http://www.gpo.gov/>).~~

^{13 5}IEC publications are available from the ~~Central Office of the~~ International Electrotechnical Commission, ~~3, rue de Varembe, P.O. Box 131, CH-1211, Geneva 20, Switzerland~~ (<http://www.iec.ch/>) ~~and the~~ ~~IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<https://www.ansi.org/> ~~<http://www.ansi.org/>~~).~~

IEC 61000-4-3, Electromagnetic compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-4, Electromagnetic compatibility (EMC)—Part 4-4: Testing and measurement techniques—Electrical fast transient/burst immunity test.

IEC 61000-4-5, Electromagnetic compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

IEC 61000-4-6, Electromagnetic compatibility (EMC)—Part 4-6: Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields.

IEC 60437 ~~Ed. 2.0 1997~~, Radio interference test on high-voltage insulators.

IEC 62271, High-voltage switchgear and controlgear.

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

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

[IEC/IEEE DIS 80005-3, Utility connections in port—Part 3: Low Voltage Shore Connection \(LVSC\) Systems—General requirements.](#)

IEEE Std 45.1TM, IEEE Recommended Practice for Electrical Installations on Shipboard—[Design](#).^{14,15}

IEEE Std [45.3TM](#) ~~995TM 1987~~, IEEE Recommended Practice for [Shipboard Electrical Installations— Systems Engineering](#) ~~Efficiency Determination of Alternating Current Adjustable Speed Drives— Part I—Load Commutated Inverter Synchronous Motor Drives~~.⁶

[IEEE Std 45.5TM, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations.](#)

¹⁴ ⁶ IEEE [publications are available](#) ~~Std 995 1987 has been withdrawn; however, copies can be obtained~~ from The Institute of Electrical and Electronics Engineers, ~~445 Hoes Lane, Piscataway, NJ 08854, USA~~ (<https://standards.ieee.org/http://standards.ieee.org/>).

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[IEEE Std 45.8™, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems.](#)

[IEEE Std 802.3™, IEEE Standard for Ethernet.](#)

IEEE Std 1566™, IEEE Standard for Performance of Adjustable-Speed AC Drives Rated 375 kW and Larger.^{7,8}

[IEEE Std 1662™, IEEE Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems.](#)

IEEE Std 1676™, IEEE Guide for Control Architecture for High Power Electronics (1 MW and Greater) Used in Electric Power Transmission and Distribution [Systems](#) ~~System~~.

IEEE Std [1709™](#) ~~1662™ 2008~~, IEEE [Recommended Practice](#) ~~Guide~~ for [1 kV to 35 kV Medium-Voltage DC](#) ~~Design and Application of Power Electronics in Electrical~~ Power Systems on Ships.

[IEEE Std 1815™, IEEE Standard for Electric Power Systems Communications—Distributed Network Protocol \(DNP3\).](#)

[MIL-STD-1399 Section 300, Part 1, Low Voltage Electric Power, Alternating Current.](#)¹⁶

[MIL-STD-1399 Section 300, Part 2, Medium Voltage Electric Power, Alternating Current.](#)

~~IEEE Std C37.90™ 1989, IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus.~~

~~IMO Resolution A830 (19) Code on Alarms and Indicators, 1995.~~⁹

NEMA ICS 1-~~1993~~, Industrial Control and System General Requirements.^{17 18}

NEMA 250, Enclosures for Electrical Equipment [1000](#) ~~1,000~~ V Maximum.

¹⁶MIL publications are available from the U.S. Department of Defense (<https://www.dsp.dla.mil/>).

^{17 8} [NEMA](#) ~~IEEE~~ publications are available from the [National Institute of Electrical Manufacturers Association](#) (<https://www.nema.org/> ~~and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA~~ (<http://standards.ieee.org/>).

¹⁸~~NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA~~ (<http://global.ihs>).

~~NFPA 70, 2007 Edition, National Electrical Code® (NEC®).~~^{11, 12}

NFPA 72-~~2010~~, National Fire Alarm and Signaling Code.¹⁸

SOLAS 74, Chapter II-1, Regulation 42, Emergency Source of Electrical Power in Passenger Ships.¹⁹

SOLAS 74, Chapter II-1, Regulation 43, Emergency Source of Electrical Power in Cargo Ships.

SOLAS 74, Chapter II-1, Regulation 50, Communication.

SOLAS 74, Chapter II-2, Regulation 21, Casualty threshold, safe return to port and safe areas. SOLAS 74, Chapter III, Regulation 6.4.2, General Emergency Alarm System.

~~SOLAS 74, Regulation III-6.4.2.~~¹³

~~SOLAS 74, Regulation III/50~~

~~SOLAS 74, Regulation II-1/42.~~

~~SOLAS 74, Regulation II-1/43. UL 363, Knife Switches.~~¹⁴

UL 489, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures.²⁰

UL 508A, Standard for Safety, Industrial Control Panels.

UL 845-~~2005~~, Motor Control Centers.

UL 913-~~2006~~, Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations.

¹⁸NFPA publications are published by the National Fire Protection Association (<http://www.nfpa.org/>).

¹⁹ ⁹ ~~SOLAS IMO~~ publications are available from ~~the~~ International Maritime Organization, ~~4 Albert Embankment, London SE1 7SR UK,~~ (<https://www.imo.org> ~~http://www.imo.org~~).

²⁰UL publications are available from Underwriters Laboratories (<https://www.ul.com/>).

¹¹. NEC and NFPA 70 are registered trademarks of the National Fire Protection Association, Inc.

¹². ~~NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269 9101, USA (<http://www.nfpa.org/>).~~

¹³. ~~SOLAS publications are available from International Maritime Organization, 4 Albert Embankment, London SE1 7SR UK, (<http://www.imo.org>).~~

¹⁴. ~~UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).~~

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* ~~:- Glossary of Terms & Definitions~~¹⁵ should be consulted ~~referenced~~ for terms not defined in this clause.²¹

~~**acceleration-insensitive drift rate:** The component of systematic drift rate that has no correlation with acceleration. See also: **drift rate; systematic drift rate.**~~

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.

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

automated systems: Software and/or hardware configured to achieve predetermined responses for well-understood operational environments without the need for constant human input.

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

autonomous systems: Systems designed with artificial intelligence and physical interfaces in order to operate adaptively in dynamic and unpredictable operational environments.

auxiliary machinery space: Spaces containing ship-service or mission machinery⁷ but located outside of the main machinery casing.

branch circuit (or final subcircuit): That portion of a wiring system that extends beyond the final overcurrent device protecting the circuit.

²¹*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.

¹⁵~~The IEEE Standards Dictionary: Glossary of Terms and Definitions is available at <http://shop.ieee.org>~~

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

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

cargo vessel: A vessel that carries bulk, containerized, or Ro/Ro 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.

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

~~code set: See: **coded character set.**~~

~~**coded character set:** A set of characters for which coded representation exist. *Syn:* **code set.**~~

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

computer-based system: A system that utilizes one or more embedded computers or processors to perform its functions.

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

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

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

controller: A device or group of devices used to control in a predetermined manner the electric [or mechanical](#) power delivered to the apparatus to which it is connected.

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

deterministic: A performance that responds to input signals fast enough to keep a sustained operation moving predictably at its required speed. For purposes of this guide, this means that the maximum [a](#) (1) jitter times, [b](#) (2) error handling times, [c](#) (3) task execution times, [d](#) (4) hardware response times, and [e](#) (5) communication times are known and specified, and further means that a certain control application may be used without additional consideration of a variability in response time or execution time. Such a system is deterministic for only those certain systems.

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

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

distribution panel: A panel that receives energy from a switchboard or a [load](#) ~~distribution~~ center and distributes power to energy-consuming devices.

~~**drift rate:** The slope at a stated time of the smoothed curve of tube voltage drop with time at constant operating conditions (adapted from ISO/IEC 9945-1:2003).~~

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

engineers operating station (EOS): A propulsion control station fitted with instrumentation, control systems, and actuators to enable propulsion and auxiliary machinery [to](#) be controlled and monitored, and the state of propulsion machinery space [to](#) be monitored, without the need of regular local attendance in the propulsion machinery space.

fail-safe: A characteristic in which, upon failure or malfunction of a component, subsystem, or system, the output automatically reverts to a predetermined design state of least critical consequence.

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

flag state authority: The authority under which a country exercises regulatory control over the commercial vessel [that](#) ~~which~~ is registered under its flag. This involves the inspection, certification, and issuance of safety and pollution prevention documents.

health monitoring: A process through which various data in a system are collected and analyzed in order to detect or predict faults or issues in the system.

human-machine interface (HMI): A system that can be comprised of hardware or software or combination of hardware and software that provides a set of mechanical and/or digital displays as well as controls (where applicable). These displays and controls are typically located on a digital dashboard or electromechanical panel or a combination of the two. It is used by the user to monitor information produced by the system or to collect information about the system. Additionally, it can also be used to provide the system with a stimulus to affect the operation of the system. Syn: man/machine interface (MMI); operator/machine interface (OMI).

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

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

~~input reference axis (IRA):~~ ~~The direction of an axis as defined by the case mounting surfaces, external case markings, or both. Contrast: **output reference axis.**~~

line replaceable unit (LRU): The smallest or lowest piece of equipment or subassembly that is replaceable onboard the vessel. Systems and subsystems may contain multiple numbers of them. Typical ones include circuit cards, sealed bearings, and drive motors.

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

~~under-voltage or~~ **low-voltage protection:** The effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power in the main circuit.

~~under-voltage or~~ **low-voltage release:** The effect of a device, operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit, but not to prevent the reestablishment of the main circuit on return of voltage.

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

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

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 fire-proof boundary of the machinery casing, and normally containing major ships equipment and prime moving equipment, including propulsion services equipment.

man/machine interface (MMI): See: [human-machine interface \(HMI\)](#).

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

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

mission plan: [A set of goals, objectives, and activities that a system may use in order to complete a mission, whether through automation or autonomously.](#)

motion plan: A set of trajectories (either predefined or generated dynamically from sensor data) that may be used by a system for executing mechanical motion in order to move from its current position to a desired future position.

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.

operator/machine interface (OMI): See: human-machine interface (HMI).

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

~~**output:** (A) Data that has been processed. (B) The process of transferring data from an internal storage device to an external storage device.~~

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

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

NOTE—An overload relay is intended to protect the motor or controller and does not necessarily protect itself.²²

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

prime mover: A primary shipboard engine, such as a diesel engine, gas turbine, or steam turbine, that converts fuel or a medium's stored energy into mechanical energy. This mechanical energy can propel—or be used to propel—the ship directly or generate—or be used to generate—electrical energy for propulsion and or distribution.

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

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

²² ⁴⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain [requirements needed to implement this standard](#).

receptacle outlet: An outlet where one or more receptacles is installed.

rectifier: A component for converting ~~alternating current (ac)~~ to ~~direct current (dc)~~ by inversion or suppression of alternate half-cycles.

remote control: A method to send a signal to a system from a source that is external or at a distance from that system.

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

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.

sensing and perception: The capability to collect data from various sensors integrated with a system and to extract information from that collected data, which can be utilized for decision-making.

~~**slip:** In an induction machine, the difference between its synchronous speed and its operating speed. It may be expressed in the following ways: (A) As a percent of synchronous speed, (B) As a decimal fraction of synchronous speed, (C) Directly in revolutions per minute.~~

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

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

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.

~~**systematic drift rate:** That component of drift rate that is correlated with specific operating conditions.~~

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

vital services: Services normally considered to be essential for the safety of the ship and its passengers and crew. These usually include propulsion, steering, navigation, firefighting, emergency power, emergency lighting, electronics, and communications functions. The identification of all vital services in a particular vessel is generally specified by the government regulatory agencies.

watertight enclosure: An enclosure constructed so that a stream of water from a hose not less than 25 mm in diameter under a head of 10 m from a distance of 3 m can be played on the enclosure from any direction for a period of 5 min without leakage. The hose nozzle ~~shall~~ should have a uniform inside diameter of 25 mm. (NEMA 250 Type 4 or 4X).

3.2 Acronyms and abbreviations

ABS American Bureau of Shipping

ABT automatic bus transfer

AIS automatic identification system

ALFUS autonomy levels for unmanned systems

ASD adjustable speed drive

ASTM American Society for Testing and Materials

BMS battery management system

CAC contextual autonomous capability

~~AC~~ ~~alternating current~~

CFR Code of Federal Regulations

CHIL controller hardware-in-the-loop

CIA confidentiality, integrity, and availability

CPP controllable pitch propellor

CRP contra rotating propellor

CT current transformer

DCS distributed control system

DVTP design verification test procedure

~~DC~~ ~~direct current~~

EMC electromagnetic compatibility

EMF electromagnetic field

EMI electromagnetic interference

EMS energy management system

EOS engineers operating station

~~EOT~~ ~~engine order telegraph~~

EUT equipment under test

FMEA failure modes and effects analysis

GPS Global Positioning System

HFE human factors engineering

HIL hardware-in-the-loop

HMI human-machine interface

HOI hardware of interest

HVAC heating, ventilation, and air conditioning

IA	interface algorithm
IACS	industrial automation and control systems
ICS	industrial control system
IEC	International Electrotechnical Commission
IED	intelligent electronic device
IGBT	insulated-gate bipolar transistor
~~GMDSS~~	~~global maritime distress and safety system~~
~~IEC~~	~~International Electro-technical Committee~~
~~IEEE~~	~~Institute for Electrical and Electronics Engineers~~
IMO	International Maritime Organization
INS	inertial navigation system
IP	ingress protection
IT	information technology
~~IRA~~	~~input reference axis~~
LAN	local area network
LC	inductor-capacitor filter
LCD	liquid-crystal display
LCL	inductor-capacitor-inductor filter
LED	light-emitting diode
LRU	line replaceable unit
LVP	low-voltage protection
LVR	low-voltage release
MASS	maritime autonomous surface ship
MIL	model-in-the-loop

<u>MMC</u>	<u>modular multilevel converters</u>
<u>MOI</u>	<u>model of interest</u>
<u>MOSFET</u>	<u>metal–oxide–semiconductor field-effect transistor</u>
NEMA	National Electrical Manufacturers Association
<u>NFAS</u>	<u>Norwegian Forum for Autonomous Ships</u>
NFPA	National Fire Protection Association
<u>NIST</u>	<u>National Institute of Standards and Technology</u>
<u>NPC</u>	<u>neutral point clamped</u>
<u>PA</u>	<u>power amplifier</u>
<u>PAC</u>	<u>programmable automation controller</u>
<u>PHIL</u>	<u>power hardware-in-the-loop</u>
<u>PIL</u>	<u>processor-in-the-loop</u>
PIV	peak inverse voltage
PLC	programmable logic control
<u>PSTP</u>	<u>periodic safety test procedure</u>
<u>PT</u>	<u>potential transformer</u>
<u>PWM</u>	<u>pulse width modulation</u>
<u>rms</u>	<u>root mean square</u>
~~PBX~~	~~public exchange~~
Ro/Ro	roll on, roll off
<u>RTD</u>	<u>resistance temperature detector</u>
~~PLCS~~	~~programmable logic control~~
RTOS	real-time operating system
<u>RTS</u>	<u>real-time simulator</u>

RTU remote terminal unit

~~RMS~~ ~~root means square~~

SCR silicon-controlled rectifier

SIL software-in-the-loop

SOLAS safety of life at sea

SWBD switchboard

TCP/IP transmission control protocol/internet protocol

THD total harmonic distortion

TTL transistor-transistor logic

UDP/IP user datagram protocol/internet protocol

~~UL~~ ~~Underwriters Laboratories~~

UPS uninterruptible power supply

UV ultraviolet

VFD variable frequency drive

VPN virtual private network

VSD variable speed drive

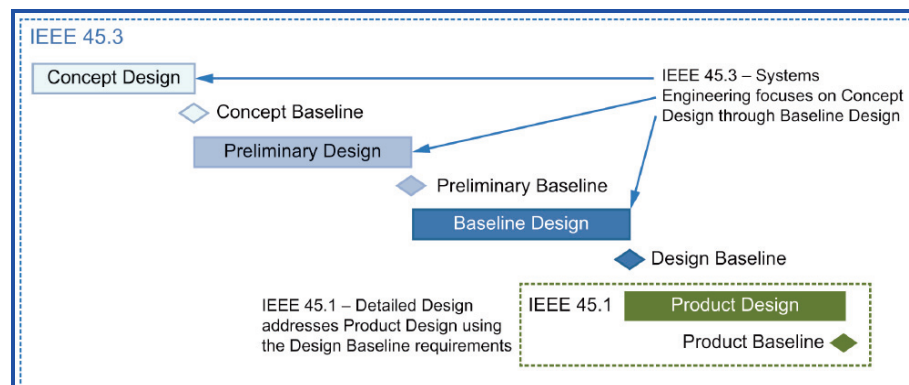
~~VOIP~~ ~~Voice Over Internet Protocol~~

4. Automation and control systems

4.1 System engineering

4.1.1 General

Figure 1 shows the design process from concept design to product baseline and the relationship between IEEE Std 45.1 and IEEE Std 45.3. This standard (IEEE Std 45.2) provides recommended practices specific to shipboard controls and automation systems primarily in support of IEEE Std 45.1 in the conduct of product design to develop the product baseline. Some clauses support IEEE Std 45.3 for all other phases of the design process. See IEEE Std 45.3 for a more complete description of the design phases and baselines.



(New)

Figure 1—Design process

4.1.2 Automation and control system functions

This document ~~clause~~ presents a guide for the design and installation of electrical and electronic equipment intended for control of key shipboard systems ~~machinery~~ in ships. This document ~~clause~~ deals with electrical, electronic, and programmable equipment and systems for control, monitoring, alarm, and protection on board vessels. It includes semiautomatic, fully automatic, and autonomous (unattended) systems, including but not limited to the following:

- Propulsion plants and associated systems including lube oil and fuel systems
- Boilers (oil, gas, or flue gas—main or auxiliary)

- c) Incinerators
- d) Steam or combustion turbines
- e) Diesel or gas engines
- f) Liquid and dry cargo handling and storage systems (including liquefied gases)
- g) Bilge and ballast systems
- h) Inert gas systems
- i) Refrigeration systems
- j) Electric power generating plants and distribution equipment and machinery
- k) Hotel auxiliary systems
- l) Damage control alarm and monitoring systems
- m) Fire detection alarm and monitoring systems

~~— Navigating bridge control systems~~

~~NOTE— Navigating bridge systems are included for those circumstances when machinery control is included in the integrated navigating bridge system. These recommendations address the remote machinery control, alarm, and monitoring aspects only. The navigation system recommendations are in 4.34.¹⁶~~

4.1.3 System design and procurement cycle

4.1.3.1 Concept design

Concept design is the beginning of the design process where the basic ship requirements and ship concepts are established. These behaviors, as applicable, are translated into high-level functional requirements for the functions described in Figure 1.

4.1.3.2 Preliminary design

During preliminary design, the functional requirements are refined and alternate machinery control systems architectures and possible implementations are analyzed to determine their suitability and effectiveness in meeting the functional requirements within an acceptable cost. Unsuitable architectures are eliminated from further consideration. Risks with the remaining architectures are identified and mitigated through such means as technical studies and experimentation. System analysis is conducted to ensure all requirements are able to be met within the proposed architectures.

4.1.3.3 Baseline design

The focus of baseline design is developing the procurement documents that incorporate the baseline design. Depending on the acquisition strategy, the design baseline may be more performance oriented or more detail oriented. In either case, technical studies and experimentation may be used to resolve knowledge gaps. The baseline design should be sufficiently complete to enable a common understanding of design and production scope between the owner and the shipbuilder to enable the two to establish a legal contract. In some cases, long lead material will be specified and procurements initiated during baseline design to support the construction schedule.

4.1.3.4 Product design

The shipbuilder often subcontracts for the design, production, and integration of the machinery control system into the ship. Close coordination between the shipbuilder or design agent in charge of the overall ship design and the machinery control system integrator is usually required to help ensure a successful outcome. During this stage, all machinery control system equipment, software, and their interconnection are identified and specifications developed. Some equipment and software may be procured during product design to support the construction schedule.

4.1.3.5 Production

During construction and fit-out of the ship, all remaining control system equipment and software are procured and tested by the producer to demonstrate adherence to the specification. Some or all of the machinery control system may be integrated in a land-based facility for integration testing prior to installation onboard ship, including controls hardware-in-the-loop (HIL) testing. Testing is also performed onboard ship, culminating in commissioning tests and sea trials.

4.2 Maintenance ~~philosophy and design~~

Shipboard controls and automation systems and equipment should be designed to support a maintenance philosophy as defined by the owner. That philosophy may be to expect the ship's crew to perform underway maintenance or to have vendor technicians perform maintenance in port. When underway maintenance by ship's crew is defined by ~~establishes~~ the owner, line replaceable units ~~unit~~ (LRU) assist in the facilitation of that philosophy. LRUs should be designed to be relatively easy for one person to remove and replace. Examples of LRUs are ~~as-a~~ circuit ~~boards~~ ~~board~~, ~~low-voltage~~ power ~~supplies~~ ~~supply~~, mechanical ~~subassemblies~~ ~~subassembly~~, or other self-contained ~~units~~ ~~unit~~ or logical ~~subassemblies~~ ~~subassembly~~. If not indicated elsewhere, electronic or electrical equipment designated as an LRU is preferred (to the extent practical) to ~~should~~ include an appropriate indicating device that distinguishes normal operation from a failed condition.

Repair of an ~~a~~ LRU should consist of a removal and replacement operation. This operation should be designed to reduce ~~minimize~~ the time from identification of the fault, through removal and replacement of the failed unit, to restoration of its normal operating condition.

A listing of recommended on-board repair parts should be provided with the control system.

4.3 Modernization

Shipboard controls and automation system equipment and systems should be designed to support a modernization philosophy as defined by the owner. In particular, network and computational capacity should incorporate excess capacity for future modifications and additions to the machinery control system. Open standards-based architectures should be employed as practical to enable new functionality as well as enabling procurement of replacements for obsolete LRUs.

4.4 Documentation

4.4.1 General

Each automation and/or control system is customized to each vessel or vessel class. As a result, documents are needed to define the hardware and computer functionality that is specific to each contract. Many documents should be required to be reviewed and/or approved by the vessel owner, shipyard, and regulatory authorities. Each contract should define which documents are to be submitted.

Project documentation for an automation or control system can be divided into the following categories:

- a) Procurement documents
- b) Design documents
- c) Factory test procedures and reports
- d) Installation documents
- e) Commissioning documents
- f) User documentation

4.4.2 Procurement documents

The owner and/or shipyard should provide (at a minimum) the following data to the automation/controls vendor:

- a) Specification detailing the scope and functions of the system
- b) Statement of Work outlining the deliverables, hardware, software, documentation, on-board service, and so forth
- c) Machinery arrangements showing location of controls in relation to the controlled units, arrangements, and details of consoles, including all support systems, and plans for all safety-related support systems, including fire detection and protection systems

4.4.3 Design documentation

4.4.3.1 General

Subclause 4.4.3 describes the minimum list of documents that should be developed by the controls system designer during product design. Documents may be required by contract to be provided to the customer, shipyard, flag state authority, classification authority, and so forth for information and/or approval.

4.4.3.2 Requirement analysis

A breakdown of the contract Statement of Work to quickly determine that all aspects are covered is required. Documents to be provided to regulatory authorities should be listed in this document.

4.4.3.3 Signal list

A signal list is a listing of all control system signal inputs and outputs showing full name, abbreviated name for use on system displays, type of sensor for inputs (e.g., 4 mA to 20 mA, RTD, thermocouple, voltage), and type of actuator/output for control outputs. Analog signals should include the range of meter scale/readout along with alarm setpoints and reset points. Analog signals should include the expected display accuracy and precision to be shown on digital readouts. The signal list evolves over the final design phase.

4.4.3.4 System one-line diagram

A drawing showing all major hardware items, their location, the power needed for each, and the data communications redundant bus connecting the items containing microprocessor controllers.

4.4.3.5 Outline and mounting diagrams

The diagram provides the mechanical outline, dimensions, weight, center of gravity, access door swing dimension, details for mounting to a yard-provided foundation, cable access locations, thermal load to ambient, and so forth. Depending on size and weight of an end item, consideration should be paid to lifting fittings to allow the shipyard to load the item.

4.4.3.6 Software functional description (for computer-/PLC-based systems)

This document defines the functions of the computer-based system. This document is written as input to computer programmers and is written in plain language. Details for alarms, auto-starts, auto-shutdowns, start inhibits, displayed meter ranges, relationship between analog sensor input and displayed data, and so forth should be included.

Examples of details for alarm functions may include: color of alarm indication, initial alarm condition flash rate, and the audible device to be actuated.

Control system computer display graphic screens should be listed with the specific equipment and signals shown on each mimic.

Propulsion control details (if part of system) should be included, for example, throttle lever position versus shaft r/min and propellor pitch (if fitted with CPP), engine speed limits, ramp up/down rates, CRP movement rates/limits, shaft r/min avoided dwell speeds, and so forth.

The control system self-monitoring techniques should be described. The vessel roll period when transiting should be included so that the proper damping functions can be applied to tank level readouts. The Signal List is a reference for this document.

4.4.3.7 Dynamic analysis (for propulsion control systems)

Dynamic analysis for ac/dc electrical marine grids is recommended to help ensure system stability and to evaluate the short-circuit transients. Especially when adopting dc distribution (IEEE Std 1709), unstable behaviors can occur if the LC filtering stages are not properly designed and integrated with high-bandwidth controlled loads. For this reason, a dynamic analysis is recommended to forecast instability beforehand and avoid ship blackout.

Numerical simulations or even hardware-in-the-loop (HIL) emulations can evaluate the system stability when the dc shipboard grid is known in detail. Given the parameters of the various power conversion components, filters, and controls, time varying as well as nonlinear behavior can be captured. Alternatively, reduced-order and averaged models based on the dominant poles of the system can be developed and used for both time- domain simulations as well as frequency-domain analysis. The latter can be used for impedance plots and the Nyquist plots to determine the margin of stability. These models can also be used for eigenvalue analysis where the typical left half plane position of all the poles indicates stability.

Damping methods to improve dc system stability can be either passive or active. In the case of passive methods, dissipative loads such as RC dampers can be suitably added to increase the system damping factor. In the case of active methods, the controls are calibrated to ensure a good margin of stability. Conversely, when the filter capacitors are intentionally oversized for the purpose of stability, additional dc short-circuit studies are recommended.

In general, there are two ways to check the dc system stability. First, time domain analyses are performed to highlight the settling times after step load disturbances. This process considers all transients—including large disturbances such as faults—and equilibrium settling times can be used as stability criteria in the large sense. HIL can also be used to perform this analysis as discussed in 4.13.2. Then, frequency domain or impedance analysis are done to define the stability margins in terms of gain margin and phase margins at various loading conditions, and this guarantees stability for small disturbances. Alternatively, dominant pole positions on the complex plane can be reported to summarize stability behavior.

Similar considerations about the necessary studies can also be done for ac shipboard power systems.

Other inputs for analysis may include engine load curves, fuel rates versus load, propeller curves, ship hull drag data (forward and astern), and reduction gear load (torque) limits. Outputs of this analysis should be diagrams showing shaft r/min (and direction) and propeller pitch versus time for changes in command throttle levers. Also, the areas of concern for torque should be shown to assure that torque limits are not exceeded for any possible command throttle lever sequence with various ship speeds ahead and astern. Time for ship to go from stop to full ahead or full astern should be calculated as well as time for the vessel to come to stop when throttle is commanded to full astern from a vessel full ahead condition. This analysis should result in optimized ship stopping times for emergency stop and best fuel efficiency vessel speeds.

4.4.3.8 System schematics

A document that shows each input sensor and output actuator with the equipment being monitored or controlled. The type of sensor cable is shown and if shielded, the location of grounding the shield is indicated. Each conductor of the cable is shown as well as the connecting terminals at both ends. Boundaries of control system enclosures are indicated to clarify equipment arrangement.

Data communication cables are shown with minimum type of cable to be used by the shipyard. Any grounded data cable connectors needed should have a model number for the connector shown on a parts list area of the drawing.

Power for the control system equipment is also shown.

4.4.3.9 Control system data bus network analysis

This document should report on an analysis of the expected performance of the control system data buses. The designer should confirm that the input contact to alarm display time is within contract requirements under various system conditions including periods of vessel shutdown with a possible large number of alarm conditions.

4.4.3.10 Human factors analysis

This is a report to demonstrate that the designer has considered human factors in the design of control console enclosures, control panels, and computer displays.

4.4.3.11 Failure modes and effects analysis (FMEA)

A failure modes and effects analysis (FMEA) as described in IEEE Std 45.1 and IEEE Std 45.3 should be conducted on the machinery control system.

4.4.3.12 Solid-state motor controller/configuration data

When used as part of the control system, each solid-state motor controller should have a project-specific data sheet that shows the information necessary to properly configure the controller device for items such as motor speed limit, motor kilowatt (kW) limit, motor speed ramp times, and so forth. This data should be included in the technical manuals and mounted in each controller enclosure.

4.4.4 Factory test procedures/reports

The control system provider should perform factory inspections and tests on all major system elements to assure compliance with the design specifications and the contract. Inspections and test should include, at a minimum, the following:

- a) Dimensional checks
- b) Functional test of hardware functions
- c) Functional test of software functions
- d) Electrical and control interface conformance tests
- e) Marine environment compatibility tests

The results of the inspections and tests should be recorded in reports to include the following:

- Date of tests
- Name of test technician
- List of any calibrated test equipment used, including the calibration expiration date

4.4.5 Installation documents

Installation documents provide instructions to the shipbuilder for safely installing control system components into the ship.

Installation documents should include considerations for protection of control devices that are exposed on cabinets and/or consoles from normal shipyard storage and ship construction environment hazards such as spills, bumps, dust, high humidity, temperature, and so forth.

For large deck-mounted cabinets or multicabinet consoles, the shipyard may need drawings to instruct them on how to safely lift the supplied items. In certain cases, a specially designed shipping foundation may be needed to prevent excessive stress due to bending.

If the end items are to be welded by the shipyard to foundations, the vendor should provide instructions to the shipyard to prevent damage to sensitive electronics from heat and from the stray currents caused by the welding equipment.

4.4.6 Commissioning documents

4.4.6.1 General

In addition to mechanical drawings showing dimensions, weight, center of gravity, mounting details, and ship interfaces for cables, piping (if needed), and so forth (all of which would be part of design documents), consideration should also be given to shipping and installation phase documentation.

At a minimum, the following document(s) should be developed to assure the safe commission of the control system on the vessel.

4.4.6.2 Preliminary tests

Preliminary tests include the following:

- a) Visual inspection check list of electrical power to each powered end item
- b) Visual inspection of all shipyard-provided data communication terminations and verification of grounded connectors, where required

- c) Initial power-on sequence check list
- d) For computer-based systems, launch programs and confirm that correct software versions are installed
- e) Functional check of vital alarm system
- f) Functional check of electric plant monitoring and control operation
- g) Functional check of all auxiliary machinery systems' remote operation
- h) Functional check of remote monitoring and control of the propulsion systems (engines, gears, clutches, propellor, shafts, steering)

4.4.6.3 Formal tests for regulatory bodies

Formal tests for regulatory bodies should be as follows:

- a) Design verification test procedure (DVTP)
- b) Periodic safety test procedure (PSTP)

4.4.7 User documentation

4.4.7.1 Technical manuals

Documentation for control and automation systems should ~~shall~~ be maintained on board the vessel (if the ship is crewed) or where the ship is controlled if the ship is not crewed. This documentation should include electronic versions of plans and technical manuals. The technical manuals should ~~shall~~ include the FMEA ~~failure mode effects analysis~~, and should include DVTPs ~~design verification test procedures~~ and PSTPs ~~Periodic Safety Test Procedures~~.

The plans and specifications should provide machinery arrangement showing location of controls in relation to the controlled units, arrangements, and details of consoles, including all support systems, and plans for all safety-related support systems, including fire detection and protection systems.

Technical manuals for software and firmware should include graphics for human interfaces for operation and installation.

All software and firmware configurations for equipment should have a backup installation copy available on the vessel. This ~~should~~ ~~shall~~ be available to ~~reinstall~~ ~~re-install~~ the software or firmware resident in the equipment.

Installation software tools and procedures for reinstallation and testing ~~should~~ ~~shall~~ be provided onboard the vessel.

Technical manuals should be provided for the controls and should contain, as a minimum, the following information:

- a) General overall system functional description concept of operations
- b) Operating instructions
- c) Test procedures to evaluate the operation and safety features of the complete system
- d) Trouble identification charts
- e) Maintenance and special repair procedures
- f) Illustrated parts lists and descriptions
- g) Software and firmware programming and user's manuals
- h) Electrical schematics
- i) Mechanical layout drawings
- j) Special purpose tools and test equipment

The operating instructions for the equipment should include sections providing examples and suggested use of the apparatus to maximize efficiency. The information should include types of conditions that can be encountered and typical responses to those conditions. Normal routine care and testing of the equipment should be discussed. Immediate responses to fault conditions of equipment, including the monitoring or control system itself, should be emphasized.

The technical instructions for the equipment should provide complete technical information on the system and the individual equipment items that make up the system. Information should be provided in a manner and in sufficient detail to allow a skilled technician to troubleshoot, identify the fault, and undertake the repair. Detailed testing and calibration procedures for the equipment should be provided and should include recommended test equipment. Any special purpose tools or test equipment that are identified in the technical manuals should ~~shall~~ be carried onboard the vessel. The documentation should include information on the various interfaces between the specific items of equipment.

The documentation provided should ~~may~~ include the following, as applicable:

- Overall description and specification of the system, software, and equipment
- Block diagrams for the computer hardware showing interfaces among workstations, local controllers, input/output data acquisition units, communication controllers, communication buses, and so on
- Logic flow or ladder diagrams
- Description of the alarm system and sequencing matrix, including how alarms are displayed, acknowledged, and assessed (if possible)
- Description of system backup units and redundancy features
- Description of the communication protocol(s), including estimated data transmission delays
- Description of the system security protocol to prevent unauthorized changes to programs
- Description of the system with regard to independence of the control/alarm/display systems, safety systems, and emergency shutdown systems
- Description of the priority handling of system tasks
- Description of uninterruptible power supply, its capacity, and the system's estimated power consumption requirements
- Equipment ratings and environmental parameters
- Installation methods

- System failure modes and effect analysis or similar analysis
- Mimic screens with display variables and manipulated values
- Signal table including a list of monitoring points, domains, their alarm settings, normal ranges, types, precision and accuracy, set and reset points, and out of range limits

4.5 General requirements

~~4.3 Control system~~

~~4.5.1 General design~~

When an automatic machinery control system is provided, the control and monitoring system should be designed and installed to achieve safe and effective operation, to at least the same level as could be obtained by skilled watch-keeping personnel. The system as installed should be capable of meeting all load and operational demands under steady-state and maneuvering conditions without the need for manual adjustment or manipulation. Therefore, the system design should accomplish at least the following:

- Unsafe effects of failure of vital automatic systems or remote-control systems are minimized by design, and failures are limited to fail-safe states (see Table 1).
- Prompt alerting of an appropriate crew member, either directly or by reliable instrumentation and alarms, of machinery failure, flooding, or fire.
- An alternative means to operate the vessel safely and to counteract the effects of the machinery failure, fire, or flooding.
- Indication at an attended control station of the status of operation of the equipment controlled from that location.

Programmable computer-based or computer-assisted systems are to be designed to provide operational capability upon loss of any processing component of the system that may cause hazards to personnel. Unless backup [systems](#), hardwired safety systems, and emergency shutdown systems are fitted, ~~all of a~~ computer-based [system](#) ~~system's~~ equipment or peripherals should be provided in duplicate and should automatically transfer duty functions to the corresponding standby system/equipment upon failure of an on-line equipment or system. Such action should be alarmed at the remote station. Additionally, particular attention should be paid at least to the following criteria in the design and installation of automatic or centralized control systems:

- *Maintainability*: The capability of keeping the control system in the designed state of operation.
- *Availability of spare components*: The capability of the manufacturer to readily supply components to avoid delaying the operation of the vessel.
- *Standardization*: The types of components used. Items that are readily available should be utilized wherever possible.
- *Operational capability*: The capability of keeping display and control device movements as simple as possible. Direction of control device movements should be parallel to the axis of the display they control.
- *Reliability*: The probability that a system will function within its design limits for a specified period of time. [Alternatively, one can define first unreliability as the probability of failure and then introduce reliability as the complement of unreliability; then, reliability is the probability of an item \(system or module\) being in its functional state without failure.](#)
- *Accessibility*: The ability to maintain components and subsystems without removal of, or interference with, other components and subsystems.

Where complex logic circuits are used for sequential startup or for operating individual plant components, indicators should be provided showing successful completion of the sequence of operation. Where a particular step is not completed in the sequence cycle, indicators should be provided designating the incomplete function. Manual override should permit control in the event of the failure of a logic circuit.

The control systems may be designed to incorporate hierarchical degrees of automation, starting from local manual control to full unattended automatic operation. The control of vital systems should be designed such that loss of automatic features automatically shifts the level of control to the next lower step or the state of least consequence. The design of the system should be such that the transfer to the next lower step does not change the status of the plant or the commanded order from that of the higher level. Additionally, the system should incorporate a feature that allows the operator to set the level of control desired from the main control station. Automatic mode changes should ~~shall~~ be alarmed. Typical fail-safe states are listed in Table 1.

Table 1—Typical fail-safe states

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

The control and automation system should support real-time monitoring and control of ship ~~propulsion, electrical, auxiliary, and steering~~ functions listed in 4.1.2. When provided for essential machinery functions, standby machines should incorporate automatic changeover features. The changeover function should be alarmed. Vital control, safety, and alarm systems should automatically transfer power sources to backup systems upon failure of the operating power source. The system should be designed such that the changeover operation does not further degrade the plant condition by inadvertently compounding the situation.

Alarm system design should be in compliance with IMO Resolution A.1021(26)-2009, with Appendix [B27].²³

4.5.2 ~~Ergonomics~~ Human factors engineering (HFE)

4.5.2.1 Control consoles and enclosures

Basic design of control consoles and enclosures should follow the guidance of ASTM F1166.

²³The numbers in brackets correspond to those of the bibliography in Annex A.