IEEE STANDARDS ASSOCIATION

IEEE Recommended Practice for Electrical Installations on Shipboard—Design

IEEE Industry Applications Society

Sponsored by the
Petroleum & Chemical Industry Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 45.1™-2017

IEEE Recommended Practice for Electrical Installations on Shipboard—Design

Sponsor

Petroleum & Chemical Industry Committee
of the
IEEE Industry Applications Society

Approved 23 March 2017

IEEE-SA Standards Board

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, navel vessels, ship, shipboard electrical systems

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

PDF: ISBN 978-1-5044-4142-1 STD22656
Print: ISBN 978-1-5044-4143-8 STDPD22656

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading "Important Notices and Disclaimers Concerning IEEE Standards Documents." They can also be obtained on request from IEEE or viewed at http://standards.ieee.org/IPR/disclaimers.html.

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association ("IEEE-SA") Standards Board. IEEE ("the Institute") develops its standards through a consensus development process, approved by the American National Standards Institute ("ANSI"), which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed through scientific, academic, and industry-based technical working groups. Volunteers in IEEE working groups are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied "AS IS" and "WITH ALL FAULTS."

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE Xplore at http://ieeexplore.ieee.org/ or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at http://standards.ieee.org.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: http://standards.ieee.org/findstds/errata/index.html. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at http://standards.ieee.org/about/sasb/patcom/patents.html. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this IEEE recommended practice was completed, the P45.1 Working Group had the following membership:

Dwight Alexander, *Chair*
Robert Koebke, *Vice Chair*
Timothy L. Gauthier, *Secretary*
Moni Islam, *Past Chair*

Mohammed Ahmed
John Amy
Paul Bishop†
Charlie Butcher
William Byrd
John Cadick
Corey Cahill
Lee Carabeo
Angela Card
Don Chambers
Carl Chowaniec
Vincent DelGatto
Norbert Doerry
Mike Drew
Kamal Garg
Lukas Graber
Torsten Gruhn
Bill Hayden
Chris Heron
Anthony Hoevenaars
Akhter Hossain
Paul Kelly
Yuri Khersonsky
Stephen Ly
Earl MacDonald
Nicole Maillette
Tim McCoy
John Merando
Daryl Moore
Dennis Neitzel
Mark Nelson
Robert Olmstead
Sergio Panetta
Kevin Peterson
Joseph Piff
Mike Roa
Gary Savage
Thomas Schubert
Robert Seitz
Gary Skibinski
Mischa Steurer
James Turso
Don Voltz
David Wallace
Vicki Warren
James Waters
James Wolfe

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

David Aho
Dwight Alexander
Saleman Alibhay
John Amy
Ettore Bartolucci
Frank Basciano
Michael Basler
Paul Becker
Gustavo Brunello
William Bush
William Byrd
Paul Cardinal
Matthew Davis
Davide De Luca
Norbert Doerry
Neal Dowling
Robert Durham
Timothy L. Gauthier
Mietek Glinkowski
Jalal Gohari
J Travis Griffith
Randall Groves
Chris Heron
Lee Herron
Werner Hoelzl
Anthony Hoevenaars
John Houdek
Richard Jackson
Ben C Johnson
Piotr Karocki
John Kay
Paul Kelly
Yuri Khersonsky
Robert Koebke
Michael Lauxman
George Cristian Lazaroiu
Wei-Jen Lee
Steven Liggio
Earl MacDonald
Arturo Maldonado
John Malinowski
William McBride
Dennis Neitzel
Arthur Neubauer
T. W. Olsen
Lorraine Padden
Richard Paes
Sergio Panetta
Kevin Peterson
K. James Phillips
Joseph Piff
Iulian Profir
Ryandi Ryandi
Daniel Sabin
Gary Savage
Bartien Sayogo
Thomas Schubert
Robert Seitz
Nikunj Shah
Xu She
Jerry Smith
Gary Smullin
Michael Steurer
James Timperley
Albert Tucker
John Turner
Demetrios Tziouvaras
James Van De Ligt
John Vergis
Daniel Ward
Kenneth White
Jian Yu

When the IEEE-SA Standards Board approved this recommended practice on 23 March 2017, it had the following membership:

Jean-Philippe Faure, *Chair*
Gary Hoffman, *Vice Chair*
John D. Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Chuck Adams
Masayuki Ariyoshi
Ted Burse
Stephen Dukes
Doug Edwards
J. Travis Griffith
Michael Janezic
Thomas Koshy
Joseph L. Koepfinger*
Kevin Lu
Daleep Mohla
Damir Novosel
Ronald C. Petersen
Annette D. Reilly
Robby Robson
Dorothy Stanley
Adrian Stephens
Mehmet Ulema
Phil Wennblom
Howard Wolfman
Yu Yuan

*Member Emeritus

Introduction

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

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

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

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

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

Contents

1. Overview 14
1.1 Introduction 14
1.2 Scope 14
1.3 Purpose 15
1.4 Application of various national and international standards 15
1.5 Equipment construction, testing, and certification 15

2. Normative references 15

3. Definitions, acronyms, and abbreviations 19
3.1 Definitions 19
3.2 Acronyms and abbreviations 24

4. System engineering 25
4.1 Introduction 25
4.2 Design baseline 26
4.3 Product design 27
4.4 Product baseline 27

5. Power system characteristics 28
5.1 Electrical power systems architectures 28
5.2 Standard systems 30
5.3 Standard voltage 30
5.4 Standard frequency 31
5.5 Selection of voltage and system type 31
5.6 AC power system characteristics 32
5.7 DC power systems characteristics 34
5.8 Key electrical power system design inputs 35
5.9 Quality of service (QoS) 35
5.10 Electrical power system concept of operation (EPS-CONOPS) 37
5.11 Marine environmental conditions 38

6. Electrical power system elements 39
6.1 Introduction 39
6.2 Power generation 39
6.3 Power distribution 39
6.4 Power conversion 41
6.5 Energy storage 41
6.6 Electrical power system supervisory control 41
6.7 Loads 42

7. Power system design 43
7.1 Power generation and energy storage capacities 43
7.2 Power conversion and transformer ratings 44
7.3 Emergency power 45
7.4 Safety 50
7.5 Power quality and harmonics 50

8. Electrical power generation 51
8.1 General 51
8.2 Installation and location 51

8.3 Generator set prime movers 52
8.4 Generators 58

9. Power distribution 64
9.1 General 64
9.2 Circuit elements 64
9.3 Shore power 65
9.4 Demand factors 65
9.5 Voltage drop 66
9.6 Lighting distribution 67
9.7 Delivery power feeders 68
9.8 Branch circuits 68
9.9 Circuit designation 70
9.10 Distribution equipment 73

10. Power conversion 81
10.1 Power electronics 81
10.2 Transformers/reactors 82

11. Energy storage 84
11.1 General 84
11.2 Specific applications 84
11.3 Rechargeable storage batteries 85

12. Electrical power system control 96
12.1 Supervisory control interfaces 96
12.2 Control system connectivity 96
12.3 Application layer protocol 97
12.4 Sources and loads 98
12.5 Voice communication systems 99

13. Motor and motor application 99
13.1 General application 99
13.2 AC and DC motors—general 100
13.3 Selection 100
13.4 Installation and location 101
13.5 Insulation of windings 101
13.6 Locked rotor kVA 102
13.7 Efficiency 102
13.8 Lubrication 102
13.9 Terminal arrangements 102
13.10 Corrosion-resistance parts 103
13.11 Nameplates 103
13.12 Ambient temperature 103
13.13 Limits of temperature rise 103
13.14 Motor application 104
13.15 Duty rating 106
13.16 Steering gear motors 106
13.17 Motor brakes 107
13.18 Magnetic friction clutches 109

14. Adjustable speed drive (ASD) applications 110

15. Electric propulsion and maneuvering system 110
15.1 Scope 110
15.2 Regulations 111

15.3 System requirements....111
15.4 Prime movers for integrated power and propulsion plants....113
15.5 Generators for integrated power and propulsion plants....114
15.6 Propulsion drive transformers....115
15.7 Propulsion motors....117
15.8 Propulsion power conversion equipment....119
15.9 Main power switchboard....120
15.10 Propulsion control equipment....121
15.11 Power management....123
15.12 Podded propulsion....123
15.13 Propulsion cables....124
15.14 Propulsion equipment location....125
15.15 Ventilation....125
15.16 Bed-plates and foundations....125
15.17 Lubrication....125
15.18 Fire extinguishers....126

16. Steering systems....126
16.1 General....126
16.2 Navigating bridge installation....126
16.3 Power supply....127
16.4 Alarm system....127
16.5 Steering gear....127
16.6 Steering control systems....128

17. Lighting equipment....130
17.1 General....130
17.2 Location....131
17.3 Provisions for portable lighting....131
17.4 Permanent watertight fixtures....132
17.5 Permanent non-watertight fixtures....132
17.6 High-intensity discharge lamp fixtures....132
17.7 Lighting for hazardous locations....132
17.8 Illumination....132
17.9 Searchlights....133
17.10 Emergency lighting....134
17.11 Nameplates....134
17.12 Solid state lighting (SSL)....134
17.13 Navigation lights and signal lights....136

18. Whistle and siren control systems....137

19. Heating equipment....138
19.1 Construction....138
19.2 Heating elements....138
19.3 Control switches....139
19.4 Temperature....139
19.5 Nameplates....139
19.6 Electrical heat trace (EHT)....139

20. Galley equipment and workshop equipment....140
20.1 Electric cooking equipment....140
20.2 Motor-driven equipment....143
20.3 Nameplates....144

21. Electrical power system protection....144

21.1 Overview 144
21.2 Electrical power system protection elements 144
21.3 Electrical power system protection design 145

22. System studies, analyses, and reports 148
22.1 General 148
22.2 Electric plant load analysis (EPLA) 149
22.3 Load flow analysis and voltage drop analysis 149
22.4 Dynamic analysis (transient and stability) 150
22.5 Fault current analysis 152
22.6 Harmonic and frequency analysis 153
22.7 Failure mode and effects analysis (FMEA) 157
22.8 Electromagnetic interference (EMI) analysis 157
22.9 Thermal analysis 157
22.10 Electrical power system data for the life-cycle cost analysis 157
22.11 Electrical power system data for the signature analysis 158
22.12 Safe return to port/survivability analysis 158
22.13 Future power growth assessment 158
22.14 Protective device coordination study 158
22.15 Grounding system design report 159
22.16 Electrical power system corrosion control report 159
22.17 Electrical power system input to ship's weight report 159
22.18 Electrical power system section of the master equipment list 159
22.19 Electrical power system input to endurance fuel calculations 159
22.20 Incident energy analysis 159

23. EMI/EMC/RFI 160

24. Materials 160
24.1 Corrosion-resistant parts 160
24.2 Flame-retardant materials 160
24.3 Brittle material 161
24.4 Cable selection, application, and installation 161

25. Power system grounding (earthing) 161
25.1 General 161
25.2 Power system grounding 161
25.3 Point of system grounding 163
25.4 Equipment grounding 163
25.5 Ground plates on nonmetallic ships 164
25.6 Lightning protection grounding 165
25.7 Stray current protection 165
25.8 Ground-fault detection 165

26. Arc flash management 166

27. Hazardous locations, installations, and equipment 169
27.1 General 169
27.2 Hazardous area classification 169
27.3 Area classification for various vessel types 174
27.4 Hazardous locations equipment protection techniques 177
27.5 Hazardous locations equipment markings 181
27.6 Approved equipment 182
27.7 Equipment Installation 183

28. Ship construction and outfitting 185

28.1 Storage and installation....185
28.2 Spare parts....186
28.3 Documentation....186

29. System operation and maintenance....186
29.1 Fire extinguishing precautions....186
29.2 Rotating machine cleanliness....186
29.3 Care of idle apparatus....187
29.4 Safety....187

Annex A (informative) Bibliography....188

Annex B (normative) Electric plant load analysis....189

IEEE Recommended Practice for Electrical Installations on Shipboard—Design

1. Overview

1.1 Introduction

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

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

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

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

1.2 Scope

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

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