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IEEE Recommended Practice for Electrical Installations on Shipboard—Electrical Testing

IEEE Industry Applications Society

Sponsored by the
Petroleum & Chemical Industry Committee

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USA

IEEE Std 45.6™-2016

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Abstract: A consensus of recommended practices for system testing in marine electrical engineering as applied specifically to vessels, shipboard systems, and equipment is provided.

Keywords: IEEE 45.6™, marine electrical engineering, marine vessels, shipboard systems, ships

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Introduction

This introduction is not part of IEEE Std 45.6-2016, IEEE Recommended Practice for Electrical Installations on Shipboard—Electrical Testing.

The IEEE Std 45™ series comprises nine recommended practices addressing electrical installations on ships and marine platforms. IEEE Std 45.6 provides a recommended practice for electrical testing of shipboard electrical power systems, including: 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 intended for use with the IEEE Standard 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.

Previous editions of IEEE Std 45 were developed as single documents addressing all areas. On 9 June 2005, Project Authorization Request (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 needed 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 PARs were approved for seven separate recommended practices. Additional PARs, approved on 11 September 2009 for switchboards and 9 December 2009 for cable systems, bring the total number of standards in the IEEE Std 45 series to nine, including:

- IEEE P45™, IEEE Recommended Practice for Electrical Installations on Ships
- IEEE P45.1™, 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™, IEEE Recommended Practice for Electrical Installations on Shipboard—Marine Sectors and Mission Systems
- IEEE Std 45.5™-2014, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations
- IEEE P45.6™, 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 P45.8™, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems

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IEEE Recommended Practice for Electrical Installations on Shipboard—Electrical Testing

1. Overview

1.1 Scope

The recommendations for electrical testing for power generation, distribution, and electric propulsion systems installed 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 IEEE Std 45™ series.

1.2 Purpose

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

1.3 Equipment construction, testing, and certification

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

1.4 Application of various national and international standards

Special precautions must be exercised when mixing equipment designed to different national and international standards.

CAUTION

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

Coordination of different equipment design and testing standards, construction ratings, installation methods, and performance must be carefully analyzed.

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.

API RP 14F, Recommended Practice for Design and Installation of Electrical Systems for Offshore Production Platforms.[1]

API Std 541:2014-12, Form-Wound Squirrel-Cage Induction Motors—500 Horsepower and Larger.

CSA 22.2 No. 245: 2015, Marine Shipboard Cable.[2]

IEC 60034-1, Rotating electrical machines—Part 1: Rating and performance.[3]

IEC 60034-2-1, Rotating electrical machines—Part 2–1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles).

IEC 60034-27, Rotating electrical machines—Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines.

IEC 60060-2, High-voltage test techniques—Part 2: Measuring systems.

IEC 60068-2-1, Environmental testing—Part 2-1: Tests—Test A: Cold.

IEC 60068-2-2, Environmental testing—Part 2-2: Tests—Test B: Dry Heat.

IEC 60068-2-30, Environmental testing—Part 2: Tests—Damp heat, cyclic.

IEC 60068-2-52, Environmental testing—Part 2: Test methods.

IEC 60068-2-6, Environmental testing—Part 2.

IEC 60270, High-Voltage Test Techniques—Partial Discharge Measurements.

IEC 60439-1, Low-voltage switchgear and control gear assemblies—Part 1: Type-tested and partially type-tested assemblies.

IEC 60664-4, Insulation coordination for equipment within low-voltage systems—Part 4: Consideration high-frequency voltage stress.

IEC 60947, Low-Voltage Switchgear and Controlgear.

[1] API publications are available from the American Petroleum Institute (http://www.api.org/~/media/files/publications/whats%20new/541_e5%20pa.pdf)
[2] CSA 22.2 No. 245: 2015, Marine Shipboard Cable is available from the Canadian Standards Association (http://standards.globalspec.com/std/85857/csa-c22-2-no-245)
[3] IEC publications are available from the American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

IEC 61000-4-2, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge 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 61934, Electrical insulating materials and systems—Electrical measurement of PD under short rise time and repetitive voltage impulses.

IEC 61960, Secondary cells and batteries containing alkaline or other non-acid electrolytes—Secondary lithium cells and batteries for portable applications.

IEC 62133, Secondary cells and batteries containing alkaline or other non-acid electrolytes—Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications.

IEC 62271-1, High-Voltage Switchgear and Controlgear, Part 1: Common Specifications (ETD 8: High Voltage Switchgear and Controlgear).

IEC 62271-100, High-Voltage Switchgear and Controlgear, Part 100: High-voltage alternating-current circuit-breakers.

IEC 62271-106, High-Voltage Switchgear and Controlgear, Part 106: Alternating current contactors, contactor-based controllers and motor-starters.

IEC 62271-200, High-Voltage Switchgear and Controlgear, Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV.

IEEE Std C37.20.1™, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.[4,5]

IEEE Std C37.20.2™, IEEE Standard for Metal-Clad Switchgear.

IEEE Std 43™, IEEE Recommended Practice for Testing Insulation Resistance of Electric Machinery.

IEEE P45.1 (Draft 1.0, June 2015), Prime movers.[6]

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

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

IEEE Std 113™, IEEE Test Procedures for Direct-Current Machines.

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

IEEE Std 400™, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems.

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[6]This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact IEEE.

IEEE Std 450™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

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

IEEE Std 1106™, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.

IEEE Std 1188a™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications—Amendment 1: Updated VRLA Maintenance Considerations.

IEEE Std 1434™, IEEE Guide to Measurement of Partial Discharges in Rotating Machinery.

IEEE Std 1580™, IEEE Recommended Practice for Marine Cable for Use on Shipboard and Fixed or Floating Facilities.

IEEE Std 1657a™, IEEE Recommended Practice for Personnel Qualifications for Installation and Maintenance of Stationary Batteries—Amendment 1: Updated Safety Sections Lead-Acid Batteries for Stationary Applications.

IES RP-12: 1998, Recommended Practice for Marine Lighting.[7]

MIL-R26, 1993, US Military Specification for wire wound resistors.[8]

NEMA MG 1: 2014, Motors and Generators.[9]

NEMA WC 54 (ICEA T-26-465): 2013, Guide for Frequency of Sampling Extruded Dielectric Power, Control, Instrumentation, and Portable Cables for Test.

UL 1309, Standard for Marine Shipboard Cable.[10]

UL 1558, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

UL 347, Medium-Voltage AC Contactors, Controllers, and Control Centers.

UL 891, Switchboards.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[11]

factory acceptance test (FAT): A component or system operational and functional test conducted at the place of manufacture prior to shipping to the customer.

[7]IES RP 12 Standard is available from the Illuminating Engineering Society of North America (http://standards.globalspec.com/std/618052/ies-rp-12).
[8]MIL-SPEC: Military specifications, standards, and handbooks are available at http://everyspec.com/MIL-STD/
[9]NEMA publications are available from the National Electrical Manufacturers Association (http://www.nema.org/pages/default.aspx).
[10]UL publications are available from Underwriters' Laboratories (http://ulstandards.ul.com/).
[11]*IEEE Standards Dictionary Online* subscription is available at: http://dictionary.ieee.org.

4. General

Occupational Safety and Health Administration (OSHA) regulations and the National Fire Protection Association (NFPA) 70E® *Standard for Electrical Safety in the Workplace®* [B11][12] provide the requirements for the safe use of test equipment. For example, NFPA 70E 110.4 states, "Only qualified persons shall perform tasks such as testing, troubleshooting, and voltage measuring within the limited approach boundary of energized electrical conductors or circuit parts operating at 50 volts or more or where an electrical hazard exists." OSHA 1910.333(b)(2)(iv)(B) [B13] states, "A qualified person shall use test equipment to test the circuit elements and electrical parts of equipment to which employees will be exposed and shall verify that the circuit elements and equipment parts are deenergized." IEEE Std 45.5-2014 [B7], along with ANSI S82.02 [B1], CAN/CSA-C22.2 [B2], IEC 60204-1 [B3], 60204-11 [B4], and IEC 61010 [B5] also provide important safety rules for the use of electrical test equipment.

After the electric installation is complete, the entire electric plant should be thoroughly inspected and tested at the dock prior to proceeding to sea trails. Tests are intended to determine general equipment condition and to confirm that the installation of electrical systems and equipment is in a satisfactory and acceptable state at the time of completion. These tests should be in addition to, and not as a substitute for, the tests of individual equipment items at the manufacturer's facility (factory acceptance test). The contingent engineering team needs to realize that satisfactory test results, although providing worthwhile information on general equipment condition, do not always confirm that any particular installation is satisfactory in all respects nor do they validate that installation interconnections are correct. Therefore, the commissioning team needs to make certain that each installation and interconnection has been adequately tested in all operational configurations.

The initial inspection, which may consist of a series of inspections during the construction of the vessel, should include a complete inspection of the electrical installation and electrical equipment. The inspection should confirm that the electrical arrangement, materials, power and control cable connections, and installations fully comply with the component and ship/vessel design documents. The inspection should also confirm that equipment and installations are correct and meet all imposed quality standards.

Electric cable should be checked during installation to confirm it is the size and type shown on the plans. The adequacy of cable supports should be checked. It should be ascertained that no cable is installed in the proximity of steam pipes or other hot objects and that cables have not been damaged during the installation from excessive pulling force, over bending, or sharp/rough edges. Cable penetrations required to be watertight should be checked for proper penetrator packing, terminal, or stuffing tube.

Rotating electrical machinery should be checked to confirm that rotating and uninsulated parts are adequately guarded from accidental contact by personnel. Equipment should be adequately guarded against ingress of possible contaminants including, but not limited to: moisture, salt, and lubricants.

Electrical equipment should be inspected to confirm that it is accessible for normal inspection and routine maintenance. Inspection should confirm that there is provision for accessing junction boxes behind paneling, and that the access is conspicuously identified. Hinged doors of electrical enclosures should be checked to confirm that they are free of interferences from adjacent structures or equipment.

Metal enclosures for electrical equipment should be inspected to confirm they are grounded, either by the method of mounting or by a separate grounding conductor. Portable equipment should be checked to confirm proper grounding through a conductor of the supply cable. Portable equipment such as power tools that are identified as "double insulated" need not have a grounding connector in the attachment cord. All non-current-carrying metallic parts of electrical equipment should be verified to be effectively grounded by the following methods. Metal frames or enclosures of apparatus should be fixed to, and be in metallic contact with, the vessels structure, provided that the surfaces in contact are clean and free from rust, scale, or paint when installed and are firmly bolted together. Alternatively, they should be connected to the hull either directly by

[12]The numbers in brackets correspond to those of the bibliography in Annex A.

ground strap or, for portable equipment, via the grounding terminal of a receptacle outlet. A reading of 0.1 Ω (dc resistance) or less should be achieved between an equipment enclosure and an adjacent structural ground potential point.

Metallic cable sheaths or armor should not be solely relied on for achieving equipment grounding. The metallic sheaths and armor should be grounded by means of connectors, or cable glands approved, listed or labeled for the purpose and designed to confirm an effective ground connection. The stuffing tube should be firmly attached to, and be in effective electrical contact with, a grounded metal structure. Conduits should be grounded by being screwed into a grounded metallic enclosure or by nuts on both sides of the wall of a grounded metallic enclosure where contact surfaces are clean and free from rust, scale, or paint.

As an alternative to the methods described in the above paragraph, armor and conduit may be grounded by means of clamps or clips of corrosion-resistant metal, making effective contact with the sheath or armor and grounded metal. All joints in metallic conduits, ducts, and in metallic sheaths of cables that are used for ground continuity should be solidly made and protected against corrosion.

Every grounding conductor should be of copper or other corrosion-resistant material and should be securely installed and, where necessary, protected against damage and electrolytic corrosion.

On wood and composite vessels, a continuous-ground conductor should be installed to facilitate the grounding of non-current-carrying exposed metal parts. The ground conductor should terminate at one copper plate of area not less than 0.2 m^2 fixed to the keel below the light waterline in a location that is fully immersed under all conditions of heel.

Every ground connection to the ship structure, or on wood and composite vessels to the continuous ground conductor, should be made in an accessible position and should be secured by a screw or connector of brass or other corrosion-resistant material used solely for that purpose.

All armor or other metal coverings of cable should be electrically continuous throughout the entire length and should be effectively grounded to the hull of the ship at both ends, except for branch circuits (final sub circuits), which may be grounded at the supply end only. The metallic braid or sheath should be terminated at the stuffing tube or connector where the cable enters the enclosure and should be in good electrical contact with the enclosure.

Methods of securing aluminum superstructures to the steel hull of a ship often include insulation to reduce galvanic corrosion between these materials. In such cases, a separate bonding connection should be provided between the superstructure and the hull. The connection should be made in a manner that reduces galvanic corrosion and permits periodic inspection.

Cable insulation resistance should be measured by self-contained instruments, such as the direct indicating ohmmeter of the generator type, applying a dc potential of 500 V. Where the normal operating voltage is less than 100 V, a direct reading ohmmeter of the appropriate voltage should be used. Where operating voltage is greater than 500 V, the test instrument should apply a dc potential approximately equal to the operating voltage. Where circuits contain solid-state devices, care should be exercised to confirm that the devices that have a voltage rating less than the test voltage are disconnected or shorted-out before the test voltage is applied.

For rotating electric machines, insulation tests should be made in accordance with the recommendations in IEEE Std 43-2013 or IEC 60034-2-1, with the machine windings in a clean and dry condition. The results obtained from the tests depend not only on the characteristics of the insulation materials and the way they are applied, but also on the test conditions. It is recommended that the data recorded during the tests include ambient conditions, particularly those concerning the ambient temperature and the degree of humidity at the time of the test.

The polarization index (ratio of 10 min to 1 min insulation resistance value) for the machine windings should be evaluated. The recommended polarization index minimum value for ac and dc rotating machines is 2.0.

The resistance should be measured with all circuits of equal voltage above ground connected together; circuits or groups of circuits of different voltages above ground should be tested separately. This test should be made at a dc voltage of 500 V for a minimum of 1 min. The recommended minimum insulation resistance R_m for ac and dc machine armature windings and for field windings of ac and dc machines can be determined per Equation (1). Although a high percentage of rotating machinery operates at less than 1000 V, not all equipment falls into that category. Refer to Table 4 of IEEE Std 43-2013 for additional information [B6]. Testing voltage and the resulting insulation resistance measurement are related to both the winding construction and the original design voltage of the equipment.

$R_m = kV + 1$ for direct current field windings.

$R_m = 100$ for ac windings rated in excess of 1000 V

$R_m = 5$ for all ac and dc windings rated below 1000 V except dc field windings (1)

where

R_m is the recommended minimum insulation resistance in MΩ at 40 °C of the entire machine winding
kV is the rated machine terminal to terminal potential, in rms kilovolts

The actual winding insulation resistance to be used for comparison with the recommended minimum value R_m is the observed insulation resistance, corrected to 40 °C, obtained by applying direct potential to the entire winding for 1 min to obtain the initial value and for 10 min to obtain the value for the polarization index. The minimum insulation resistance of the field windings of machines separately excited, with voltage less than the rated voltage of the machine, should be not less than 1 MΩ.

In addition to insulation resistance testing, partial discharge (PD) testing should be performed on medium and high voltage equipment at the manufacturer's factories for all major transformers, generators, power cables, and switchboards to confirm long term reliability. The power cables terminations and butt splices should receive PD testing at the ship yard. Perform PD testing according to IEEE Std 1434.

5. New installations

5.1 Circuits

Each power and lighting circuit should be tested for insulation resistance between all insulated poles, ground, and where practicable, between poles. Each power and lighting circuit should have an insulation resistance between conductors and ground of not less than the following:

— Up to 5-A load: 2 MΩ
— Up to 10-A load: 1 MΩ
— Up to 25-A load: 0.4 MΩ
— Up to 50-A load: 0.25 MΩ
— Over 50-A load: 0.1 MΩ

If necessary to obtain the desired resistance, loads may be disconnected from the circuit.

Each interior communication circuit of 115 V and above should have an insulation resistance between conductors and between each conductor and ground of not less than 1 MΩ. For circuits below 115 V, the insulation resistance should be at least 0.33 MΩ. This test should be made at a dc voltage of 100 V for a minimum of 1 min.

5.2 Generating sets

The commutation, electrical characteristics, over speed trips, governing, range of excitation control, lubrication, and absence of vibration should be satisfactorily demonstrated. Tests should be made to demonstrate compliance with IEEE P45.1 (Draft 1.0, June 2015). Each generating set should be run at full rated (kW) load until constant temperature has been reached and in no case for less than 4 h. If generating sets are intended to operate in parallel, they should be tested in all combinations over a range of loading sufficient to demonstrate that load sharing and parallel operation are satisfactory. Voltage and speed regulation, when load is suddenly applied and removed, should comply with IEEE P45.1 (Draft 1.0, June 2015). The insulation resistance of all generators should be measured in both cold and hot conditions immediately before and after running at normal full load. Automatic, local, and remote starting and stopping systems should be tested.

5.3 Switchboards

Before switchboards, motor control centers, and distribution panels are put into service, they should be tested to confirm the insulation resistance is not less than 1 MΩ when measured between each bus-bar and ground and between each bus-bar. This test should be made with all circuit breakers and switches open; all fuses for pilot lamps, ground indicating lamps, voltmeters, and so on removed, and all voltage coils disconnected. Low-voltage switchboards are those rated 600 V ac and less according to IEEE Std C37.20.1, or 1000 V ac and less according to IEC 60947. Medium-voltage switchboards are those rated 601 V to 38.0 kV ac according to IEEE Std C37.20.1, or 1.01 kV to 35.0 kV ac according to IEC 60947.

5.3.1 Factory tests

Prior to delivery, tests should be performed to confirm that the switchboard is in accordance with these recommendations and operates at its specified rating. Tests should be in accordance with the following standards:

a) Switchboards operating at a root-mean-square (rms) voltage less than 1000 V should meet the requirements of UL 891 or IEEE Std C37.20.1-2015, UL 1558-1999, or IEC 60947 for low-voltage, metal-enclosed power circuit breaker switchgear.

b) Metal-clad switchgear including medium-voltage power circuit breakers should comply with the requirements found in IEEE Std C37.20.2-2015 or IEC 62271-200. All medium-voltage motor starters of the vacuum type should meet the requirements of UL 347-2016, IEC 62271-100, IEC 62271-1 and/or IEC 62271-106.

5.3.2 Dockside shipboard tests

Dielectric withstand tests should be made on switchboards after installation in the ship, prior to control and power cables being terminated and rechecked again post cable termination. The assembly should be tested in accordance with the standards specified in IEC 62271-1 and IEC 60439.

After installation is complete, the switchboard and associated control equipment should be subjected to a complete functional test of all control circuits.

All switches, circuit breakers, and associated equipment should be operated to demonstrate suitability and compliance with recommended manufacturer's specifications.

All switchboards should be fully loaded (or as close as practicable), and no overheating should occur.

Reverse power relays, reverse current and overcurrent relays, preferential tripping relays, and all electrical and electromechanical interlocks should be satisfactorily operated. Generator, bus tie, and main propulsion feeder circuit breakers should be test-tripped to confirm that adjustable settings comply with the system design values. All circuit breakers and protective relays settings should be verified by performing a short circuit analysis and coordination study.

Switchboards should be checked for handrails, guardrails, insulating floor covering, drip covers, and backs and sides on the enclosure. Adequate working space around the switchboard should be verified. Switchboard-mounted apparatus should be checked for identifying nameplates. Circuit nameplates should be compared with the rating or setting of the overcurrent devices and with the plans. The accessibility of items requiring maintenance or adjustment should be checked. Meters should be checked for proper operation. The operation of automatic paralleling devices and mechanical and electrical interlocks should be observed.

PD testing should be performed to verify long term reliability of the insulation within medium- and high-voltage equipment. The long term effects of partial discharge on the insulation systems causes progressive deterioration of insulating materials, ultimately leading to electrical breakdown. The effects of partial discharge within medium and high-voltage cables and equipment can ultimately lead to insulation failure. The cumulative effect of partial discharges within solid dielectrics is the formation of numerous, branching partially conducting discharge channels, a process called treeing. Repetitive discharge events cause irreversible mechanical and chemical deterioration of the insulating material. Damage is caused by the energy dissipated by high energy electrons or ions, ultraviolet light from the discharges, ozone attacking the void walls, and cracking as the chemical breakdown processes liberate gases at high pressure. This chemical transformation of the dielectric tends to increase the electrical conductivity of the dielectric material surrounding the voids. In doing so, this increases the electrical stress in the gap region, accelerating the breakdown process that can cause insipient faults. This becomes more of a longevity issue when high harmonic conditions exist on the power system.

Partial discharge conditions can usually be prevented through careful design, material selection and factory testing. In critical medium and high voltage equipment, the integrity of the insulation is confirmed using partial discharge detection equipment during the manufacturing stage as well as periodically through the equipment's useful life. Partial discharge prevention and detection are essential to confirm reliable, long-term operation of high voltage equipment. Additional testing requirements can be obtained from IEC 60060-2, IEC 60270, IEC 61934, IEC 60664-4, IEC 60034-27, IEEE Std 1434, and IEEE Std 400.

Power equipment should be de-rated when harmonic conditions exceed 5%, the K-Factor, or equivalent harmonic de-rating, should be determined. The K-factor is a weighting of the harmonic load currents according to their effects on transformer heating, as derived from IEEE Std C57.110 [B9]. A K-factor of 1.0 indicates a linear load (no harmonics). The higher the K-factor, the greater the harmonic heating effects. When a non-linear load is supplied from a transformer, it is sometimes necessary to de-rate the transformer to avoid overheating and consequent insulation failure.

5.4 Control systems

5.4.1 Control system testing

Control systems should be tested in accordance with the specific requirements of the cognizant regulatory agency and classification society.

Testing should be accomplished in a hierarchical structure beginning with component inspection and qualification, proceeding to subassembly performance testing and qualification, and ending with installed system performance testing and qualification. Manufacturers should provide mechanical, electrical, and electronic components that have been inspected and performance-proven at the component or material level, subassembly, and system levels. These tests should be structured such that successful completion of the testing provides reasonable assurance of the system performance in the expected marine environment.

In addition to the requirements for testing of control systems during construction, assembly, and during shipboard installation trials, control systems should incorporate features into the design that provide for routine in-service, built-in testing. Means for testing complex circuits and check points for calibration purposes should be provided. In assessing the requirements for built-in test equipment, it should be assumed that maintenance and repair will normally be carried out by removing faulty line replacement units to a test bench or suitably equipped workshop.

5.4.2 Environmental conditions

Control components should be designed and type tested for operation at the following conditions. Equipment should be tested according to the environmental procedures as specified in Table 1, and in accordance with the performance procedures in Table 2. This does not modify the equipment ambient temperature conditions specified elsewhere in these recommendations.

Table 1—Environmental tests for control and monitoring equipment

No	Test	Procedure according to	Test parameters	Other information
1	Visual inspection	—	—	—Conformance to drawings, design data —Quality of workmanship and construction
2	Dry heat [a]	IEC 60068-2-2: 2007, Environmental testing—Part 2: Tests. Test Bb, Dry heat for non-heat-dissipating specimen with gradual change of temperature	Temperature: 55 °C ±2 °C Duration: 16 h or Temperature: 70 °C ±2 °C Duration: 2 h	—Equipment operating during conditioning and testing —Functional test during the last hour of the test temperature —Functional test after recovery
		IEC 60068-2-2: 2007, Environmental testing—Part 2-2: Tests. Test Bd, Dry heat for heat-dissipating specimen with gradual change of temperature	Temperature: 70 °C ±2 °C Duration: 2 h or Temperature: 55 °C ±2 °C Duration: 16 h	—Equipment operating during conditioning and testing with cooling system on, if provided —Functional test during the last hour at the test temperature —Functional test after recovery
3	Damp test	IEC 60068-2-30: 2005, Environmental testing—Part 2-30: Tests. Test Db and guidance: Damp heat, cyclic (12 + 12-h cycle)	Temperature: 55 °C Humidity: 95% Duration: 2 cycles/12 + 12-h cycle	—Measurement of insulation resistance before test —Equipment operating during complete 1st cycle, switched off during 2nd cycle except for functional test —Functional test during the first 2 h of the 1st cycle at the test temperature and during the last 2 h of the 2nd cycle at the test temperature —Recovery at standard atmosphere conditions —Insulation resistance measurements and performance test

Table continues

Table 1—Environmental tests for control and monitoring equipment *(continued)*

<table>
<tr><th>No</th><th>Test</th><th>Procedure according to</th><th colspan="4">Test parameters</th><th>Other information</th></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Cold [b]</td><td>IEC 60068-2-1: 2007 Environmental testing—Part 2: Tests. Test A: Cold (Concerns cold tests on both non-heat-dissipating and heat-dissipating specimens)</td><td colspan="4">Temperature: 5 °C ±3 °C
Duration: 2 h
or
Temperature: 25 °C ±3 °C Duration: 2 h</td><td>—Initial measurement of insulation resistance
—Equipment not operating during conditioning and testing except for functional test
—Functional test during last hour at the test temperature
—Insulation resistance measurement and functional test after recovery</td></tr>
<tr><td>—</td><td colspan="4">Temperature: 25 °C ±3 °C
Duration: 2 h
or
Temperature: 5 °C ±3 °C
Duration: 2 h</td><td>—</td></tr>
<tr><td>5</td><td>Salt mist [c]</td><td>IEC 60068-2-52: 1996, Environmental testing—Part 2: Test methods—Test Kb Salt mist, cyclic (sodium, chloride solution)</td><td colspan="4">Four spraying periods with storage of 7 d after each.</td><td>—Initial measurement of insulation resistance and initial function test
—Equipment not operated during condition
—Functional test on the 7th day of each storage period
—Insulation resistance measurement and op test after recovery</td></tr>
<tr><td rowspan="6">6</td><td rowspan="6">Insulation resistance</td><td rowspan="6">—</td><td>Rated supply voltage</td><td>Test voltage</td><td colspan="2">Minimum insulation resistance</td><td rowspan="6">—IR is to be carried out before and after; damp test, cold test, and salt mist test
—Between all circuits and earth
—On the supply terminals, where appropriate</td></tr>
<tr><td>—</td><td>—</td><td>Before</td><td>After</td></tr>
<tr><td>(V)</td><td>(V)</td><td>MΩ</td><td>MΩ</td></tr>
<tr><td>Un > 65</td><td>2 × Un</td><td>10</td><td>1.0</td></tr>
<tr><td colspan="4">Min 24 V</td></tr>
<tr><td>Un > 65</td><td>500 V</td><td>100</td><td>10</td></tr>
<tr><td rowspan="4">7</td><td rowspan="4">High potential</td><td rowspan="4">—</td><td colspan="2">Rated voltage
(V)</td><td colspan="2">Test voltage
Un (50 or 60 Hz)
(V)</td><td rowspan="4">—Separate circuits are to be tested against each other and all circuits connected with each other tested against earth
—Printed circuits with electronic components may be removed during test
—Period of application; 1 min</td></tr>
<tr><td colspan="2">up to 65</td><td colspan="2">up to 65</td></tr>
<tr><td colspan="2">66 to 250</td><td colspan="2">66 to 250</td></tr>
<tr><td colspan="2">251 to 500</td><td colspan="2">251 to 500</td></tr>
</table>

Table continues

Table 1—Environmental tests for control and monitoring equipment *(continued)*

No	Test	Procedure according to	Test parameters	Other information
8	Electrostatic discharge	IEC 61000-4-2: 2008, Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 2: Electrostatic discharge immunity test. Basic EMC publication	Test voltage: 8 kV according to level 3 severity standard	—To simulate electrostatic discharge as may occur when persons touch —Test is to be confined to the points and surfaces that can normally be reached by the operator —The equipment is to operate during testing —As a result of the test, neither permanent or transient effects nor damage to the equipment are allowed
9	Radiated electro-magnetic field	IEC 61000-4-3: 1995, Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 3: Radiated, radio-frequency, electromagnetic field immunity test	Frequency range: 30 kHz to 500 MHz Field strength; 10 V/m: According to severity level 3 Field strength to be adopted according to severity.	—To simulate electromagnetic fields radiated by different transmitter —The test is to be confined to the appliance exposed to direct radiation by transmitters at their place of installation —As a result
		IEC 61000-4-4: 1995, Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 4: Electrical fast transient/ burst immunity test. Basic EMC publication	Test voltage: ± 10%: a) 2 kV on power supply b) 1 kV on data and control lines acc. to severity level 3.	—To simulate interference by electric arcs generated when actuating electrical contacts —Interference effect occurring on the power supply, as well as at the external wiring of the test specimen

Table continues

Table 1—Environmental tests for control and monitoring equipment *(continued)*

No	Test	Procedure according to	Test parameters	Other information
10	Conductance interference	IEC 61000-4-6: 2013, Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 6: Immunity to conducted disturbances, induced by radio-frequency fields	Testing signal 1.5 V efficient in the range between 10 kHz and 50 MHz Modulation: 30% Modulation frequency: 1 kHz	To simulate electromagnetic fields coupled as high frequency into the test specimen via the connecting lines
		IEC 61000-4-5: 2014, Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 5: Surge immunity test	Test voltage: 1.0 kV differential mode; 2.0 kV common mode Rise time: 1.2 ms Surge time/50% value/50 µs acc. to severity level 3.	—To simulate interference generated, for instance, by switching on or off high-power inductive consumers —The test is to be carried out at the power supply
11	Vibration	IEC 60068-2-6: 2007, Environmental testing—Part 2: Tests—Test Fc: Vibration (sinusoidal)	2 to 13.2 Hz-amplitude 1.0 mm ± 0.152 13.2 Hz to 50 Hz-amplitude ± 0.076 mm. +0.000 -0.025 For severe vibration conditions such as equipment mounted on diesel engines, air compressors, etc., higher frequency and acceleration values will be considered.	—Duration in case of no resonance condition 90 min at 30 Hz —Duration at each resonance frequency at which Q > 2 is recorded, 90 min —During the vibration test, operational conditions are to be demonstrated —Tests are to be carried out in 3 perpendicular planes —It is recommended, as guidance, that Q does not exceed 5
12	Inclination[d]	—	Static: Athwart ships: 22.5° Fore and aft: 10° Dynamic: Athwartships: 22.5° Fore and aft:10° Duration: 10 s	—This test is to be carried out immediately after the vibration test —For static conditions, the test is to be carried out for a period of sufficient duration to determine the satisfactory operation of the equipment

[a]Dry heat at 70 °C is to be carried out for equipment located in a non-air-conditioned space.
[b]For equipment installed in non-weather-protected locations or cold locations, test is to be carried out at −25 °C.
[c]Salt mist test is to be carried out for equipment installed in weather-exposed areas.
[d]For athwartships position, the angle of inclination is to be increased to 45° if switches, levers, or similar are installed.

Table 2—Performance tests for control and monitoring equipment

No	Test	Procedure according to	Test parameters	Other information
1	Visual inspection	—	—	—Conformance to drawings, design data —Quality of workmanship and construction
2	Functional test	The equipment specification	Standard atmosphere conditions: —Temperature: 25 °C – 10 °C —Relative humidity: 60% ± 30% —Air pressure: 96 kPa ±10 kPa	—Confirmation that operation is in accordance with the requirements specified for particular automatic systems or equipment —Checking of self- monitoring features —Checking of specified protection against an access to the memory and effects of un-erroneous use of control elements in the case of computer systems
3	Power supply failure	—	—Three interruptions during 5 min —Switching-off time 30 s each case	Verification of the specified action of the equipment on loss and restoration of supply in accordance with the system design
4	Power supply (electric)	—	Combination V and frequency variation permanent (%) (%) 1 +10 +5 2 +10 −5 3 −10 −5 4 −10 +5 Combination V and frequency transient 1.5 s 5 s (%) (%) 5 +20 +10 6 −20 −10 Electric battery supply: a) +30% to −25% for equipment connected to battery during charging b) +20% to −35% for equipment not connected to the battery during charging	—
	Power supply (electric)	—	Pressure: ± 20% Duration: 15 min	—

NOTE—Ambient temperature and humidity ranges
Open weather decks and open bridges: Temperature range: −25 °C to + 55 °C
Machinery spaces: Temperature range: 0 °C to +55 °C, Relative humidity: 10% to 95%
Enclosed areas other than machinery spaces: Temperature range: 25 °C to +55 °C
Relative humidity: 10% to 95%
Storage and transport conditions: Temperature range: 25 °C to +55 °C
Console and stand-alone equipment: Interior temperatures: 0 °C to +55 °C

5.5 Control apparatus

5.5.1 Tests

Tests should be performed to confirm that the control apparatus is in accordance with these recommendations and is suitable for controlling the motor to which it is to be applied. It is not intended that each individual item of control apparatus be tested completely to verify compliance with these recommendations. Tests should be made to determine that the apparatus functions properly, with other tests performed or information obtained from previous tests on duplicate apparatus, as may be necessary to confirm that the apparatus meets these recommendations.

5.5.2 Limits of temperature rises

Temperature rise limits and measurement procedures are provided in Table 3. The temperature rise values are based on 50 °C ambient temperatures (see 5.6.2.1 for 45 °C ambient).

5.5.2.1 Transformers

The limits of temperature rise in a 40 °C ambient should be in accordance with Table 4. Transformers should also be designed to operate in an ambient temperature of 50 °C without exceeding the recommended total hot spot temperature, provided the output kilovoltampere at rated voltage does not exceed 90% of the rated capacity of the transformer with Class A insulation and 94% of the rated capacity of a transformer with Class B insulation.

5.5.2.2 Motors

It is recommended that ac and dc motors have a design temperature rise of 80 °C, by resistance, in a 40 °C ambient temperature (NEMA Class B), but be constructed with a minimum of National Electrical Manufacturers Association (NEMA) Class F insulation to provide optimum balance between initial cost and long-life operations.

AC and dc motors normally are designed for 40 °C ambient temperatures, and thus, they should be derated in accordance with manufacturer's recommendations if operated in higher ambient temperatures. Insulation of motor windings with quality insulation materials that are designed to be resistant to the salt laden moist atmosphere locations is recommended.

Deck-winch and direct-acting capstan motors should be rated on a full load run of at least 1/2 h; direct-acting windlass motors should be rated on a full load run of at least 1/2 h; and those operating through hydraulic transmission should be rated for 30-min idle pump operation, followed by full load for 1/4 h. Steering-gear control motors should be rated on a full load run of 1 h.

The temperature rise of each of the various parts of ac motors and dc motors when tested in accordance with the full load rating should not exceed values given in Table 3.

5.5.2.3 Coils

The temperature rise of coils, when tested in accordance with the rating, should not exceed the values given in Table 3. Temperatures are measured as indicated.

Table 3—Limits of observable temperature rises for ac and dc control

Coil type	Method of temp. determination (see 5.5.2.8 and 5.5.2.9)	Limits of observable temperature rise (°C above 50 °C ambient)			
		A	B	F	H
Wire-wound coils	Thermometer Resistance	55 75	80 100	105 125	130 150
Single-layer series coils with exposed surfaces uninsulated or enameled	Thermometer	80[a]			

[a]Applies to coils with a fiber or other similar insulating sleeve or collar for insulating the coil from the frame or core. The allowable rise for rotating equipment is much lower at a 50 °C ambient condition and is also dependent on application, machine construction, and service factor. Refer to NEMA MG1-2011 Section II.

Table 4—Transformers and dc balance coils temperature rise

	Copper temperature rise by resistance (°C)				Hottest spot temperature rise (°C)			
Class of insulation								
Part	A	B	F	H	A	B	F	H
Insulated windings	55	80	115	150	65	110	145	180

NOTE—Metallic parts in contact with or adjacent to insulation should not attain a temperature in excess of that allowed for the hottest spot copper temperature adjacent to that insulation.

5.5.2.4 Contacts

The temperature rise of contacts, when tested in accordance with the rating, should not exceed the following values: laminated contacts 55 °C, and solid contacts 65 °C. All temperatures should be measured by the thermometer method described in 5.5.2.8.

5.5.2.5 Mechanical parts

Mechanical parts not in contact with insulation may reach temperatures that will not be injurious in any respect.

5.5.2.6 Buses, connecting straps, and terminals

The temperature rise, when tested in accordance with the rating, should not exceed 40 °C when measured by the thermometer method described in 5.5.2.8.

5.5.2.7 Resistors

The temperature rise, when tested in accordance to MIL-R26, should not exceed 365 °C when the thermocouple is placed in contact with the resistive conductor, or 240 °C when the mercury thermometer is placed in contact with the embedding material. The temperature rise of the issuing air, when measured 1 in from the enclosure, should not exceed 165 °C. All temperatures should be measured by the thermometer method described in 5.5.2.8.

5.5.2.8 Thermometer method of temperature measurement defined

This method is the measurement of temperature by mercury or alcohol thermometers, by resistance thermometer, or by thermocouple, with the instrument being applied to the hottest accessible part of the apparatus.

5.5.2.9 Resistance method of temperature measurement defined

This method is the determination of the temperature rise by comparison of the measured winding resistance taken at operating conditions with the measured winding resistances taken at known minimum and maximum ambient temperatures. Measurements should be taken with the winding energized and deenergized.

5.5.2.10 Ambient temperature

Controllers installed in main and auxiliary machinery spaces containing significant heat sources, such as prime movers and boilers, should be selected on the basis of 50 °C ambient temperature. Controllers for other locations where the ambient temperature will not exceed approximately 45 °C may be selected on the basis of 45 °C ambient temperature. In the latter case, 10 °C additional rise should be allowed for all parts.

5.5.3 High potential test

The standard test voltage for all clean and dry switching and control apparatus should be as in Table 5.

The test voltage should be successively applied between each electric circuit and grounded metal parts, and between each principal electric circuit and all other principal circuits. Caution should be used in choosing points of application when sensitive devices, such as semiconductors, are included. Circuits that may be grounded in use should be disconnected from ground for this test.

Table 5—Test voltage of high potential

Voltage rating (V)	Test voltage
0–600 601–2400 > 2400–15 000	1000 V + (2x nominal voltage rating) 2000 V + (2.5x nominal voltage rating) 19 kV rms or 27 kV dc

Other dielectric withstand test features, such as characteristics of test voltage, duration of tests, reduction of test voltage values for assemblies, and so on, should be in accordance with NEMA ICS 1-2000 [B10]. Reference IEC 62271-1 for high voltage equipment.

5.6 Motors, generators, and controllers

5.6.1 General

Each motor, along with all associated control equipment, should be run under operating conditions for a sufficient length of time to demonstrate correct alignment, wiring, capacity, speed, and satisfactory operation. Motor driving pumps, ventilation fans, and similar loads should be operated as nearly as practicable under their individual service conditions. Motor driving cargo winches should hoist and lower their specified loads. Motors for which it is difficult to obtain actual operating loads, such as motor driving warping capstans, machine tools, and other similar load characteristics, should be able to run to demonstrate suitability.

Motor controllers should be checked to confirm proper starting of the motor under service conditions and that properly rated overcurrent devices are installed. Each motor starter not completely disconnected from all sources of potential when the disconnect switch is opened (due to electrically interlocked circuits necessary for proper operation of the apparatus of for other valid reasons) should be checked to confirm that attention is directed to such conditions by a suitable warning label. The remote control units for stopping ventilation fans, oil pumps, and pumps discharging overboard in way of survival craft should be satisfactorily operated.

5.6.2 Tests

Prior to delivery, tests should be performed to confirm that the electric machine is in accordance with these recommendations and operates at its specified rating. When an electric machine is a duplicate of one already tested, only such check tests as described in this subclause may be made as necessary to demonstrate that the machine operates successfully. Spare parts should be given an insulation resistance test prior to installation. Tests should be conducted in accordance with the following:

— For single-phase motors: NEMA MG 1-2014 or IEC 60034-2-1

— For polyphase induction motors: NEMA MG 1-2014, IEEE Std 112-2004, IEEE Std 841-2009, API Std 541:2014-12, or IEC 60034-2-1

— For synchronous motors: IEEE Std 115-2009 or IEC 60034-2-1

— For dc motors: NEMA MG 1-2014 or IEC 60034-2-1

— For IEC motors: IEC 60034-2-1

— For chemical duty motors up to and including 373 kW (500 HP): IEEE Std 841-2009

— For chemical duty motors above 373kW (500 HP): API Std 541:2014-12

The tests that should be performed are:

— Temperature-rise

— Insulation resistance

— High potential

— Overload

5.6.2.1 Temperature-rise test

After the machines have been run continuously under full load and steady state temperatures have been reached, the temperature rises should not exceed those given in Table 6 or Table 7.

Table 6—Limits of observable temperature rise for ac motors

			Ambient							
Item	**Machine part**	**Method of temperature determination**	**50 °C**				**65 °C**			
			A	**B**	**F**	**H**	**A**	**B**	**F**	**H**
1	Windings									
	a) All except b) and c)	Resistance	50	70	95	115	34	60	80	105
	b) Totally enclosed nonventilated enclosures only	Resistance	55	75	100	125	40	65	85	110
	c) Encapsulated only	Resistance	55	75	100	—	40	65	85	—
	d) 1500 hp and less	Embedded detector	60	80	105	130	40	65	90	115
	e) Over 1500 hp	Embedded detector	55	75	100	125	40	65	85	110
2	Field winding of synchronous motors									
	a) Salient pole	Resistance	50	70	95	115	35	60	80	105
	b) Cylindrical rotor	Resistance	—	75	95	115	—	65	85	105

Table 7—Temperature ratings of generators

Machine part		Method of measurement	Ambient temperature (°C)	Temperature rise (°C)	Allowable hot spot rise (°C)	Total temperature (°C)
All windings		**Resistance**	**45**	**75**	**10**	**130**
Windings 1563 kVA and less		**RTD**	**45**	**85**	**0**	**130**
Windings 1563 kVA and above						
a)	**< 7000 V**	**RTD**	**45**	**80**	**5**	**130**
b)	> 7000 V	RTD	45	95	0	130
Field winding		Resistance	45	80	5	130
All windings		Resistance	50	70	10	130
Windings 1563 kVA and less		RTD	50	80	0	130
Windings 1563 kVA and above						
a)	< 7000 V	RTD	50	75	5	130
b)	> 7000 V	RTD	50	80	0	130
All windings		Resistance	45	75	10	130
Field winding		Resistance	50	75	5	130

RTD = Resistance temperature detector

The allowable rise for rotating equipment is much lower at a 50 °C ambient condition and is also dependent on application, machine construction, and service factor. Refer to NEMA MG1–2011 Section II.

5.6.2.2 Insulation resistance

Insulation resistance testing of electrical rotating machinery should be performed in accordance with the recommendations in IEEE Std 43-2013, including the corrections for temperature and humidity. The results obtained from the tests depend not only on the characteristics of the insulation materials and the way they are applied, but also on the test conditions. The test values obtained should be appropriately adjusted for the test conditions at time of test. The polarization index (ratio of 10-min to 1-min insulation resistance value) for the machine windings should be determined. The recommended minimum value of polarization index for ac and dc machines is 2.0. The resistance should be measured with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltages should be tested separately.

This test should be made at a dc voltage of 500 V for a minimum 1 min.

5.6.2.3 High-potential

The dielectric strength of the insulation should be tested by the continuous application for 1 min of an alternating voltage whose value is 1000 V plus twice the rated voltage of the circuit to which the machine is to be connected. The test voltage should be applied between all circuits and ground, between shunt and other field windings, and between brush rings of opposite polarity.

When synchronous motors are to be started with alternating current, the fields should be tested in accordance with the following, depending on the field starting arrangements:

a) Field short-circuited. The field windings should be tested with 10 times the exciter voltage but not less than 2500 V, nor more than 5000 V.

b) Field open-circuited and sectionalized. The field windings should be tested with 1.5 times the maximum rms voltage that can occur between the terminals of any section under the specified starting conditions, but not less than 2500 V or 10 times the rated excitation voltage per section, whichever is greater.

c) Field open-circuited and connected all in series. The field windings should be tested with 1.5 times the maximum rms voltage that can occur between the field terminals under the specified starting conditions, but not less than 2500 V or 10 times the rated excitation voltage, whichever is greater.

d) Resistor in series with field. The field windings should be tested with a voltage equal to twice the rms value of the IR drop across the resistor but not less than 2500 V. The IR drop should be taken as the product of the resistance and the current that would circulate in the field winding if short-circuited on itself at the specified starting voltage.

Phase-wound rotors of induction motors should be tested with twice their normal induced voltage plus 1000 V. When induction motors with phase-wound rotors are to be reversed while running at approximately normal speed by reversing the primary connections, the test should be four times the normal induced voltage plus 1000 V.

For fractional horsepower motors (250 V or less) rated 0.37 kW and less, the dielectric strength of the insulation should be tested by the application of alternating voltage whose effective value is 1000 V for 1 min for ac motor tests and 900 V for 1 min for dc motor tests. When fractional horsepower motors are produced in quantities, the high-potential test may be modified to consist of the application of a 20% higher voltage than recommended in the Overload test below, applied for 1 s.

5.6.2.4 Overload

The overload test for motors should be performed at rated speed, or in the case of a motor with a range of speeds, at the highest and lowest speeds. The test should be made with a gradual increase of torque and the appropriate excess torque given in this subclause. Synchronous motors and synchronous induction motors should withstand the excess torque without falling out of synchronism and without adjustment of excitation circuit preset at the value corresponding to rated load.

— DC motors: 50% for 15 s
— Polyphase ac synchronous motors: 50% for 15 s
— Polyphase ac synchronous induction motors: 35% for 15 s
— Polyphase ac induction motors: 60% for 15 s
— Single-phase ac motors: 33% for 15 s

5.6.2.5 Commutation test

The commutation test on dc motors should consist of the application of a momentary torque of 50% in excess of that corresponding to its rating, for 15 s with fixed brush setting. There should be no severe sparking or damage to the commutator or brushes. The commutation of ac commutator motors should be essentially sparkless over the specified range of load and speed.

5.6.2.6 Voltage drop

One lighting circuit from each distribution panel and switchboard should be selected for voltage drop testing. With all lamps burning and all other permanently connected loads on that circuit operating, the current in the feeder and the voltage at the most remote branch outlet should be measured. For all distribution circuits, unless stated otherwise, the combined maximum voltage drop from the ships service switchboard to any point in the system should not exceed 5%. If the voltage drop on this sample circuit does not meet the recommendations, all lighting circuits should be tested, and corrective action taken.

For power circuits, the voltage drop in branch circuits fed from distribution panels should be measured. Equipment should be loaded to approximately full rating, and voltage drop should be determined by measuring the current in the circuit and the voltage at the device's terminals. For auxiliaries fed from switchboards, the voltage drop and feeder current should be measured at the maximum load imposed during scheduled dockside tests. Voltage measurement should be made at the motor output terminals of the motor controller.

The voltage at the generator switchboard should be maintained at rated value. Voltage drop should not exceed the recommended values. The voltage drop tests are system tests performed during ship commissioning.

5.6.2.7 High resistance grounded systems

Under self-powered condition under full load, a ground fault shall be placed on the system. The current will be monitored at the point of the fault and no adverse effect should be witnessed. The ground fault current shall be monitored to ensure stability.

5.7 Brakes

Tests should be performed prior to delivery to confirm that the brake is in accordance with the design recommendations contained in IEEE P45.1. When a brake is a duplicate of one already tested, only such tests need be made that are necessary to demonstrate that the brake operates successfully. Spare coils should be given regular high-potential tests as described in 5.6.2.3. Other spare parts need not be tested in the entire assembled form. Temperature rise for coils need not be tested in the entire assembled form. Tests for waterproofness should be of the same nature as those for the motor, to which the brake is attached. Temperature-rise and insulation tests should be made in accordance with 5.6.2.1 and 5.6.2.2. Spare coils for ac brakes should be tested for short-circuited turns.

5.8 Magnetic friction clutches

Tests should be made prior to shipment for balance, temperature rise, and dielectric strength, in accordance with manufacturer's specifications. The temperature rise should conform to Table 6 with the clutch stationary. The clutch should develop its rated torque under normal conditions without slipping.

5.9 Distribution equipment

5.9.1 Circuit breakers

Circuit breakers should meet other national or international requirements and be tested or certified by a nationally recognized independent testing laboratory as suitable for shipboard applications.

5.9.2 Receptacles, plugs, and switches (non-watertight)

Receptacles and switches should have sufficient contact surface and meet all tests and requirements set by a nationally recognized independent testing laboratory.

5.10 Galley equipment

Cooking appliances, including their control equipment, should be tested at the manufacturer's facility. For portable appliances, the leakage current should not exceed 1 mA, and for stationary appliances, 1 mA or 1 mA per kW rated input, whichever is the larger, for each heating element that can be switched off separately.

5.11 Lighting

Circuits should be tested to confirm that all lighting fixtures, receptacles, and other connected fittings are in satisfactory operating condition. A photometric survey should be conducted to confirm that illumination levels are satisfactory and meet the specified requirements. Lighting design, maintenance considerations, testing, and illumination levels for any space should comply with IES RP-12-1998 and API RP 14F, as applicable.

5.12 Storage batteries

Storage batteries used for ship service diesel generator set starting and main propulsion diesel engine starting should be checked for capacity. The batteries should have sufficient capacity (without recourse to charging) to provide not less than 12 consecutive starts of each main engine, if of the reversible type, and not less than six consecutive starts if of the nonreversible type. For ship service diesel generator sets, battery capacity should provide not less than six consecutive starts.

Emergency diesel generator set batteries should be checked to confirm that they have sufficient capacity to provide three consecutive starts from each energy source within 30 min.

The recommendations of this subclause apply to permanently installed power, control, and monitoring storage batteries. These batteries may be either lead-acid or alkaline type batteries, and either vented or sealed. When selecting the type of battery, consideration should be given to the suitability of the battery type for the specific application. Battery maintenance and testing considerations should comply with IEEE Std 450-2010, IEEE Std 1188a-2005, IEEE Std 1106-2015, IEEE Std 1657a-2009, IEC 62133: 2012, and IEC 61960: 2011.

5.13 Marine shipboard cable

Marine shipboard cables should be listed as Marine Shipboard Cable by a nationally recognized testing laboratory. These cables should meet the performance and construction requirements of IEEE Std 1580-2010, or UL 1309-2014 or CSA 22.2 No. 245-1015, and installed using the recommended practice of IEEE Std 45.8-2016 according to Table 8.

Table 8—Performance test requirements of IEEE Std 1580

Test to be performed	Test categories		
	Type test (TT)[a]	Production sample (PST)[b]	Routine test (RT)[c]
Insulation	X	X	
Jacket	X	X[d]	
High potential		X	X
Partial discharge			X[i]
Conductor resistance			X
Insulation resistance			X
Flammability	X	X[e]	
Ease of stripping		X	
Salt water immersion	X		
Cable immersion in oil	X		
Pull-through metal plates	X		
Bending endurance	X		
Cold bend test	X		
Cold impact test (optional)	X[f]		

Table continues

Table 8—Performance test requirements of IEEE Std 1580 *(continued)*

Test to be performed	Test categories		
	Type test (TT)[a]	Production sample (PST)[b]	Routine test (RT)[c]
Vibration	X[g]		
Incidental motion (repeated flexing)	X[h]		
Insulation discharge resistance test	X		

[a]Type tests (TT)—Type tests are the minimum initial testing for a manufacturer to determine compliance with this recommended practice. TT should be qualified by a third party NRTL as meeting this recommended practice. Unless otherwise specified, TT should be performed on a 3 conductor 6 AWG cable for power and distribution, 7 conductor 12 or 14 AWG cable for control, and a 7 or 8 pair 18 AWG for signal cables. Any other cables in their respective cable designation for distribution, control, or signal that are 23 mm in diameter or larger may also be considered representative. This does not relieve the manufacturer from ensuring compliance with the test requirements for all cable types and sizes.
[b]Production sample tests (PST)—Production sample tests should be performed at the frequency established in NEMA WC 54 (ICEA T-26–465). Where no frequency is identified for a particular test in NEMA WC 54 (ICEA T-26–465), the testing frequency should be determined by the product certification organization.
[c]Routine tests (RT)—Routine tests should be performed on each length of finished cable.
[d]PST for weatherometer and mechanical water absorption as related to the jacket/sheath shall be done at a frequency of every three years.
[e]PST for flammability and when invoked for smoke, acid gas, and toxicity tests as related to the insulation/jacket/sheath shall be done at a frequency of every three years.
[f]This test applies to Transport Canada requirements test at –35 °C cold impact test per 4.13 of CSA 22.2 No. 03.
[g]This test applies to Type MC (CWCMC) for use in areas of high vibration.
[h]This test applies to Type MC (CWCMC) for use in areas of repeated flexing.
[i]Partial Discharge Testing is required only for shielded cables rated 2001 V and greater except for discharge-resistant cables.

5.14 Fire detection, alarm, and sprinkler systems

Fire detection, alarm, and sprinkler systems, and their components, should have been tested by an independent laboratory to nationally or internationally recognized testing protocols. See NFPA 72-2016 [B12] for more information about fire detection and alarm systems.

All detectors should be capable of being operationally tested and restored to normal operation without replacing parts. Detectors installed in damp or wet locations, such as roll-on/roll-off spaces or machinery spaces, should be specifically designed and tested for such use.

5.15 Electric propulsion and maneuvering systems

5.15.1 Generators and motors

A dedicated propulsion bus should normally have a voltage total harmonic distortion of no more than 8%. If this limit is exceeded in the dedicated propulsion bus, it should be verified by documentation or testing that malfunction or overheating of components does not occur.

Generators and motors should successfully pass the following tests at the place of manufacture. The following tests should be conducted in accordance with IEC 60034-2-1, IEEE Std 112-2004, IEEE 113-1985, IEEE Std 115-2009, or NEMA MG 1-2014, as applicable:

a) Temperature rise under rated load or rated current conditions
b) High potential
c) Overload capacity, as specified
d) Cold resistance of all circuits
e) Partial discharge testing for medium and high-voltage systems
f) Mechanical balance (special considerations should be made on differences in stiffness of test bed and the actual installation)

5.15.2 Control equipment

Controls for electric propulsion equipment should be inspected when finished, and high potential tests and insulation resistance measurements should be made on the various circuits at the place of manufacture. The functional operation of controls and displays, and satisfactory tripping and operation of all relays, contactors, and various safety devices, should also be demonstrated.

5.15.3 Motor drives

Semiconductor static power converters for propulsion system drives should be tested and inspected at the place of manufacture. Duplicate units of previously tested power converters need be tested only as deemed necessary to demonstrate successful operation. Simulate, as closely as possible, the upstream impedances associated with the shipboard system to determine the impact (in both directions) between system and drive. Also, apply as close to the rated capacity of the proposed load as possible, up to and including using a rotating load instead of a simple resistor bank, where possible.

5.16 Communication systems

Each interior communications system and alarm system should be tested to verify that they perform their required function. Particular attention should be paid to testing all essential electrical communication systems, including electric engine order telegraphs, electric docking telegraphs, automatic fire alarm and detection systems, general announcing and public address systems, the general emergency alarm system, sound-powered telephone systems, and dial telephone systems.

5.17 Steering systems

The operation of electric and electrohydraulic steering gear and associated steering controls should be functionally tested to demonstrate that manufacturer installation requirements are met.

5.18 Control systems

All propulsion, auxiliary machinery, and electric plant control and safety systems installed to comply with the requirements for an automated machinery system or a periodically unattended machinery space should be checked for correct installation and material condition and be performance-tested to verify satisfactory operation.

5.19 Emergency electrical systems

The complete emergency electrical supply and distribution system should be tested to verify proper performance. This should include the following tests (where applicable):

— Operation of the emergency generator automatic starting system

— Operation of the transitional emergency battery automatic transfer system

— Capacity test of the emergency storage battery

— Operation of the emergency lighting system

— Operation of emergency power driven equipment

5.20 Electric heating systems

Electric heating and reheat systems should be checked for proper functioning. Overheat cut-outs should be checked for proper operation and temperature rating. Electrical connections should be checked to confirm that they are tight. The interior of reheat boxes should be checked to confirm that they are free from excessive amounts of combustible dust.

5.21 Battery systems

Industrial installations tend to have battery racks grounded; however, neither the vented lead acid (VLA) nor the valve-regulated lead-acid battery (VRLA) standards require the rack be grounded. Only the NiCad standard requires the rack to be grounded. The only way to have an arc flash in a battery bank system is:

— Positive to ground

— Negative to ground

— Positive to negative

If the rack is not grounded, you can effectively eliminate the first two; leaving only positive to negative. IEEE Std 450-2010 [B8] suggests verifying that the electrolyte level of each cell is between the high- and low-level marks imprinted on the cell case. Inspect each battery cell jar, cell container cover, and seals. Examine the plates in each cell for sulfation. Examine the plates in each cell for the proper color that indicates a fully charged battery based on the manufacturer's information. Examine, if possible, through the clear battery container case the plates, bus bar connection to each plate, and bus bar connection to the post of each battery cell for corrosion and other abnormalities. Inspect the lower part of the post seals and the underside of the cover for cracking or distortion. Examine the cell plates, spacers, and sediment space of each cell to determine if any deterioration has occurred that could affect a cell relative to the rest of the cells in the battery. Examine the cell posts of each cell to determine if any of them have grown or lifted to a larger degree than the rest of the posts of the battery. There are two types of cell/battery failures for which to check.Category 1 failures:

— Cracked jars where electrolyte is leaking from the cell

— Individual cell voltage (ICV) on float less than 1.8 V

— Open circuit

— Significant visual deterioration of the plates

— Hydration (typically requires replacement of the entire battery at the earliest opportunity)

— Container and/or cover cracks, or other conditions, that breach the cell boundary above the electrolyte level (may not require cell replacement, but should be repaired as soon as possible due to the increased potential for a battery explosion)

Cell/battery failures in Category 1 require immediate corrective action and may require bypassing the affected cells and float voltage adjustments, and/or cell/battery replacement, etc. at the earliest opportunity.

Category 2 failures:

— Copper contamination (May require immediate bypassing of the cell; contact the manufacturer for guidance. This condition is not correctable and cell replacement is required.)
— Post seal failure (May require increased post cleaning activities and, if not correctible, require cell replacement.)
— Sulfation (Indicates self-discharge and requires close monitoring of ICV. If not recoverable by single cell charging, cell replacement will be required.)

Cell/battery failures in Category 2 do not pose an immediate threat to battery function, and corrective actions can be performed as part of scheduled maintenance. It should be noted that these conditions can worsen and result in the cell reaching Category 1 limits, so increased monitoring of the cell/battery condition is recommended.

6. Existing installations

Electric equipment and systems should be continually maintained to confirm that the installation is kept as close as practicable to the original physical condition. Electrical equipment and systems should be periodically inspected and tested for the purpose of observing the possible development of physical changes or deterioration. These inspections and tests, at the intervals required by classification societies or national authorities, should include the following items:

a) The equipment and installation should be generally inspected and tested under working conditions and electric cables inspected as far as practicable without dismantling equipment.

b) Generators and all motors driving essential auxiliary machinery should be inspected as far as may be practicable without dismantling equipment, unless such dismantling is deemed necessary as a result of test or observation.

c) An insulation resistance test should be made on generators, motors, cables, heaters, and fittings using a direct indicating ohmmeter of the generator type, applying a dc voltage of 500 V; the insulation resistance measured should not be less than the values given in IEEE Std 43-2013. All generators should be run individually or simultaneously, and all main switches and circuit breakers operated under load and their reverse power, overcurrent, under voltage, and under frequency trip circuits tested.

d) The functioning of the complete emergency electrical supply system should be tested. This should include the following:

    1) Operation of the emergency generator automatic starting system

    2) Operation of the transitional emergency battery automatic transfer system

    3) Where the emergency source of power is supplied by batteries, operation under the specified load conditions

    4) Operation of the emergency lighting system

e) All essential electrical communication systems should be tested to verify proper operation.

f) Where the control of the propulsion machinery or the propeller is provided by electric or electronic means, a general inspection of the complete control system should be conducted.

g) The operation of electric and electrohydraulic steering gear should be tested. Particular attention should be paid to the functioning of the motor overload alarm, motor stopped indication, and supply circuit-breaker-tripped alarm.

It is further recommended that in addition to required inspections, periodic measurements of resistance of the insulation be made between conductors and the frame or ground of rotating equipment and in circuits between conductors and between conductors and ground. The value of insulation resistance will afford a useful indication as to whether the equipment or system is in a suitable condition for continued service. This data can be used to detect deterioration conditions and to allow for corrective action prior to equipment or system failure.

The best indication of the magnitude of current leakage from a winding or circuit is given by a comparison of the observed insulation resistance with previously measured values. The change from the last measured value of resistance is far more significant than is the absolute value of the resistance. It is recommended that a log of successive readings be kept for each important machine and circuit on board ship. In addition, remarks should be entered into the log to describe properly the observed condition of the machine and circuit for future comparison. Log entries should typically include the following:

— For machines: Supply cable connected or disconnected; machine blown out, machine dried out, dusty, oily, or wet; condition of connecting leads, brush rigging, brushes, commutator; clearances between pole pieces and armature; temperature; humidity; repairs made.

— For circuits: Equipment and appliances connected or disconnected to the supply cables; cable and connection boxes dirty, oily, or wet; condition of connected equipment and appliances; temperature; humidity; repairs made.

Any large and abrupt decrease in insulation resistance should be investigated immediately. The insulation resistance is subject to variation with temperature, humidity, and cleanliness of parts. When the insulation resistance falls, it can, in most cases when no defect or ground exists, be brought up to a proper value by cleaning and drying. It is difficult to prescribe definite recommendations for the actual value of insulation resistance of a machine or circuit because their values vary with type, size, voltage rating, kind and condition of insulating material used, method of construction, and the insulation record of the machine and circuit. Considerable judgment based on the results of previous measurements should be exercised to determine whether the machine or circuit is suitable for continued service or should be repaired or replaced. The frequency of periodic inspections and insulation resistance tests is dependent on the magnitude and importance of the electric installation on board the vessel as well as the service and climatic conditions to which such installations are subjected.

The use of logs or records covering these recommendations, which will also show other pertinent information contingent on the vessel's individual service conditions, is recommended.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

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[B6] IEEE Std 43-2013, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.[16,17]

[B7] IEEE Std 45.5-2014, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations.

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[B10] NEMA ICS 1: 2015, Industrial Control and Systems: General Requirements.[18]

[B11] NFPA 70E®: 2015, Standard for Electrical Safety in the Workplace.[19]

[B12] NFPA 72®: 2016, National Fire Alarm and Signaling Code.

[13]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).
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