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Small craft — Electric propulsion system

Petits navires — Système de propulsion électrique

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 188, *Small craft*, together with CEN/BT/WG 69, *Small craft* and IEC/TC 18, *Electrical installations of ships and of mobile and fixed offshore units*.

Introduction

Electrical propulsion systems are becoming more common in recreational craft and other small craft and propulsion system voltages of up to AC 1 000 V and DC 1 500 V are possible together with variable speed drives operating at frequencies which differ from 50/60 Hz or DC.

Electric propulsion systems for small craft are generally designed and constructed from a number of component parts many of which can be of proprietary origin and all of the electrical and control items are interconnected by cables and operated as a system.

There are a significant number of electrical propulsion system architectures for small craft and the main types are the following.

— DC sourced. The main power source is a propulsion battery which is either recharged from on-board DC generators, or on-board AC generators/an AC shore supply through battery chargers. The electric propulsion system(s) may be variable speed through a DC motor controller or AC through a Variable Frequency Drive (VFD) or be fixed speed with a variable pitch propeller or other mechanical means of providing thrust. The electric propulsion system may be electrically separate from other electrical systems on board (e.g. be fully insulated via the motor controller, or be an AC IT system via a VFD or motor starter). Or the electrical propulsion system may be integrated with the whole craft DC electrical system using converters DC/DC, DC/AC to provide for different services/consumers.

— AC sourced. The main power source is AC generator(s) generally configured as TT, TN-C or TN-S. The electric propulsion system(s) may be DC variable speed through a AC/DC converter and DC motor controller, or AC through a VFD, or be fixed speed with a variable pitch propeller or other mechanical means of providing thrust. The electric propulsion system may be DC fully insulated system or be an AC IT system via a galvanically isolated VFD or via an isolating transformer. A DC propulsion system(s) may be supported by propulsion battery.

— Also possible are hybrid systems similar to the types being introduced for road vehicles where the source is an internal combustion engine providing, for example, energy to a relatively lightweight energy storage system with power take-off via converters to propulsion motor(s) and other electrical consumers.

It is essential that the electric propulsion system designer/installer be competent with all aspects of the equipment included in the design of a particular system such that the component parts of the propulsion system are integrated in a coherent and safe manner.

Current electrical standards for small craft of less than 24 m LH are the following:

a) ISO 10133 which is limited to recommendation for the design, construction and installation of direct current systems that operate at a voltage of DC 50 V or less; and

b) ISO 13297 which is limited to single phase alternating current electrical systems less than AC 250 V.

Neither of these standards includes requirements for electrical propulsion systems.

c) IEC 60092-507 is applicable to small craft up to 50 m/500 GT and includes requirements for three-phase systems not exceeding AC 500 V and single-phase systems not exceeding AC 250 V and for DC systems and sub-systems not exceeding DC 50 V nominal, and includes a section on electric propulsion systems.

Small craft — Electric propulsion system

1 Scope

This International Standard addresses the design and installation of alternating current (AC) and direct current (DC) electrical systems used for the purpose of electrical propulsion and/or electrical hybrid (system with both a rechargeable battery and a fuelled power source) propulsion.

This International Standard applies to electrical propulsion systems operated in the following ranges either individually or in combination:

— direct current of less than 1 500 V DC;

— single-phase alternating current up to AC 1 000 V;

— three-phase alternating current up to AC 1 000 V.

This International Standard applies to electrical propulsion systems installed in small craft up to 24 m length of the hull (L_H according to ISO 8666).

This International Standard also lists in Annex A additional information to be included in the owner's manual as well as Annex B additional information to be provided to the installer.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8846, *Small craft — Electrical devices — Protection against ignition of surrounding flammable gases*

ISO 9094, *Small craft — Fire protection*

ISO 10133:2012, *Small craft — Electrical systems — Extra-low-voltage d.c. installations*

ISO 10239, *Small craft — Liquefied petroleum gas (LPG) systems*

ISO 10240, *Small craft — Owner's manual*

ISO 11105, *Small craft — Ventilation of petrol engine and/or petrol tank compartments*

ISO 13297:2014, *Small craft — Electrical systems — Alternating current installations*

ISO 25197:2012, *Small craft — Electrical/electronic control systems for steering, shift and throttle*

IEC 60079-series, *Electrical apparatus for explosive gas atmospheres*

IEC 60092-202:1994/Amd 1:1996, *Electrical installation in ships — Part 202: System design — Protection*

IEC 60092-303, *Electrical installation in ships — Part 303: Equipment — Transformers for power and lighting*

IEC 60092-352, *Electrical installation in ships — Part 352: Choice and installation of electrical cables*

IEC 60092-507:2014, *Electrical installations in ships — Part 507: Small vessels*

IEC 60898-1, *Electrical accessories — Circuit-breakers for overcurrent protection for household and similar installations — Part 1: Circuit-breakers for a.c. operation*

IEC 60945, *Maritime navigation and radiocommunication equipment and systems — General requirements — Methods of testing and required test results*

IEC 60947-2, *Low voltage switchgear and control gear — Part 2: Circuit breakers*

IEC 61558-2-4, *Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1100 V — Part 2-4: Particular requirements and tests for isolating transformers and power supply units incorporating isolating transformers*

IEC 61558-2-6, *Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1 100 V — Part 2-6: Particular requirements and tests for safety isolating transformers and power supply units incorporating safety isolating transformers*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
safety voltage
<AC> voltage which does not exceed AC 50 V r.m.s. between conductors, or between any conductor and earth, in a circuit isolated from the supply by means such as a safety isolating transformer, or converter with separate winding

<DC> voltage which does not exceed 50 DC V between conductors, or between any conductor and earth, in a circuit which is isolated from higher voltage circuits

Note 1 to entry: Consideration should be given to the reduction of the limit of 50 V under certain conditions, such as wet surroundings or exposure to heavy seas or where direct contact with live parts is involved.

Note 2 to entry: The voltage limit should not be exceeded either at full load or no load, but it is assumed, for the purpose of this definition, that any transformer or converter is operated at its rated supply voltage.

[SOURCE: IEC 60092-101:1994, 1.3.19]

3.2
rated voltage
U_0
<TN systems> nominal AC r.m.s. line voltage to earth

<IT systems> nominal AC r.m.s. voltage between line conductor and neutral conductor

<DC systems> nominal DC voltage between poles

[SOURCE: IEC 60092-507:2014, 3.1.4]

3.3
live part
conductor or conductive part intended to be energized in normal operation including a neutral conductor, but by convention not a PEN conductor (a conductor combining the functions of both a protective conductor and a neutral conductor)

Note 1 to entry: This term does not necessarily imply risk of electric shock.

[SOURCE: IEC 60050-195:1998, 195-02-19, modified as follows: The text “or a PEM conductor or PEL conductor” has been deleted. The text in brackets has been added]

3.4
earthed
grounded, en US
connected to the general mass of the hull of the craft in such a manner as will ensure at all times an immediate discharge of electrical energy without danger

[SOURCE: IEC 60092-101:1994, 1.3.9, modified as Note 1 to entry has been deleted]

3.5
readily accessible
capable of being reached quickly and safely for effective use without the use of tools

[SOURCE: ISO 13297:2014, 3.17]

3.6
final circuit
portion of a wiring system extending beyond the final overcurrent protection device for that circuit

[SOURCE: IEC 60092-101:1994, 1.3.17, modified – The words "overcurrent protective device of a board" have been replaced with "overcurrent protection device for that circuit"]

3.7
overcurrent protection device
device provided to interrupt an electric circuit in case the conductor current in the electric circuit exceeds a predetermined value for a specified duration

3.8
fuse
device that by the fusing of one or more of its specifically designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time

Note 1 to entry: The fuse comprises all the parts that form the complete device.

[SOURCE: IEC 60050-441:1984, 441-18-01, modified]

3.9
circuit-breaker
mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions, and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of a short circuit

[SOURCE: IEC 60050-441:1984, 441-14-20]

3.10
residual current device
RCD
mechanical switching device designed to make, carry and break currents under normal service conditions and to cause the opening of the contacts when the residual current attains a given value under specified conditions

[SOURCE: IEC 60050-442:1994, 442-05-02, modified as Note has been omitted]

3.11
protective conductor
PE (identification)
conductor provided for purposes of safety, for example, protection against electric shock

Note 1 to entry: In an electrical installation, the conductor identified PE is normally also considered as protective earthing conductor.

[SOURCE: IEC 60050-195:1998, 195-02-09]

3.12
bond
connection of non-current-carrying parts to ensure continuity of electrical connection, or to equalize the potential between parts comprising, for example, the armour or lead sheath of adjacent length of cable, the bulkhead, etc.

[SOURCE: IEC 60092-101:1994, 1.3.7, modified – Last part concerning “cables in a radio-receiving room” has been deleted.]

3.13
conductor
conductive part intended to carry a specified electric current

[SOURCE: IEC 60050-195:1998, 195-01-07]

3.14
neutral conductor
conductor electrically connected to the neutral point and capable of contributing to the distribution of electrical energy

[SOURCE: IEC 60050-195:1998, 195-02-06]

3.15
line conductor
phase conductor (in AC systems) (deprecated) pole conductor (in DC systems) (deprecated)

conductor which is energized in normal operation and capable of contributing to the transmission or distribution of electric energy but which is not a neutral conductor

[SOURCE: IEC 60050-195:1998, 195-02-08]

3.16
transformer
energy converter with isolating separation between the input and output windings and the protective conductor

3.17
switch
mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions which may include specified operating overload conditions and also carrying for a specified time currents under specified abnormal circuit conditions such as those of short circuit

Note 1 to entry: A switch may be capable of making but not breaking short-circuit currents.

3.18
panel board
assembly of devices, such as circuit breakers, fuses, switches, instruments and indicators, for the purpose of controlling and/or distributing electrical power

Note 1 to entry: Examples of devices include circuit breakers, fuses, switches, instruments and indicators.

3.19
disconnector
mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements

[SOURCE: IEC 60050-441:1994, 441-14-05]

3.20
battery pack
mechanical assembly comprising battery cells and retaining frames or trays and possibly components for battery management

Note 1 to entry: Note1 to entry: Typical battery packs will be a single assembly, voltage and connection in an enclosure.

Note 2 to entry: Several connected battery packs form a battery bank.

[SOURCE: ISO 12405-2:2012, 3.2, modified by additional Note 1 and 2 to entry]

4 General requirements

4.1 General

Electric propulsion systems for small craft are generally designed and constructed from a number of component parts many of which can be of proprietary origin and all of the electrical and control items are interconnected by cables and operated as a system.

It is essential that the propulsion system designer/installer shall be competent with all aspects of the equipment included in the design of a particular system such that the component parts of the propulsion system are integrated in a coherent and safe manner.

The rated power output of each electric propulsion system at the motor shaft shall be designed to match the propeller characteristics and the required rotational speed range or thrust range of variable pitch propellers/thrusters.

The electric propulsion system may be electrically separate from other electrical systems on board a small craft.

Different types of AC electrical system include four-wire with neutral earthed, but without hull return (TN-C), five-wire with neutral earthed, but without hull return (TN-S), and IT systems with their particular requirements for earth leakage current monitoring, alarm and tripping systems.

DC systems may be either earthed, or be fully insulated with particular requirements for insulation resistance monitoring, alarm and tripping systems. For DC propulsion systems operating at voltages greater than safety voltage, a three-wire system (e.g. DC +48 V/0/−48V) may be considered with the mid-point conductor earthed to limit prospective touch voltage.

For DC electric propulsion systems and other electrical systems with rated nominal voltages in excess of safety voltage, the precautions against the risk of electric shock shall be observed.

DC electric propulsion systems may have large capacity battery bank(s) or pack(s) as the main power source, and particular attention is required for the following:

a) ventilation requirements necessary for battery bank or battery pack compartments;

b) requirements for an overcurrent device and an isolation switch for each propulsion battery bank or battery pack;

c) circuit protection requirements for permanently energised circuits supplied from a battery bank or battery pack.

Electric propulsion circuits shall be designed to protect against the following:

— fire by the use of overcurrent protection, grounding/earthing, terminal protection and conductor type and size;

— shock by the use of enclosures, conductor and terminal insulation, automatic disconnection and grounding/earthing system protection as appropriate.

Electric propulsion circuits shall not interact with other circuits in such a way that circuits would fail to operate as intended.

4.2 Components of an electric propulsion system

The electric propulsion system may include several sub-systems and components including, but not limited to, the following:

— batteries;

— battery management systems;

— AC or DC generators;

— AC/DC, DC/DC, DC/AC, AC/AC converters, Variable Frequency Drives;

— electric propulsion motors;

— propulsion panel board;

— propulsion motor controls, monitoring, system alerts and trip alarms;

— transformers;

— conductors and cables;

— isolation switches (disconnectors), circuit breakers, contactors, fuses.

Each of these propulsion system components shall conform to the relevant ISO/IEC standard.

4.3 Electric propulsion systems

4.3.1 An electrical propulsion system may be

a) DC, sourced from battery(s) or DC generator(s) or AC/DC converters from an AC source, or

b) AC, sourced from alternator(s) or a DC/AC converter from a DC source [e.g. battery(s)].

The energy source(s) of an electric propulsion system may be reserved for this purpose and be electrically separate from other electrical systems on board a craft, or all electrical systems on board a craft may be directly connected to a common source but propulsion system(s) may have specific requirements for electrical separation, earthing/bonding, conductor installation, etc. from the other items of electrical equipment and circuits included in the overall design.

The rated voltage of an electric propulsion may be different from other electrical systems on-board a craft and uses either AC or DC systems.

— For an AC propulsion system, it may be at variable frequency.

— For a DC propulsion system sourced from an AC system, the DC electrical propulsion system may be obtained from an AC/DC converter with galvanic separation between input and output and appropriate arrangements made at the output for fully insulated or negative earth propulsion systems. Similarly, an earthed two wires propulsion system may be supplied from an insulated two wires source via a DC/DC converter with galvanic separation and vice versa.

— For a DC propulsion system sourced from a DC system, the source shall have the same characteristics.

Systems may require attention to the treatment of the neutral earth, and also have specific requirements in respect of earthing and bonding relative to the requirements of other electrical systems on-board a craft.

4.3.2 A DC electrical propulsion system may be configured as

a) fully insulated two-wire system (IT) or

b) two-wire system with negative earth/bonded (TN-S, TN-C, TN-C-S).

4.3.3 A single-phase AC electrical propulsion system may be configured as

a) single-phase two wire insulated (IT), or

b) single-phase two-wire with earthed neutral (TT or TN-C without hull return); or TT (when shore connected), or

c) single-phase three-wire with mid-point earthed, both neutral and protective conductor (PE) earthed at the energy source without hull return (TN-S).

4.3.4 A three-phase electrical propulsion system may be configured as

a) three-phase three-wire insulated (IT), or

b) three-phase four-wire with earthed neutral (TT or TN-C without hull return); or TT (when shore connected), or

c) three-phase five-wire with mid-point earthed, both neutral and protective conductor (PE) earthed at the energy source without hull return (TN-S).

If the AC propulsion system is required to be an IT from a TN source (or vice-versa), then an isolation transformer conforming to IEC 61558-2-4 (U_0 up to AC 1 100 V, maximum rated output 25 kVA for single phase, 40 kVA for three-phase) may be used providing galvanic separation between primary and secondary windings with appropriate arrangements being made at the secondary circuit(s).

If an AC 110 V single-phase propulsion system is required sourced from an IT or TN source and increased safety is required, then a safety isolating transformer may be used conforming to IEC 61558-2-6, reducing the prospective touch voltage U_0 to 63,5 V. (Note that secondary winding centre tap is required to be earthed).

An AC propulsion system may be sourced from a DC source via a DC/AC converter providing galvanic separation between input and output allowing the AC propulsion system (single-phase or three-phase) to be IT or TN as required. The DC/AC converter may also be variable frequency. Similarly, an AC/AC converter may be used providing galvanic separation and allowing the propulsion system (single-phase or three-phase) to be IT or TN as required. The AC/AC converter may also be variable frequency type (variable frequency drive).

NOTE For craft with metallic hull, the large cross-section area of metal for earth return paths enables simple method of earthing and bonding (TT, TN and IT systems) in which non-current-carrying parts can be bonded direct to the hull of the craft.

A craft with a non-metallic hull requires to be provided with a protective conductor which may be separate from the neutral conductor (TN-S) or not separate (TN-C).

4.4 Arrangements for other electrical equipment and circuits on-board a small craft connected to a common energy source for both propulsion and general electrical installation

4.4.1 DC systems

In DC systems, equipment and circuits may be connected to the same source as the propulsion system as follows:

a) Where the DC propulsion system requires to be insulated from earth as in 4.3.2 a), other equipment and circuits shall be directly connected to the common DC source(s) these other electrical equipment and circuits shall also be fully insulated from earth (in this case, a common insulation resistance monitoring system as specified in 6.3). Each item of electrical equipment or final circuit connected shall be provided with an overcurrent/fault protection device [circuit breaker or fuse(s)] which in the case of a fully insulated system shall trip both poles of the protective device.

b) If either the propulsion system or the other equipment is required to be fully insulated and the other negatively earthed or vice versa (or is a three-wire system with centre earth), DC/DC converters with galvanic separation between input and output may be used where the output(s) can be configured to be fully insulated or negative earthed or earthed three-wire as appropriate. Each propulsion system or item of electrical equipment or final circuit connected to a DC/DC converter shall be provided with an overcurrent/fault protection device [circuit breaker or fuse(s)] and in the case of fully insulated propulsion system or other equipment or final circuits, the protective device shall trip both poles of the circuit feeding the equipment or circuits. The input circuit to each DC/DC converter shall be protected by an overcurrent device at the source.

c) DC equipment and circuits rated at different voltages may be connected to a common source via DC/DC converters, each provided with input and output overcurrent/fault protection device [circuit breaker or fuse(s)] as in b) above. If the DC/DC converters have galvanic isolation between input and output, the connected equipment or circuits may be either configured as fully insulated or have the negative pole earthed or be centre wire earthed in three-wire systems.

d) AC equipment and final circuits (including AC propulsion systems) may be connected to a common DC system via DC/AC converters, the output of which may be variable frequency/voltage in the case of AC VS drives. Each item of AC electrical equipment or final circuit connected shall be provided with an overcurrent/fault protection device [circuit breaker or fuse(s)], and where appropriate a RCD, and the appropriate equipment or final circuit configuration also being made at the converter output.

4.4.2 AC systems

In AC systems, equipment and circuits may be connected to the same source as the propulsion system as follows:

a) Where the AC propulsion system requires to be insulated from earth (IT) and is supplied from a non IT type source and/or if the rated voltage of the of the AC IT propulsion system is different from the rated voltage of the source and other equipment and circuits connected to the source, then the AC propulsion system may be connected via an isolating transformer conforming to IEC 61558-2-4 which provides isolation between primary and secondary windings or AC/AC converter. Each item of propulsion equipment or circuit(s) connected to the isolation transformer secondary winding or converter output shall be provided with an overcurrent/fault protection device [circuit breaker or fuse(s)] and the IT propulsion system and circuits shall be monitored for earth (ground) faults as in 6.4. Each propulsion system isolation transformer primary circuit or AC/AC converter shall be protected by an overcurrent device at the source.

b) Alternatively, if the AC propulsion system is directly supplied from an AC source with both propulsion system and source having a common system configuration (IT, TT or TN type), then other electrical equipment and circuits requiring different configuration(s) or rated voltage(s) may be supplied from the AC source via isolation transformer(s) conforming to IEC 61558-2-4 providing isolation between primary and secondary windings or AC/AC converters with the appropriate circuit arrangements then made on the secondary output circuits (IT, TT, TN-C or TN-S). Each item of electrical equipment or final circuit so connected to the secondary winding of an isolation transformer or output of an AC/AC converter shall be provided with an overcurrent/fault protection device [circuit breaker or fuse(s)] and where appropriate, an RCD. If safety isolated equipment or circuits are required to be connected (i.e. AC reduced low voltage AC 63,5 V/0/-63,5 V) referenced to earth (ground), then a safety isolating transformer may be employed conforming to IEC 61558-2-6. Separated extra-low voltage (SELV) transformers (e.g. for lighting circuits) may also be employed. Each isolation transformer/safety isolation transformer primary circuit or AC/AC converter shall be protected by an overcurrent device at the source.

c) DC propulsion systems equipment and circuits [which may be supported by battery(s)] may be connected to an AC system via AC/DC converter (or rectifier). Each item of electrical propulsion equipment or other final circuit connected to the AC/DC converter output or battery supported DC system shall be provided with an overcurrent/fault protection device [circuit breaker or fuse(s)], and in the case of a fully insulated system the protective device shall trip both poles and the system shall be monitored for low insulation resistance as in 6.4. Each AC/DC converter shall be protected by an overcurrent device at the AC source.

4.5 Environmental factors

4.5.1 The propulsion system shall be designed for the environment in which it is intended to be used. Where necessary, consideration shall also be given to raw water cooling temperature ranges up to 35 °C (95 °F).

4.5.2 Ventilation shall be adequate to maintain the ambient temperature at or below the maximum at which the equipment is designed to operate. Enclosures for electrical equipment shall be mechanically strong and rigid, and mounted so that the equipment will not be affected by the distortion, vibration or movement of the craft's structure that occur during normal operation of the small craft.

4.5.3 Natural air-cooling of enclosures should be designed with sufficient ventilation openings or with sufficient cooling surface to dissipate the heat so that enclosed equipment will operate within their design temperature limits.

4.6 Electrical ratings

Electrical and electronic equipment shall function under the normal voltage and frequency variations and harmonic distortion which may occur in the electric propulsion system in normal operation, including transient overloads induced by propulsion system start-up, without damage, tripping or overheating.

The basic limits and associated requirements are that DC systems shall be designed to operate within the following limits:

a) the nominal DC voltage tolerance at the battery terminals over which all DC equipment shall operate is −25 % to +33 %;

b) the essential services of the craft shall remain functional to the minimum voltage at the battery terminals;

c) when battery chargers/battery combination are used as DC power systems, adequate measures should be taken to keep the voltage within the specified limits during charging, quick charging and discharging of the battery.

The basic limits and associated requirements are that AC systems shall be designed to operate within the following limits:

a) frequency: ±5 %;

b) voltage: +6 %/−10 %;

c) single harmonic distortion: <3 %;

d) total harmonic distortion: <5 %.

AC variable frequency drives shall conform to the manufactures design parameters.

4.7 Equipment

4.7.1 Transformers

Transformers used for power, lighting and as static converters, starting transformers, static balancers, saturable reactors and transductors, including single-phase transformers rated at less than 1 kVA, and three-phase transformers rated at less than 5 kVA, shall comply with IEC 60092-303.

Isolation transformers for general use shall comply with IEC 61558-2-4.

Transformers shall be installed in well-ventilated locations. Their connections shall be protected against such mechanical damage, condensation and corrosion as may be reasonably expected.

Transformers with liquids containing polychlorinated biphenyls (PCBs) shall not be used.

4.7.2 Converters

Semiconductor converters shall conform to IEC 60146.

Converters shall be installed according to the component manufacturer's instructions such that they operate within the design specifications.

NOTE ISO 13297:2014, Clause 15, contains requirements for inverters and inverter/chargers for AC outputs of up to AC 250 V and DC outputs of 12 V, 24 V and 32 V.

4.7.3 Motors

The requirements of the IEC 60034 series shall apply.

4.8 Enclosures

4.8.1 Energized parts of electrical equipment shall be guarded against accidental contact by the use of enclosures.

4.8.2 Access to enclosures housing energized parts of the electrical system shall require the use of hand tools or have a protection of at least IP2X. Further details of appropriate IP ratings are given in ISO 10133:2012, Clause 9, of ISO 13297:2014, Clause 12 and IEC 60092-507:2014, 4.7.

4.9 Identification of equipment and conductors

4.9.1 All electrical equipment and enclosures shall be marked with the following:

a) the name of manufacturer;

b) the model number or designation;

c) the electrical rating in volts and amperes or volts and watts;

d) the phase and frequency, if applicable;

e) a certified safe type, if applicable.

4.9.2 All cables and conductors shall be identified by label (cables, multi-core cables, single core cables). All conductors greater than DC 50 V shall indicate the correct polarity and be orange in colour or otherwise identified as exceeding DC 50 V. All conductors for systems operating at a voltage greater than AC 250 V shall be identified as such.

4.10 Segregation of DC and AC systems

Craft equipped with both DC and AC electrical systems shall have the DC and AC distribution from either separate distribution boards, or from a common distribution board with a partition to separate the DC and AC sections from each other.

4.11 Steering and throttle controls

Electrical/electronic control systems for steering, ahead/astern, and speed or power shall meet the requirements of ISO 25197 (see also Clause 5).

4.12 Electromagnetic compatibility (EMC)

Electrical and electronic equipment shall conform to IEC 60945.

ICOMIA Guideline 49-13, recommended practice for EMC of small craft, includes guidance on the practical testing of EMC in small craft.

4.13 Electrical equipment in the vicinity of battery banks

All electrical equipment located in the same vicinity as a battery, battery pack or battery bank that has the possibility of emitting flammable gas or substances shall be ignition protected according to ISO 8846 or IEC 60079 series.

NOTE All lead-based batteries have the possibility to produce flammable gas.

4.14 Hazardous areas

4.14.1 Areas and equipment that can endanger the safety of the crew (e.g. battery compartments, electrical assemblies) shall be

a) accessible only with the use of tools or keys and

b) labelled appropriately to the hazard they present.

4.14.2 Enclosures covering electrical connections and storage batteries shall be marked to indicate hazards by the use of the symbols in Figure 1, as applicable.

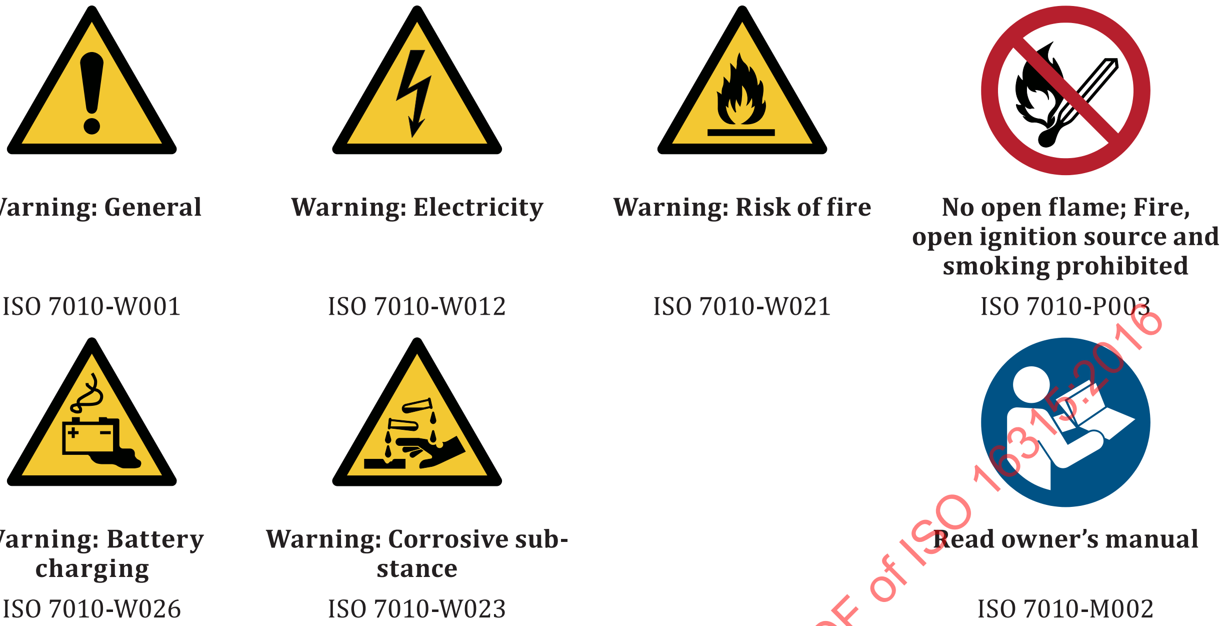

Figure 1 — Safety signs

5 Controls, monitoring, system alerts and trips alarms

5.1 Electrical/electronic controls for electric propulsion systems

5.1.1 Controls

Control systems shall control, and also limit, energy flow to prevent damage between the battery and/or power sources and propulsion machinery in either direction. This requirement is in addition to proper overcurrent protection of the installation. It shall be noted that the propeller(s) may continue to rotate when a small craft is under way caused by inertia of the rotating equipment and/or movement of the craft through the water when neutral is selected or an emergency stop or trip or battery disconnect switch is operated. Special precautions shall be taken in the case of permanently excited propulsion motors to prevent the generation of hazardous system voltages under these circumstances.

Consideration shall also be given to the effects of fault tripping on critical system components.

Propulsion control(s) shall typically include the following controls and switches for each propulsion motor/propeller system depending on the system design.

a) Electric propulsion On/Off control for each propulsion system (e.g. start/stop propulsion generator, close/open propulsion battery circuit breaker or contactor, close/open propulsion system circuit breaker in main electrical system). Consideration shall be given to making the on/off control capable of being lockable in the "off" position;

b) Ahead/Neutral/Astern control;

c) Propeller speed control.

The controls b) and c) may be combined into a common control device for each propulsion motor/propeller system.

NOTE ISO 25197 provides detailed type testing criteria for mechanical, environmental and EMC for such electrical /electronic steering, shift and throttle systems intended for use in small craft.

5.1.2 Emergency stop

An “Emergency stop” pushbutton switch or equivalent device shall be provided for each propulsion system. The “emergency stop” switch or equivalent device shall “lock-off” when operated and be capable of being manually reset at the steering/control position only. The emergency stop circuit shall be hard-wired to immediately power off the associated propulsion system when the “emergency stop” is operated.

A battery isolation switch can be used as an emergency stop switch provided it meets the requirements of this section.

5.1.3 Fault trip reset

A propulsion system fault trip reset facility shall be provided which shall be effective when the following conditions are satisfied:

a) no propulsion system trip is present (first warning alarms are allowable);

b) ahead/Neutral/Astern control is set at Neutral position;

c) propeller speed control set at minimum speed;

d) the “emergency stop” (5.1.2) and/or “battery disconnector” (5.1.3) control is not operated.

5.1.4 “Get you home” mode

In case of an electric propulsion control failure, a manual emergency control mode or alternative means shall be provided for the craft to be navigated to a position of safety in accordance with SOLAS.

5.2 Instruments, alerts and trip alarms

5.2.1 General

Instruments, alerts and trip alarms shall be provided, as appropriate, for each electric propulsion system.

Where a separate propulsion control panel is installed which provides for system alerts and trip alarm a common system alert and fault trip alarm indicator may be provided at the steering/control station.

5.2.2 Operating mode and status

Operating mode and status shall be provided for the following:

a) operating mode indication for systems using a combination of combustion and electric systems for propulsion;

b) system status (e.g. energized/available or system fault);

c) propulsion drive system active (e.g. ahead/astern or generator mode);

d) propeller speed;

e) capacity monitor [e.g. a fuel gauge or battery state-of -charge indicator (0 % to 100 %) remaining] for the source(s) of stored energy of each system;

f) power meter(s) up to rated power (0 % to 100 % or KW) or DC battery current(s) (A).

Consideration shall be given to extending the range display of these instruments to indicate the safe maximum power or current allowed under temporary overload conditions.

5.2.3 System alerts

System alerts shall be provided as appropriate for the main operational or component parts of an electric propulsion system. For example:

a) high propulsion motor temperature;

b) high battery compartment temperature (for battery sourced electric propulsion systems);

c) low state of charge (for battery source systems);

d) low insulation resistance (IR) (for fully insulated DC systems);

e) single earth fault (for AC IT systems);

f) loss of cooling.

5.2.4 Fault trip alarms

Fault trip alarms shall be provided as appropriate for the main operation or component parts of an electric propulsion system. For example:

a) propulsion motor system overload trip;

b) motor and /or converter high temperature trip;

c) very low IR trip (for fully insulated DC systems);

d) second earth fault trip (for AC IT systems).

6 Protection against electric shock

6.1 Protection against direct contact

6.1.1 Live parts shall be protected against accidental contact by the use of enclosures or be completely covered by basic insulation which can only be removed by destruction. Horizontal top surfaces of barriers or enclosures which are readily accessible shall be provided with a degree of protection of at least IP4X.

6.1.2 All exposed non-current-carrying conductive parts shall be connected to earth either via the protective conductor (AC TN-C, TN-S systems), or to the negative pole of a 2-wire earthed DC system, or to the earthed conductor of a DC 3-wire system or by connection direct to a steel hull (DC fully insulated system, and AC TT, IT systems).

6.1.3 Each single component of the system shall conform to a minimum insulation resistance of 500 Ω/V for DC components and 1 000 Ω/V for AC components.

6.2 Automatic disconnection of supply to the electric propulsion system under fault-to-earth conditions (earthed two wire DC systems and earthed neutral AC systems)

For earthed DC 2-wire systems or for AC TN-C, TN-S and TT systems a protective device (fuse, circuit-breaker) shall automatically disconnect the supply to the electric propulsion system in the event of a fault between a live part and an exposed non-current-carrying conductive part of the system in accordance with Table 1. The overcurrent current rating or trip setting shall be determined by the characteristics of the electric propulsion system, and the fault rating of the protective device shall be determined by reference to the prospective short current rating from the source together with any contribution from converters/propulsion motors plus contributions from any other converter when connected to a common DC or AC energy source.

The fuse ratings and trip settings of circuit breakers shall be determined in accordance with 7.2 with maximum disconnection times given in Table 2.

Table 1 — Overcurrent/earth (ground) fault tripping requirements for electric propulsion systems

— Voltage type	— Requirement
AC	— In earthed neutral systems, the protective arrangements for final circuits particularly to locations in confined or exceptionally damp spaces where particular risk due to conductivity might exist shall be: a) an overcurrent protective device and — b) a residual-current protective device with sensitivity of 30 mA maximum for final circuits to locations where there is an increased risk of personal contact with live conductive parts.
DC	— A protective device (fuse, circuit-breaker) shall automatically disconnect the supply to the circuit or equipment in the event of a fault between a live part and an exposed non-current-carrying conductive part.

NOTE 1 Further information can be found in IEC 60898–1, IEC 60947–2, IEC 61008-1[4] and IEC 61009-1.[5]

NOTE 2 For earthed AC propulsion systems consideration may be given to the use of a 100 mA or 300 mA rated RCD if the potential for nuisance tripping of essential navigational/propulsion equipment is considered a hazard, provided that suitable measures for protection against direct contact shall be installed.

Table 2 — Maximum disconnection times

Rated voltage (U_0)	$50 V < U_0 \leq 90 V$		$90 V < U_0 \leq 230 V$		$230 V < U_0 \leq 400 V$		$U_0 > 400 V$	
AC or DC system	AC	DC	AC	DC	AC	DC	AC	DC
Breaking time: TN or IT or TT systems or DC systems	0,8 s	0,5 s	0,4 s	0,5 s	0,2 s	0,4 s	0,1 s	0,1 s
Breaking time: TT system (when connected to a shore supply)	0,3 s		0,2 s		0,07 s		0,04 s	

U_0 is in:

— TN systems: nominal AC r.m.s. line voltage to earth;

— IT systems: nominal AC r.m.s. voltage between line conductor and neutral conductor, as appropriate;
— DC systems: nominal DC voltage to earth.

6.3 Fault-to-earth monitoring and tripping arrangements for DC fully insulated systems, DC 3-wire systems

6.3.1 For fully insulated DC two wire systems or 3-wire systems with the centre wire earthed, insulation resistance monitoring shall be provided on each pole relative to earth. The system shall provide an alert on a single pole fault-to-earth current equivalent to a resistance of less than 500 Ω/V, and shall trip the propulsion system on a "second fault" to earth in the opposite pole (which may also to create a current overload).

6.3.2 A protective device performing the trip function (fuse, circuit-breaker) shall automatically disconnect the supply to the electric propulsion system in the event of the "second fault". The "second fault" trip function may be combined with the system overcurrent trip function in a common circuit breaker. The "second fault" trip setting shall be determined by the characteristics of the electric propulsion system, and the fault rating of the earth fault protective device or overcurrent circuit breaker shall be determined by reference to the maximum prospective fault current rating of the source together with any contribution from converters/propulsion motors plus any contributions from other converter when connected to a common DC or AC energy source.

6.4 Fault-to-earth tripping in AC non-neutral earthed systems (IT-type system)

Fault-to-earth tripping in AC IT-type system shall be arranged as follows:

a) For AC IT-type propulsion systems, the phase conductors are insulated from earth and the star point of the source is either isolated from earth or deliberately connected to earth through a high impedance. It is permissible for a single fault between a live part and an exposed non-current-carrying conductive part to occur without automatic disconnection, provided that earth monitoring or a permanent insulation controller is fitted. A “second fault-to-earth” shall result in automatic disconnection

b) The earth fault monitoring and tripping arrangements applied to an AC electric propulsion system shall not allow a prospective touch voltage exceeding AC 50 V to persist for a time sufficient to cause a risk of harmful physiological effect in a person in contact with an energised exposed non-current-carrying conductive part.

c) The earth fault monitoring and tripping function may be combined with an overcurrent circuit-breaker (which automatically disconnects the supply to the electric propulsion system in the event of an overcurrent fault which also may occur as a result of a second fault-to-earth). The trip setting shall be determined by the characteristics of the electric propulsion system connection conductor. The fault rating of the earth fault protective device or overcurrent circuit breaker shall be determined by reference to the prospective fault current rating of the source together with any contribution from converters/propulsion motors plus contributions from any other converter connected to a common DC or AC energy source.

7 Protection against over-current

7.1 General

Each propulsion system shall be protected against overload by circuit-breaker(s) or fuse(s).

Circuit-breakers shall be selected in accordance with IEC 60947 or IEC 60898-1.

Each fuse or circuit-breaker at the source of a circuit shall be designed to protect the conductor with the smallest cross section in the circuit being protected.

7.2 Characteristics of protective devices

Each protective device for AC or DC propulsion systems shall be selected in such a way that:

a) its rated current or current setting (I_n) is not less than the design current (I_b) of the system;

b) its rated current or current setting (I_n) does not exceed the lowest of the current-carrying capacities (I_z)of any of the conductors in the circuit;

c) the current (I_2) causing effective operation does not exceed 1,45 times the lowest current- carrying capacity (I_z) of any of the conductors of the circuit;

d) the breaking and making capacity shall be in accordance with at least the maximum prospective short-circuit or earth-fault current at the point at which the device is installed. However if the short-circuit breaking or making capacity of the device is less than the maximum prospective short-circuit or earth fault current, it shall be backed up by a fuse or circuit-breaker in accordance with IEC 60092-202:1994/ Amd 1:1996, 6.1.3 and 6.2.

e) the maximum disconnection times shall be in accordance with Table 2.

For adjustable protective devices, the rated current (I_n) shall be the current setting selected.

7.3 Overcurrent devices in the outgoing circuit(s) from a battery

Each battery or battery pack output circuit shall be protected by an over-current protection device (circuit breaker or fuse) with a fault current rating determined by the maximum short circuit current that a fully charged battery can deliver at the location at which the circuit breaker or fuse is installed and a trip setting determined in accordance with 7.2. The over current protection shall be located as close as practicable and shall be within 1,8 m of the battery output terminals measured along the conductors.

Where a remote controlled circuit breaker or contactor-fuse arrangement is employed as a means of isolation (disconnector) in accordance with 8.2, the remote circuit breaker or the fuse of a contactor-fuse arrangement may be used as the means of overload protection for the outgoing circuit with a trip setting determined in accordance with 7.2.

For each battery system connected to fully-insulated two-wire systems, over-current protective device shall be two pole type.

8 Battery monitoring and installation

8.1 General arrangements

Isolators (disconnectors) and switches shall not require tools for their operation and manual operating mechanisms shall be readily accessible from outside the battery pack or enclosure. Isolators (disconnectors) shall be provided with a means of locking in the OFF position.

Batteries shall be secured against movements and inclinations (pitch and heel) occurring during craft use and shall be protected against falling objects. Batteries as installed in the craft shall be capable of inclinations of up to 30° without leakage of electrolyte. Means shall be provided in monohull sailing craft for containment of any spilled electrolyte up to inclinations of 45°.

Lead-acid storage batteries and alkaline storage batteries shall not be placed in a common cabinet or container or in close vicinity to each other. Batteries shall be installed above anticipated bilge water level.

Where batteries, except for sealed types, are fitted in a machinery space, drip trays or containers resistant to the effects of the electrolyte shall be provided. Batteries shall not be installed directly above or below a fuel tank or fuel filter and any other metallic component of the fuel system within 300 mm above the battery top, as installed, shall be electrically insulated.

Battery terminals and any exposed conductor terminations shall be protected against direct contact by persons or tools as detailed in ISO 10133:2012, Clause 5. Care shall be taken when performing inspection and maintenance work to prevent bodily contact with exposed live battery components and to avoid contact of uninsulated tools between battery terminals/exposed conductors and earth or between poles. The connectors on battery packs or the battery bank output connection that have a total voltage of DC 60 V or greater, shall be at least IP 2X when connected or disconnected.

Switches and other electrical equipment shall not be placed in battery compartments or containers unless it meets the requirements of ISO 8846 or IEC 60079 series.

8.2 Isolation of battery packs or battery banks

Each battery pack or battery bank shall be capable of being disconnected from the DC system circuits by a readily accessible manually operated isolation switch (disconnector) immediately adjacent to the battery compartment. The isolation/disconnector switch shall be located as close to the battery output terminals as possible and within 1,8 m measured along the conductor.

A remote-control isolator or remote-control circuit breaker may be used as an isolation switch (disconnector) when fitted with a manual on/off mechanism and is installed in a readily accessible location immediately adjacent to the battery compartment.

In fully insulated systems, isolation switches shall be two pole, and in negative earth systems, isolation switches shall be single pole in the positive conductor circuit. In negative earth systems, a separate isolation switch may be installed for the engine-cranking motor circuit(s).

The minimum interrupting capacity (Icn) of an isolation switch, or circuit breaker performing this function, shall be the maximum short circuit current that a fully charged battery can deliver at the location at which the isolating switch or circuit breaker is installed. The minimum continuous current rating of an isolation switch or a circuit breaker used as an isolation switch shall be at least equal to the current carrying capacity of the connecting conductor.

If a remote controlled isolator (disconnector), or a remote-control contactor with in-line fuse, or a remote-control circuit breaker (each without a manual operating facility) is installed to operationally disconnect a battery pack, then a manually operated isolation switch shall also be provided between the remote-control isolator, remote-control contactor/fuse arrangement or remote-control circuit breaker and the battery pack terminal(s) or output connection to battery bank(s).

For batteries with terminals not protected against direct contact, it shall be arranged for facilities to be provided to break battery packs down into groups of less than DC 60 V (nominal) by off-load isolation switches (disconnectors), the main isolating switch having been previously operated to “off”.

Battery packs in excess of 60 V DC shall be of the touch safe type or shall have protection that requires the use of tools for removal of covers to protect against accidental contact.

8.3 Operational switching of battery pack(s) or battery bank(s)

Operational switching (on/off) may be controlled by remote-control contactor/fuse arrangements or remote-control circuit breakers which shall be installed in the positive conductor from each battery pack or output connection to battery banks, for negative earth systems, and for fully insulated systems such operational switching devices shall be double pole installed in both positive and negative conductors from each battery pack or output connection to battery bank(s). The continuous current rating of remote control contactor/fuse arrangements or remote-control circuit breakers shall be the maximum design current for the circuit(s) being controlled from the battery pack or battery bank. Operational switching devices shall have as a minimum interrupting capacity (Icn) the design short circuit current at the location at which they are installed.

8.4 Permanently energized circuits

The following systems may be connected between the isolation switch or remote-control device performing an isolation switch function and the battery pack or battery bank terminal(s):

a) electronic devices with protected memory and protective devices such as bilge-pumps and alarms, which shall be individually protected by a circuit-breaker or fuse as close as practical to the battery terminal(s);

b) ventilation exhaust blower of engine/fuel-tank compartment which shall be protected by a fuse(s) or circuit-breaker as close as practical to the battery terminal(s);

c) charging devices intended to be used when the craft is unattended (for example, solar panels, wind generators) which shall be individually protected by a fuse(s) or circuit breaker as close as practical to the battery terminal(s);

d) for an electric propulsion system battery pack or battery bank, a circuit maintaining a remote-control switch coil or remote-control contactor coil via a control switch at the steering/control position shall be individually protected by a fuse or circuit breaker as close as practical to the battery terminal(s) on a battery pack or as close to the battery terminal output point on a battery bank.

8.5 Ventilation

Battery compartments shall be ventilated according to battery manufacturer's recommendations relative to the following requirements:

a) location in which lead-acid or alkaline batteries are placed shall be ventilated to free air so that hydrogen cannot accumulate, or where batteries are installed in a closed compartment or container(s) reserved for batteries, a vent system or other means shall be provided to permit the discharge to the open air from the battery compartment or container those explosive gasses released by battery during charge to the open air;

b) the air inlet to battery compartments or containers shall be below the level of the battery, and the outlet shall be at the highest point of the compartment or container and shall lead directly to the open air with bends of no more than 45°;

c) if natural ventilation is impractical or insufficient, mechanical ventilation shall be provided. Where mechanical ventilation is employed, charging system(s) shall be interlocked so as to switch off if the ventilation fails. An alert shall be provided at the helm position if mechanical ventilation failure occurs;

d) cable entries to battery compartments shall be gastight.

8.6 Electrical apparatus for explosive gas atmospheres

It shall be noted that propulsion battery pack(s) or battery bank(s) may be placed low in a craft hull because of their effect on the stability of the craft. In the event of a fault with LPG systems or leakage of other inflammable gas or vapour which may accumulate in the lower portions of the hull of a craft particular precautions shall be taken to prevent the operation of a battery isolation switch or other operational switching device being a source of ignition.

For such electrical equipment which is intended for use in explosive gas atmospheres or which is installed where flammable gases, vapours or explosive dusts are liable to accumulate, such as in spaces containing petrol-powered machinery, petrol fuel tank(s), or joint fitting(s) or other connections(s) between components of a petrol system, and in compartments or lockers containing LPG cylinders and/or pressure regulators, shall conform to ISO 8846, ISO 10239, ISO 11105 and ISO 9094 or IEC 60079 series.

9 Electrical installation

9.1 General

Conductors for DC and AC propulsion systems and other electrical distribution systems connected to a common source shall be selected in accordance with IEC 60092-352.

Propulsion system conductors shall be installed in conduit or ducts, on dedicated conductor trays, or by clamps or other methods direct to surfaces in accordance with IEC 60092-352. See also ISO 10133 and ISO 13297.

Except where designed for this purpose, the component parts/equipment, motors and conductors comprising an electric propulsion system shall be installed above the maximum possible bilge water level taking into account the craft's conditions of heel and trim. Dedicated inverter/controller power circuits between the inverter/controller and motor shall be designed and installed to minimize conducted or radiated electromagnetic emissions.

9.2 Segregation of electrical propulsion system cables

Electrical circuits for the propulsion system shall be physically separated from the remainder of the craft's electric systems by being

a) installed in a physically separate conduit or cable trunking or