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INTERNATIONAL STANDARD

Electrical installations in ships –
Part 501: Special features – Electric propulsion plant

IEC 60092-501:2013(E)

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ELECTRICAL INSTALLATIONS IN SHIPS –

Part 501: Special features – Electric propulsion plant

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60092-501 has been prepared by IEC technical committee 18: Electrical installations of ships and of mobile and fixed offshore units.

This fifth edition cancels and replaces the fourth edition published in 2007. It constitutes a technical revision.

This edition included the following significant technical changes with respect to the previous edition:

a) requirements regarding system responsibility, electromagnetic compatibility (EMC), harmonic distortion and filtering, special requirements for ships with propulsion motor(s) and podded drives, and power management system (PMS);
b) overall technical review to update the standard according to general requirements and referenced equipment standards.

The text of this standard is based on the following documents:

FDIS	Report on voting
18/1338/FDIS	18/1353/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60092 series, published under the general title *Electrical installations in ships*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

IEC 60092 forms a series of International Standards for electrical installations in sea-going ships, incorporating good practice and coordinating, as far as possible, existing rules. These standards form a code of practical interpretation and amplification of the requirements of the International Convention on Safety of Life at Sea, a guide for future regulations which may be prepared and a statement of practice for use by shipowners, shipbuilders and appropriate organizations.

ELECTRICAL INSTALLATIONS IN SHIPS –

Part 501: Special features – Electric propulsion plant

1 Scope

This part of IEC 60092 specifies requirements for all electric propulsion plants and gives the specifications, system design, installation and testing of at least:

– generators and their prime movers;
– switchboards;
– transformers/reactors;
– semiconductor convertors;
– propulsion motors;
– excitation systems;
– control, monitoring and safety systems;
– wires, cables, busbars, trunking systems;
– harmonic filters.

Bow and stern thrusters intended as auxiliary steering devices, booster and take-home devices, all auxiliary generating plants, and accumulator battery powered propulsion machinery and equipment are excluded.

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.

IEC 60034 (all parts), *Rotating electrical machines*

IEC 60034-1:2010, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60076 (all parts), *Power transformers*

IEC 60092 (all parts), *Electrical installations in ships*

IEC 60092-101, *Electrical installations in ships – Part 101: Definitions and general requirements*

IEC 60092-202, *Electrical installations in ships – Part 202: System design – Protection*

IEC 60092-301, *Electrical installations in ships – Part 301: Equipment – Generators and motors*

IEC 60092-302, *Electrical installations in ships* – Part 302: *Low-voltage switchgear and controlgear assemblies*

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

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

IEC 60092-401, *Electrical installations in ships – Part 401: Installation and test of completed installation*

IEC 60092-504:2001, *Electrical installations in ships – Part 504: Special features – Control and instrumentation*

IEC 60146 (all parts), *Semiconductor convertors*

IEC 60146-2, *Semiconductor convertors – Part 2: Self-commutated semiconductor converters including direct d.c. convertors*

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

IEC 60533:1999, *Electrical and electronic installations in ships – Electromagnetic compatibility*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments*

IEC 61180-1, *High-voltage test techniques for low-voltage equipment, Part 1: Definitions, test and procedure requirements*

IEC 61378-1, *Convertor transformers – Part 1: Transformers for industrial applications*

IEC 61439-1, *Low-voltage switchgear and controlgear assemblies Part 1: General rules*

IEC 61439-2, *Low-voltage switchgear and controlgear assemblies Part 2: Power switchgear and controlgear assemblies*

IEC 61800 (all parts), *Adjustable speed electrical power drive systems*

IEC 62271-200:2011, *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*

International Convention for the Safety of Life at Sea (SOLAS):1974, *Consolidated edition 2009*

3 Terms and definitions

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

3.1
appropriate authority
governmental body and/or classification society with whose rules the installation is required to comply

[SOURCE: IEC 60092-101:1995, 1.3, modified — The words “a ship“ has been replaced with “the installation”.]

3.2
azimuth drive
system which moves the propulsion unit around the vertical axis

3.3
double sensor
two sensor elements in one housing

3.4
motor supply lines
cables and/or busbars used for supply to the propulsion motor(s)

3.5
local control station
place of control where a system is installed which creates a reference value for the convertors independent from the remote control system and any external limitations

3.6
main control station
place of control of the main propulsion system which is manned under seagoing conditions

3.7
inaccessible spaces
spaces that are not accessible during operation without dry docking.

3.8
nominated body
installer or manufacturer that has been given direct responsibility for the complete propulsion system

3.9
single failure criterion
criterion applied to a system such that it maintains manoeuvrability in the presence of any single failure

[SOURCE: IEC 60050-393:2003, 393-18-27, modified — The phrase “it is able to perform its safety task” has been replaced with “it maintains manoeuvrability”]

3.10
podded drive
propulsion system in which the motor is located in a dedicated, submerged unit (pod housing) of the ship

3.11
power management system
PMS
control and safety system which provides the load depending starts and stops of the prime movers, the load sharing, etc.

3.12
propulsion generator
generator mainly used for power supply of the propulsion system

3.13
propulsion motor
electrical motor intended to provide propulsion power

3.14
propulsion switchboard
switchboard mainly used for power distribution to the propulsion systems

3.15
redundant sensor
two single sensors in separate housings

3.16
remote control system
system which comprises all equipment necessary to operate units from a control position where the operator cannot directly observe the effect of his actions

4 System

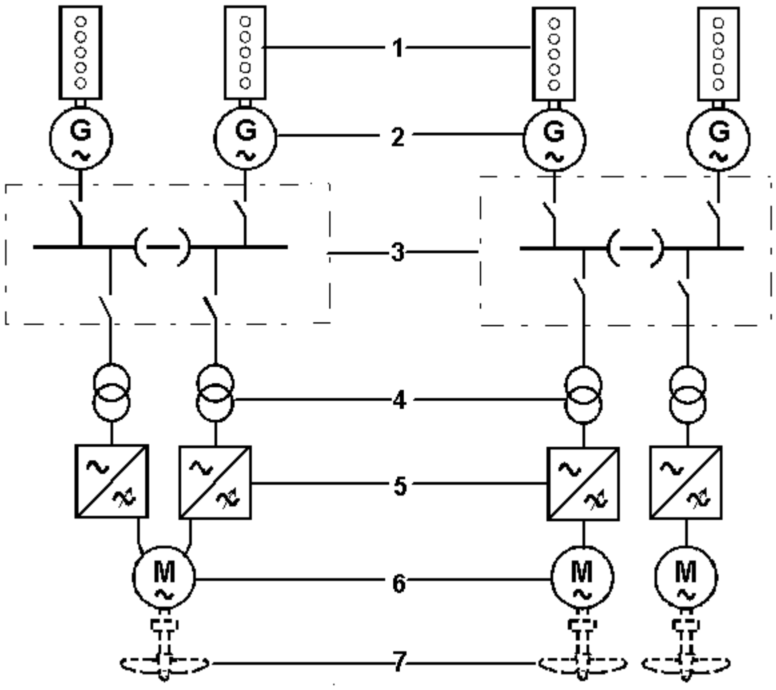
4.1 System design

4.1.1 General

A typical electrical propulsion system may consist of the following hardware components:

– propulsion generators;
– switchboard;
– transformers to convert the ships voltage to the convertor voltage;
– convertor to supply the electric motor;
– control system;
– propulsion motor.

A typical configuration of the hardware components is shown in Figure 1.



Key

1 main engine
2 propulsion generator
3 switchboard
4 propulsion transformer
5 propulsion convertor
6 propulsion motor
7 propeller

Figure 1 – Typical equipment (configuration) for ships with one or two propellers

4.1.2 Design requirements

The single failure criterion shall be the basis of the design of the electric propulsion system.

Recognizable failures should not injure the single failure criterion. Undetected failures should be avoided. However, it may be unavoidable that some undetected failures may injure the single failure criterion.

It shall be possible for all machinery essential for the safe operation of the ship to be controlled from a local position, even in the case of failure in any part of the automatic remote control system, see Clause 14.

4.1.3 Blocking devices for shafts

Each shaft shall be equipped with a blocking device to prevent shaft rotation, allowing towing or the operation of the remaining shaft(s). The drive(s) for the remaining shaft(s) may be limited as long as manoeuvring capability is maintained under all weather conditions.

4.1.4 Special requirements for ships with only one propulsion motor

Synchronous and induction motors shall be equipped with two stator winding systems which can be disconnected from the respective convertor. Each convertor shall be designed for at least 50 % nominal power of the propulsion drive.

DC motors shall have two separate rectifiers, each for 50 % nominal motor current, with means for disconnecting each rectifier. The convertors shall be mutually independent. Any single failure in one convertor shall not result in complete loss of propulsion power.

Motors with permanent excitation shall be equipped with two stator winding systems which can be disconnected from the respective convertor. Additionally, there shall be a braking or blocking system which can fix the shaft under all weather and normal towing conditions. Alternatively, a decoupling system may be used which ensures standstill of motor shaft.

NOTE Winding damages will lead to the total loss of the propulsion motor. In this case the single failure design criteria cannot be fulfilled.

Auxiliary machinery vital to the propulsion system, such as cooling, lubrication, etc. must be provided in duplicate in order to provide continued or restored propulsion capability in the event of a failure or malfunction of any single auxiliary component.

4.1.5 Special requirements for ships with more than one propulsion motor

Any electrical failure in a propulsion convertor or propulsion motor shall not make all shafts unavailable.

Special consideration in this respect shall be given to shaft lines driven by permanent exited propulsion motors.

4.2 System responsibility

There shall be one nominated body responsible for the integration of the complete propulsion system.

This body shall have the necessary expertise and resources enabling a controlled integration process.

4.3 Torsional stress and torsional vibrations

Motors and shaftlines shall be capable of withstanding all loading conditions. Evidence shall be provided by means of a torsional vibration calculation.

The entire oscillating system may include prime movers, generators, transformers, convertors, exciters, motors, slip couplings, gears, shafts and propellers.

The manufacturers of the components shall provide all necessary information to the system responsible body, see 4.2.

The highest oscillating torque may be expected during a two-phase short-circuit of the motor. The highest steady state torque may be expected during a three-phase short-circuit of the motor.

All possible load conditions shall be managed by the propulsion plant.

4.4 Protection and operational stability

The required protection criteria are defined in Annex A.

Shutdowns of the system shall be avoided as far as possible.

The control system shall be able to control the propulsion system under all weather and manoeuvring conditions.

Other on-board systems shall not influence the propulsion or manoeuvrability of the ship, for example no common communication links, no common hardware. This shall also apply for azimuth drives.

Special consideration shall be given to electromagnetic interference.

All means for normal operation of the propulsion system, including necessary power generation, shall have interlocks in order to prevent incorrect operation and damages.

4.5 Protection against moisture and condensate

Effective means, for example space heaters or air dryers, shall be provided in motors, generators, convertors, transformers and switchboards to prevent accumulation of moisture and condensate, even if they are idle for appreciable periods.

4.6 Excitation systems

4.6.1 General requirements

Every excitation system shall be supplied by a separate feeder.

The obtainable current and voltage of excitation systems and their supply shall be suitable for the output required during manoeuvring, overcurrent and short-circuit or stalling conditions.

Excitation power circuits may be protected against short-circuits only, and tripping shall be alarmed.

If the built-in short-circuit monitoring device of the excitation system trips, the respective circuit breaker of the generator or motor shall also trip.

If the excitation system is fitted with independent safety devices, for example against under-frequency and over-voltage or voltage/frequency-functions, they shall be adjusted in such a way that the system protection reacts first.

Excitation circuits shall be provided with means for suppressing voltage rise when an excitation switch is opened.

Special consideration shall be given to the total harmonic distortion and power factor.

4.6.2 Generators

The steady and transient regulation conditions of the excitation system including the automatic voltage regulator shall be in accordance with IEC 60092-301.

Excitation systems shall be supplied from the generator side and the generator shall be self-excited. In general, the voltage built-up shall be done without the aid of an external electric power source.

External power supply may be used for exciter control circuits provided that redundancy for this external source is arranged, even for the voltage built-up. The external source of power shall be supplied from the corresponding main switchboard section and emergency source of electrical power with battery backup. At least two external power supplies for all generators are required. Every generator excitation system shall be supplied by independent power supply.

4.6.3 Propulsion motors

The exciter circuits shall be supplied from the same energy source supplying the stator windings.

This means, the switchboard section supplying the stator winding should be the energy source of the associated exciter system.

4.7 Wires, cables, busbars, trunking systems

Choice and installation of cables shall be in accordance with IEC 60092-352 and IEC 60092-401.

The cables for different propulsion systems shall be installed separately.

If the convertor technology requires special properties of the cabling between convertor and motor, the specification of the convertor manufacturer shall be observed.

NOTE Example: PWM-convertors require low cable capacitance.

Design of cabling, busbars, trunking systems and slip rings shall take into account special failure conditions including magnitude and duration of failure currents.

5 Electromagnetic compatibility (EMC) and harmonic distortion

5.1 General

Propulsion systems shall comply with performance criterion A of IEC 61000-6-2. This means no degradation of performance or loss of function is allowed during normal operation.

5.2 Total harmonic distortion, THD

Equipment producing transient voltage, frequency and current variations is not to cause malfunction of other equipment on board, neither by conduction, induction or radiation.

The design shall take in account that propulsion convertors create interferences within the propulsion network.

For the propulsion network the total harmonic distortion (THD) value of the voltage shall not exceed 10 %. If a THD value of 10 % is exceeded, the person responsible for the propulsion system, see 4.2, shall ensure interference-free operation of all connected equipment.

If the propulsion network and the ship's network are directly connected, the THD value of ships network voltage shall not exceed the values stated in IEC 60092-101.

The design of cabling and cables, transformers, protection devices etc. shall take into account the high level of harmonic currents caused by the convertor system.

The additional heating contribution caused by the harmonic distortion shall be defined by all parties.

5.3 Conducted and radiated RF emissions

Convertors exceeding the radiated and conducted emission limits of 6.2 of IEC 60533:1999 shall be installed according to the requirements for special power distribution zone as described in IEC 60533:1999. The immunity requirements of the propulsion convertor shall comply with at least the requirements for all other equipment on board.

Conducted and radiated emissions leaving the convertor cabinet or room shall be reduced to a system-compatible level.

6 Prime movers

6.1 General requirements

The engines driving the propulsion generators are auxiliary engines and have to comply with the specification of the relevant authorities for main engines and of IEC 60092-504.

6.2 Speed deviations

If the propulsion generators are also used for supplying the ship network, static and dynamic frequency deviations shall meet the requirements of the ship network.

Where the speed control of the propeller requires speed variation of the prime mover, the governor shall be provided with means for local control as well as for remote control.

The prime mover rated power in conjunction with its overloading and load build-up capabilities shall be adequate to supply the power needed during transitional changes in operating conditions of the electrical equipment due to manoeuvring and sea and weather conditions.

6.3 Parallel operation

In case of parallel operation of generators, the governing system used shall permit stable operation to be maintained over the entire operational load range of the prime-movers.

The speed governor characteristics of prime movers shall be such that in parallel operation the load on individual generators is shared, as far as possible, in proportion to the output of each generator.

Any vessel speed change or throttle movement shall not cause a ship's service power interruption.

6.4 Regenerated energy from propeller

When manoeuvring, for example from full propeller speed ahead to full propeller speed astern, regenerated power may occur.

The amount of regenerated power shall be limited by the control system, so that tripping due to overspeed or reverse power is avoided.

Means external to the mechanical and electrical rotating machinery may be provided in the form of for example braking resistors to absorb excess amounts of regenerated energy and to reduce the speed of the propulsion motor.

7 Generators

7.1 General requirements

Generators shall be designed in accordance with the IEC 60034 series and IEC 60092-301.

Generators shall have a protection degree of at least IP 23. High voltage generators shall have a protection degree of at least IP 44.

Generators operating with semiconductor convertors shall be designed for the expected harmonics of the system. A sufficient reserve shall be considered for the temperature rise, compared with sinusoidal load.

Stator windings of generators rated above 500 kVA shall be provided with temperature sensors.

Generators above 1 500 kVA shall be equipped with differential current protection.

7.2 Bearing and lubrication

7.2.1 General

All bearings shall be equipped with temperature devices or a thermometer shall be installed. The measuring point shall be as specified in IEC 60034-1.

Adequate lubrication shall be ensured even in inclined positions. Provision shall be made for checking the bearing lubrication.

Generators shall be equipped with devices which, in the event of a failure of the normal lubricating oil supply, provide adequate lubrication until the machine has come to standstill.

No lubricating liquid shall flow out of the bearings and penetrate into the machine.

In case of bearings with forced lubrication, an alarm shall be given for the failure of the oil supply (loss of oil pump, loss of pressure in the bearing supply pipe) and the attainment of excessive bearing temperatures. If the temperature rises further, the generator shall be stopped.

To avoid damage to bearings, it is essential to ensure that no harmful currents can flow between bearings and shaft. At least one bearing shall be mounted electrically insulated from the machine.

7.2.2 Sleeve bearings

Sleeve bearings shall be easily replaceable.

Two-part bearings shall be fitted with thermometers indicating, wherever possible, the temperature of the lower bearing shell.

7.2.3 Roller bearings

Roller bearings shall be sufficiently preloaded, where applicable.

7.3 Cooling

The temperature of the cooling air of machines provided with forced air ventilation, air ducts, air filters or water coolers shall be continuously monitored by means of thermometers which are readable from outside the machine. Temperature sensors shall be provided to trigger an alarm.

For machines with a closed circuit cooling method with a heat exchanger, the flow of primary and secondary coolants shall be monitored.

For machines with water cooled heat exchangers, leakage monitoring is required.

7.4 Protection

The protection shall be in accordance with IEC 60092-202.

7.5 Test

Propulsion generators shall be individually tested at the manufacturer's works. The scope of the tests is stated in the IEC 60034 series.

The additional heating caused by total harmonic distortion, see 5.2, shall be taken into account during the temperature rise test.

8 Propulsion switchboards

8.1 General

The propulsion switchboard shall be in accordance with IEC 62271-200 (high-voltage) adapted to shipbuilding requirements or IEC 60092-302 (low-voltage) and shall be designed like a main switchboard. The longitudinal segregation of the busbar shall be done by a load switch disconnector or equivalent equipment.

The power generation used for the propulsion motors could be used for ship service distribution.

Special consideration shall be given to the total harmonic distortion, see 5.2, and power factor.

8.2 Test

A complete test of the protection devices, interlockings etc. shall be carried out in the test requirements for main switchboards.

9 Propulsion transformers

9.1 General requirements

9.1.1 General

Transformers and reactors shall be in accordance with IEC 60092-303 and power transformers in accordance with IEC 61378-1 and the IEC 60076 series.

Special consideration shall be given to the total harmonic distortion, see 5.2, and power factor and in case of PWM type convertors, increased core losses.

Where propulsion transformers are fitted, at least two independent units shall be provided for a single shaft solution.

Only transformers with separate windings shall be used. Auto-transformers are permitted for motor starting.

Transformers producing low voltage from high voltage shall be equipped with an earthed shield winding between the low-voltage and high-voltage coil.

The winding temperatures of propulsion transformers shall be monitored.

9.1.2 Degree of protection

Transformers located in engine rooms shall have a protection degree of at least IP 23. High voltage transformers, located in engine rooms, shall have a protection degree of at least IP 44. Other degrees of protection may be chosen in accordance with IEC 60092-503.

9.2 Cooling

9.2.1 Liquid cooled transformers

Measures shall be taken to ensure that the windings are completely covered by liquid, even for inclinations up to and including 22,5°.

They shall be provided with a collecting arrangement which permits the proper disposal of the liquid.

In case of flammable liquids a fire detector and a suitable fire extinguishing system shall be installed in the vicinity of the transformer. The fire fighting system may be manually operated.

Liquid cooled transformers shall be provided with gas-actuated protection devices.

The liquid temperature shall be monitored. A prealarm shall be actuated before the maximum permissible temperature is attained. When the maximum permissible temperature limit is reached, the transformer shall be switched off.

The liquid filling level shall be monitored by means of two separate sensors. The monitoring system shall actuate an alarm at the first stage and shall trigger a shutdown at the second stage, when the permissible limit is exceeded.

9.2.2 Air cooled transformers

Air flow and temperatures of the cooling air for forced-ventilated transformers shall be monitored.

9.2.3 Air forced/water cooled transformers

For transformers with a closed cooling circuit method with a heat exchanger, the flow of primary and secondary coolants shall be monitored. Leakage water and condensed moisture shall be kept away from the windings. Leakage monitoring is required.

9.3 Instrumentation

Propulsion transformers shall be equipped with a three-phase ammeter on primary side.

9.4 Protection

Each propulsion transformer shall be protected against primary and secondary side short-circuit.

If the primary side of transformers is protected for short-circuit only, overcurrent protection shall be arranged on the secondary side.

Protection on secondary side may be achieved by the convertor.

High voltage transformers shall be equipped with differential protection if the primary protection is not adequate.

9.5 Test

Propulsion transformers shall be individually tested at the manufacturer's works. The scope of the tests including the vector-group test is stated in IEC 60076.

The additional heating caused by total harmonic distortion, see 5.2, shall be taken into account during the temperature rise test.

10 Convertors

10.1 General

Convertors shall be designed in accordance with the IEC 60146 series and IEC 61800 series.

The installation of convertors shall be in accordance with requirements of IEC 60533. See also 5.3 in this document.

Two completely separate convertors shall be installed.

Common control of the convertors is not permitted. This means, for example, that two single sensors or one double sensor shall be installed.

Two galvanically isolated actual speed sensors shall be provided, one for each control system. Common housing of both sensors is permitted.

If the convertor feeds a permanently excited synchronous motor, a switch with breaking capacity shall be fitted in the motor-convertor line which opens automatically in case of an inverter fault.

Devices which support fault diagnosis shall be installed.

10.2 Design of semiconductor convertors

Propulsion convertors shall be designed for the nominal torque of the drive. Short-term overload and speed variations resulting from overloads shall not lead to a shutdown of the system.

The mechanical housing for semiconductor convertors shall be in accordance with the standards of main switchboards, where applicable.

High voltage convertors shall be treated like high voltage switchgear and controlgear in accordance with IEC 62271-200 adapted to shipbuilding requirements. The enclosures shall be manufactured to withstand accidental arcs in accordance with Annex AA of IEC 62271-200:2011, or shall be located in a way that personnel safety is ensured.

The power components for semiconductor convertors shall be easily replaceable.

10.3 Cooling of semiconductor convertors

If semiconductor convertors are fitted with forced-cooling, means for monitoring the cooling system shall be provided.

In case of a failure of the cooling system, measures shall be taken to prevent damage to the convertor. An alarm shall be given. The alarm signal can be generated by the flow of the coolant, or by the temperature of the semiconductors.

If semiconductors are cooled by liquid, this liquid circuit shall be restricted to one convertor system. Liquid quality shall be observed.

Single failure criterion in convertor cooling systems shall not lead to the tripping of all convertors of the ship's propulsion.

Manoeuvrability of the ship shall be maintained.

10.4 Protection

The following protection of convertors shall be provided.

- Operational overvoltages in a supply system to which convertors are connected shall be limited by suitable devices to prevent damage. Protective fuses for these devices shall be monitored.
- A suitable control shall ensure that the permissible current of semiconductor elements cannot be exceeded during normal operation.
- Semiconductors shall not be damaged by direct short-circuit at the terminals. Protection by fuses is permitted. The convertor shall control the current in such a way that no components are damaged when the convertor is switched on to a blocked motor.

10.5 Test

Convertors shall be individually tested at the manufacturer's works. The scope of the tests, for example functional test, adjustments, limitations, failure handling, is stated in IEC 60146-2.

All protection and limiting functions with project related settings shall be tested before installation. All alarms of the category Alarm, Reduce and Stop shall be tested and documented with their settings. Proper coordination of convertor and motor protection functions shall be demonstrated.

11 Harmonic filtering

Line filters can be used to ensure the required harmonic distortion in the mains at any step of propulsion.

Each individual filter circuit shall be protected against overcurrents and short-circuit currents. Failure of harmonic filters shall be monitored. Harmonic filter protection circuits shall be fail-safe.

If filter circuits become faulty an emergency operation shall be possible. Instructions and limitations for such cases shall be provided and demonstrated during SAT (Sea Acceptance Test).

The estimated service life of the used harmonic filter shall be taken into account.

Using line filters, the filter layout shall be designed for any conceivable line configuration. In particular, self-resonance shall be excluded under any load condition and all generator combinations.

In the case of several parallel filter circuits, the current symmetry shall be monitored. An asymmetrical current distribution in the individual filter circuits and the failure of one filter shall be alarmed.

The additional heating caused by total harmonic distortion shall be taken into account during the temperature rise test.

The cabinets for harmonic filters shall be in accordance with the standards of main switchboards, where applicable.

12 Propulsion motors

12.1 General requirements

For motors, the requirements of the IEC 60034 series and IEC 60092-301 shall apply.

Motors shall have a protection degree of at least IP 23 according to IEC 60529. High voltage motors shall have a protection degree of at least IP 44.

Stator windings of AC motors and interpole, mainpole and compensation windings of DC motors, all rated above 500 kVA, shall be provided with temperature sensors.

Motors operating with semiconductor convertors shall be designed for the expected harmonics of the system. A sufficient reserve shall be considered for the temperature rise, compared with sinusoidal load. The motor insulation shall be designed according to the requirements of the connected convertor.

12.2 Bearing and lubrication

The requirements of generator bearing and lubrication apply, see 7.2, with the following additional requirements.

In case of bearings with forced lubrication, redundant pumps shall be provided.

Motor bearings can be shaft bearings. The requirements of the appropriate authority should be considered.

12.3 Cooling of propulsion motors

The requirements of generator cooling apply, see 7.3, with the following additional requirements.

Sufficient cooling shall be ensured under all load and speed conditions.

Suitable temperature detectors shall trigger an alarm.

If the cooling of the propulsion motors fails, restricted service (manoeuvrability) shall be possible. Interventions by the operator, for example opening of emergency air flaps are permitted.

12.4 Protection against moisture and condensate

Propulsion motors shall be equipped with an electric heating designed to maintain the temperature inside the machine at about 3 K above ambient temperature.

12.5 Protection

12.5.1 Overcurrent

Overcurrent protective devices in the main and excitation circuits shall be set sufficiently high so that there is no possibility of their operating due to the overcurrents caused by manoeuvring or normal operation in heavy seas or in floating broken ice.

The control system shall ensure that manoeuvring, normal operation in heavy seas or rough weather or operation in broken ice will not overload any part of the system.

Short-circuit and overcurrent protection is required and may be provided by the convertor.

Annex A gives an alarm-matrix of the different motor designs such as permanent excited motors, synchronous motors, asynchronous motors and DC motors.

In case of overcurrent the system shall be able to switch off the faulty part of the system.

12.5.2 Overspeed of propulsion motors

An independent overspeed protection device is required, see SOLAS 1974 Chapter II-1, Regulation 27, first paragraph.

Propulsion motors shall be capable of withstanding overspeed up to the limit reached in accordance with the characteristics of the overspeed protection device at its normal operational setting.

12.6 Test

Propulsion motors shall be individually tested at the manufacturer's works. The scope of the tests is stated in the IEC 60034 series.

The additional heating caused by total harmonic distortion, see 5.2, shall be taken into account during the temperature rise test.

After the first temperature rise test and after each repeated inspection, an insulation resistance measurement shall be carried out.

If the neutral point is not accessible, the stipulated phase-against-phase insulation test is not possible. The manufacturer shall offer an equivalent test.

12.7 Short-circuit withstand capability

Motors shall be capable of withstanding a sudden short-circuit at their terminals under all conditions without suffering damage, see 10.1. Both cases, three and two phase short-circuits, shall be considered.

Steady state short-circuit current of permanent excited motors shall not cause thermal damages of the motor and the current carrying components (for example cables, feeders, slip rings).

12.8 Accessibility and facilities for repairs *in situ*

For purposes of inspection and repair, provision shall be made for access to the stator and rotor coils, and for the withdrawal and replacement of field coils.

Facilities shall be provided for supporting the shaft to permit inspection and withdrawal replacement of bearings.

Adequate access shall be provided to permit resurfacing of commutators and slip rings, as well as the renewal and bedding of brushes, rotating rectifiers and protection equipment, if any.

Slip couplings shall be designed to permit removal as a unit without axial displacement of the driving and driven shaft, and without removing the poles.

13 Special requirements for podded drives

13.1 General requirements

The manufacturer shall take into account that during operation, inaccessible spaces and special environmental conditions require sufficient measures, for example highly reliable materials and components, adequate amount of sensors, special mechanical precautions.

The components, for example controls, sensors, slip rings, cable connections and auxiliary drives, shall withstand the strength of vibration, of at least 4 g from 3 Hz to 100 Hz.

13.2 Sensors

13.2.1 General requirements

The manufacturer shall prepare a list of all sensors with type, location of their installation, task and values (range, set points and action caused).

Important operational values for maintaining the drive and control ability in inaccessible areas shall be recorded, evaluated and shown redundantly.

The recorded results shall be checked for plausibility. Implausible input signals shall trigger an alarm. It shall be possible to differentiate extreme measure values from sensor faults.

Sensors which can only be changed during dry docking shall at least be constructed as double sensors.

13.2.2 Bearings

Oil minimum and maximum levels shall be monitored. Oil temperature shall be monitored as well (maximum value). This applies also during operation. Oil leakage shall be indicated by an alarm. Inspection of the oil level shall be possible, independent from the alarm and monitoring system.

This applies to circulated lubrication systems as well. These systems shall additionally be equipped with flow monitoring.

Shaft bearings shall be monitored to observe changes during operation, for example by analysis of temperatures, vibrations and oil quality.

The temperature of the shaft bearings shall be monitored. The alarm shall be carried out in two steps (action 1: alarm, action 2: stop). The temperature indication for shaft bearings shall be provided independently from the alarm and monitoring system. Redundant sensors are required.

The measurement of the motor bearing temperature shall be carried out in accordance with 8.9 of IEC 60034-1:2010.

13.2.3 Bilges

All areas below water line shall be equipped with bilge level sensors. In addition to the conventional bilge sensors (high level, HL), independent sensors (high high level, HHL) shall be provided which stop the propulsion automatically and protect it from consequential damages.

The shaft sealing system shall be monitored in a way that ingress of sea water is detected before consequential damages appear. An emergency sealing system shall be provided. In combination with the emergency sealing system there shall be a braking or blocking system which can fix the shaft under all weather and normal towing conditions. The activation of sealing and breaking system shall be indicated at each control station.

13.2.4 Fire alarm

An effective fire monitoring shall be provided.

13.2.5 Accessible areas

Sufficient illumination and temporary ventilation shall be provided for accessible areas where regular maintenance work needs to be carried out. Entries to these areas shall be locked in such a way that access is only possible, if the personnel cannot be endangered by the drives.

13.3 Protection of the propulsion motor against internal fault

Motors of more than 1 MW and all permanent excited motors shall be provided with protection against internal faults that also monitors the connections between the convertor and motor. In the case of a fault, the power supply to the defective equipment shall be interrupted within an appropriate period of time.

13.4 Air humidity

Humidity shall be monitored for motors with closed air systems.

13.5 Motor supply lines

Cables operated at high temperature limits shall be installed separate from other cables. If required, a protection against contact shall be provided.

Test reports of temperature rise tests of busbars with increased current density or cables operated at high conductor temperature values shall be submitted to the nominated body, see 4.2.

During the temperature rise test on the sea trial, it shall be proven that the permitted maximum temperature values in the area of the terminals are not exceeded.

IP protection for all terminals, cable glands and busbar connections shall be at least IP 44.

These requirements are also valid for control cables.

13.6 Slip rings

13.6.1 General

It shall be taken into account that the mechanical and electrical characteristics of the slip rings can be degraded by contamination with oil, carbon dust and salt mist air, or by oxidation.

Enclosures for slip ring assemblies shall ensure at least a degree of protection IP23 according to IEC 60529.

Provisions shall be taken that no person is endangered in case of arc fault.

The suitability of used materials at maximum permitted temperature values shall be proven. The permitted conductor temperature values of the connected cables shall not be exceeded. During the temperature rise test at the sea trial, it shall be proven that the permitted temperature limits are not exceeded.

In case of data transmission carried out via a bus system, two redundant transmission paths shall be provided. Failure of each single system shall be alarmed.

External or forced cooled slip rings shall be dimensioned sufficiently for restricted operation without the cooling system. The cooling system failure shall be alarmed.

13.6.2 Tests

Each slip ring shall pass an individual test as follows:

- visual inspection;
- insulation resistor measurement;
- high voltage withstand test IEC 61180-1 or IEC 62271-200;
- slip ring contact resistance;
- functional test of auxiliaries (e.g. sensors, data transfer).

A type test shall be performed for each slip ring design on the basis of IEC 62271-200 or IEC 61439-1 and IEC 61439-2:

- environmental tests (vibration 4 g, ambient temperature 55°C, humidity 100%);
- temperature rise test without rotation;
- endurance test:

  a rotation test with 1 r/min shall be carried out as follows:

  – 100 rotations with 10% rated current (In);
  – 100 rotations with 90% rated current (In);
  – 1 rotation with 150% rated current (In);
  – 100 rotation without current;

  after this tests the slip ring contact resistance measurement shall be repeated;
- short-circuit according to motor characteristics;
- impulse voltage withstand test.

For signal and low voltage circuits the suitable test criteria shall apply. Special conditions regarding EMC shall be taken into account.

During sea trials the maximum allowed temperatures of slip rings, brushes and cabling shall be demonstrated.

13.7 Azimuth drive

13.7.1 General requirements

Azimuth drives shall meet the requirements of steering gear in accordance with SOLAS 1974 Chapter II-1, Regulations 29 and 30. Single failure criterion shall be ensured for all electrical controls and all electronic controls, sensors and hydraulic components. For these purposes, a failure mode effect analysis (FMEA) shall be provided and practically proven, as far as possible, by the nominated body, see 4.2. Safe operation of the ship shall be ensured independently of the angular position of the pod and ship's speed in the event of any failure. The position of the azimuth drive shall be mechanically indicated on site.

At least two independent azimuth drives shall be provided for each podded drive, whereby one drive shall be supplied from the emergency switchboard and the other from the main switchboard.

Azimuth drives shall be protected against overcurrent (for example by convertor, if applicable) and short-circuit. They shall be able to supply 160 % of the torque necessary for the rated speed of movement in accordance with SOLAS 1974 Chapter II-1, Regulations 29 and 30 for 60 s. Azimuth systems with different design, for example hydraulic systems, shall also be able to fulfil these requirements.

13.7.2 Thrust azimuth angle

Generally, the thrust azimuth angle shall be limited to ± 35°, see SOLAS 1974 Chapter II-1, Regulation 29 and 30. At low propulsion power rating, low ship speed or crash-stop manoeuvre, these limits may be exceeded.

The thrust azimuth angle shall be limited, related to the propulsion shaft power and/or selected operation mode so that the safety of the ship is not endangered. The propulsion power shall be limited, related to the actual azimuth angle so that the safety of the ship is not endangered.

Reaching or exceeding the limitations shall be alarmed.

After triggering the limitation, it shall be possible to move the azimuth drive back to the allowed range without manual reset.

13.7.3 Control

The operation and indication equipment shall be arranged in a way that the moving direction or the thrust direction of the ship is clearly discernible. It shall be clearly discernible for the operator whether the moving direction or the propulsion direction was chosen.

13.7.4 Additional requirements on control stations for azimuth drives

For local control for propulsion, see 14.5. The local control station for azimuth drives shall be equipped accordingly:

- rudder control;
- ammeter for each supply side current of each load component;
- azimuth angle indicator for each podded drive;
- plant ready for operation for each drive;
- plant disturbed for each drive;
- power limited (from convertor);
- control from engine control room;
- control from the bridge;
- running indication for the associated propulsion drive; and
- alarms according to SOLAS 1974 Chapter II-1, Regulation 29 and 30.

The local control station can be activated locally and shall have the highest priority.

13.7.5 Additional start blocking criteria

For starting of the plant the following criteria should be fulfilled:

- drive is not accessible;
- emergency sealing system is not activated;
- sufficient number of azimuth drives are available;
- no communication fault to podded drive.

14 Control

14.1 General

Computer based systems shall be designed and tested in accordance with IEC 60092-504. Any loss of automatic function shall be alarmed.

14.2 Power management system (PMS)

14.2.1 General

Additional to the requirements described in IEC 60092-504, the following requirements shall apply.

– For power supply with generators operating in parallel, there shall be a device/computer program for automatic power management, which will ensure adequate power generation, even in transit/manoeuvre. Automatic load based disconnection of diesel generators in manoeuvre mode is forbidden.
– In case of under-frequency of the supplying mains, overcurrent or overload, and reverse power, the propulsion power has to be limited.
– If generators are running in parallel and one of them is tripping, the power supply system shall be provided with suitable means of load reductions to protect the remaining generators against unacceptable load steps. The same requirement applies to bus tie breakers.
– Tripping of the bus tie breaker may not lead to any malfunction of the system. It is not necessary that the system remains in the automatic mode if the supply system is split.

14.2.2 Test

Power management systems shall be subjected to a functional test (software FAT) in the manufacturer’s works. Joint testing with the propulsion switchboard is recommended.

A test specification shall be defined.

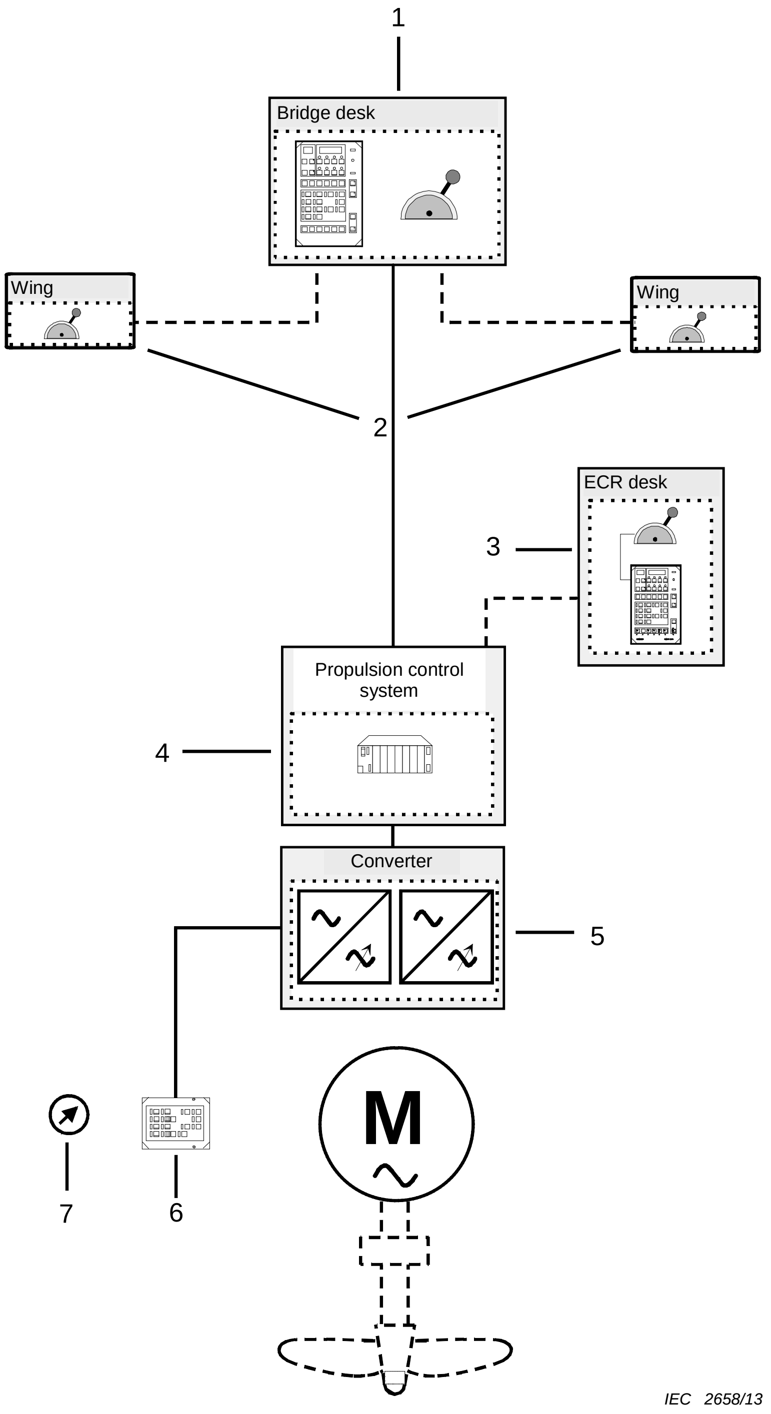
14.3 Typical control configuration

The control configuration shall comply with IEC 60092-504.

The typical system configuration consists of control stations, one central processing unit, two convertors, one motor (two winding systems), one local control panel (two independent reference inputs) and one telegraph receiver.

The wing control and the engine control room (ECR) control are not mandatory for vessels with restricted operational area.

Local control shall be possible if the remote control system failed. Therefore the local control panel shall be directly connected to the convertors and shall have the highest priority.



Key

1 bridge desk
2 wing
3 engine control room (ECR) desk
4 propulsion control system
5 convertors
6 local control panel
7 telegraph receiver

Figure 2 – Typical control configuration

14.4 Location of manoeuvring controls

Whenever control outside the engine room is applied, an arrangement shall be provided whereby the propulsion plant can also be controlled from the engine room or control room.

The local control station shall be located in the vicinity of the drives or convertors so that changes in the control of propulsion can be recognized.

14.5 Main and local control stations

Additional to the requirements of 9.5 of IEC 60092-504:2001, the following requirements shall apply.

At least mutually independent main and local control stations shall be provided. In the case of breakdown, malfunctioning or loss of power supply of the propulsion control system, the control of the convertors shall remain possible at the local control panel, see Figure 2.

The bridge shall be fitted with a system which ensures that the steering, the monitoring and the control of the steering gear can be operated independently of the propulsion system. Communication to all local control stations in parallel shall be possible.

All alarms shall be acknowledgeable at the local control stations. Alarms which do not require any further intervention can be acknowledged at the main control station. Restart of the propulsion plant shall be possible from both control stations, depending on which one has been preselected. After a blackout, it shall be possible to restart the propulsion plant at the main control station.

Each control station shall have an emergency stop device which is independent of the drive's control and the active control station. The emergency stop device shall ensure the tripping of the feeder breaker for the propulsion convertor.

If the control station in ECR is not foreseen according to 14.3 an emergency stop device shall be available at its place.

14.6 Measuring, indicating, control and monitoring equipment

14.6.1 General requirements

Failures in measuring, monitoring and indicating equipment shall not cause a failure of the drives control, for example, failure of the actual value or of the reference value shall not cause an excessive increase of propeller speed and/or direction.

14.6.2 At local control station

At least the following measuring and control equipment as well as indicators shall be provided:

– speed setting;
– local remote switch;
– ammeter for each supply side current of each load component;
– indication excitation on;
– revolution indicator for each shaft;
– pitch indication for plants with variable pitch control;
– indication plant ready for operation;
– indication convertor on/off;
– indication plant disturbed;
– indication power limited;
– indication control from engine control room; and
– indication control from the bridge;
– indication control from local.

14.6.3 At (main) control station on the bridge

At the (main) control station on the bridge, at least the following measuring and indication equipment shall be provided:

- control levers;
- revolution indicator per shaft;
- shaft power meter;
- indication plant ready for switching on;
- indication plant ready for operation;
- indication plant disturbed;
- indication power limitation;
- indication request to reduce the power if not automatically controlled or equipped with override push button;
- indication control from engine control room;
- indication control from the local control station; and
- indication generators used for propulsion;
- selector switch operation modes (i.e. sea mode, estuary mode, harbour mode).

An indicator for remaining power is recommended.

When two or more control stations are provided for variable speed and pitch propellers, a propeller speed and pitch indicator shall be provided at each control station.

14.6.4 At (main) control station in the engine control room

At the (main) control station in the engine control room, at least the following measuring and indication equipment shall be provided:

- control levers;
- revolution indicator for each shaft;
- shaft power meter;
- indication plant ready for switching on;
- indication selected operation mode;
- indication plant ready for operation;
- indication plant disturbed;
- indication power limitation;
- indication request to reduce the power if not automatically controlled or equipped with override push button;
- indication control from the local control station;
- indication control from the bridge; and
- indication generators used for propulsion.

For fault monitoring of the equipment, see Annex A.

14.7 Availability

In general, the loss of power of any other control and monitoring system or the malfunctioning of these systems shall not result in loss of propulsion, steering or azimuth drives.

Propulsion and azimuth drives and controls shall have self-acting routines to detect failure.

Any failures, for example loss of power, wire failure etc., shall result in non-critical new condition (fail to safety).

14.8 Start blockings

The start-up process of the propulsion plant shall be interlocked such that starting is impossible if existing malfunctions would trigger a shutdown or if the start-up process itself would cause damage to the propulsion plant.

The following interlocks should be considered, if applicable:

– shaft locking device not released;
– no cooling of static converter (overridable);
– no cooling of propulsion motor (overridable);
– no cooling of propulsion transformer (overridable);
– malfunction in exciter device;
– malfunction in static converter;
– convertor control: shutdown activated;
– propulsion switchboard switch-off active;
– emergency stop actuated;
– set point not equal to zero;
– bearings: lubrication oil pressure too low;
– conductivity of the cooling medium too high;
– protection triggered;
– switchgear circuit breaker malfunction;
– missing enabling signal from variable-pitch propeller.

The pilot light “plant ready to start for switching on” may only be activated when all the prerequisites for start-up have been met.

The pilot light “plant ready for operation” may only be activated if the propulsion plant would respond to set point setting.

14.9 Factory acceptance test (FAT)

For the first vessel of a series, the remote control shall be set up with all control stations and tested.

15 Tests

15.1 General

In addition to the standard tests described in other parts of the IEC 60092 series, the following special tests shall be carried out.

All tests of components or subsystems or systems carried out during manufacturing, factory acceptance test and dock and sea trials shall be documented. The test results shall be documented in such a way that single components can be identified and traced.

The current, voltage and temperature capabilities of cables, busbar systems and slip rings shall be verified by type tests or routine tests.

15.2 In-process tests

A plan shall be generated before production which indicates all tests carried out by the manufacturer and sub-suppliers.

15.3 Factory acceptance test

Before the factory acceptance test is carried out, the test procedure shall be documented.

As far as practicable, all normal acceptance tests of equipment shall be carried out at the manufacturer's works to show that they meet the requirements of this standard and the ordering specification.

In addition to the standard tests described in other clauses of the IEC 60092 series, all protective devices shall be tested to show that they are electrically and mechanically satisfactory.

15.4 Dock and sea trials

Before the dock and sea trials, the test procedure shall be documented.

Complete tests shall be carried out including heat run and manoeuvring tests which shall include a crash stop of the ship from full speed to zero speed.

All tests necessary to demonstrate that each item of the plant and the system as a whole is satisfactory for duty shall be performed.

The test program shall include tests of the propulsion plant in normal and abnormal conditions.

The grid quality in the ship's propulsion network and mains shall be checked according to the following items:

– measurement at various propulsion speeds in normal operation;
– measurements to determine the most unfavourable mains and propulsion plant configuration;
– measurement at various propulsion speeds in most unfavourable mains and propulsion plant configuration;
– repetition of measurement without harmonic filter as far as possible.

The measurement results shall be recorded.

Start-up and stop sequences shall be tested, both those initiated by manual action and those initiated by the power management system, when relevant.

Safety functions, alarms and indicators shall be tested. A physical check of all sensors shall be performed.

Where an FMEA is required, FMEA proving tests shall be performed. Test procedures shall be provided for each of the failures considered in the FMEA. FMEA proving tests shall be completed prior to the initial survey of the ship.

All control modes shall be tested from all control locations.

Immediately prior to and after trials, the insulation resistance of power circuits shall be measured and recorded.

As far as possible, the tests shall be executed during dock trials.

16 Documentation

The nominated body, see 4.2, shall be responsible for ensuring that complete documentation is available for all relevant components and systems.

Each manufacturer shall give documented evidence of conformity that his plant fulfils the requirements of this standard.

Annex A
(normative)

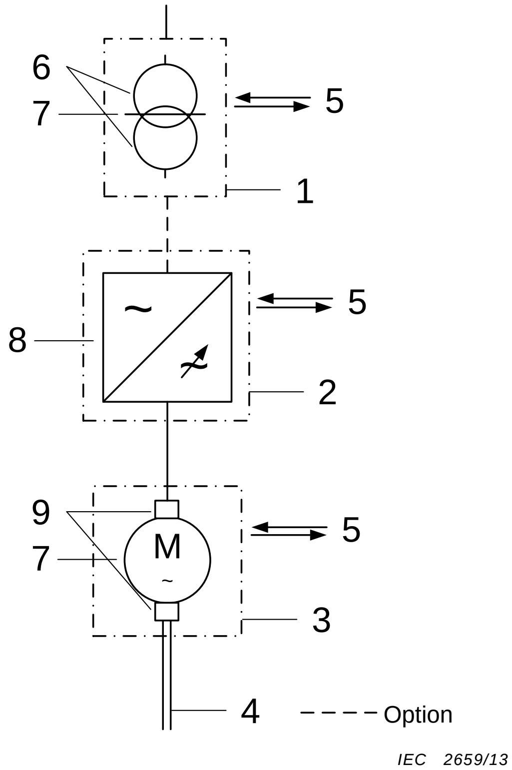
Protection and alarm matrix

A.1 General

This annex provides protection and alarm matrixes for different motor designs such as permanent excited motors (Table A.1), synchronous motors (Table A.2), asynchronous motors (Table A.3) and DC motors (Table A.4).

A.2 Protection and alarms

The set points for warning, alarm, reduction and stop should be separated or time delayed to allow crew intervention before progression to the next level of protection as far as practicable.



Key

1 transformer
2 convertor
3 motor
4 shaft
5 coolant
6 core
7 winding
8 power supply, mains and auxiliaries
9 bearings

See Tables A.1, A.2, A.3 and A.4 for requirements to monitoring.

Figure A.1 – Propulsion equipment with monitored items

Figure A.1 shows the typical parts of a propulsion unit which shall be monitored as a minimum.

Table A.1 – Protection and alarms, permanent excited motor *(1 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last step action Stop/trip
3	**Motor**							
9	Bearing oil lubrication							
	Temperature	High		X	C	X	-	X
	Filling level	Low	Inspection glass	X	C	X	-	-
9	Bearing housing temperature	Max	Thermometer	X	C	X	-	X
7	Stator winding temp.	Max	-	X	C	X	X	i.a.
5	External cooling							
	Cooling air temperature	Max	Thermometer	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
4	Speed	Overspeed	-	X	C	X	-	X
4	Locked rotor protection	Active	-	X	C	X	-	X[a]
3	Earth fault monitoring	Min	-	X	C	X	-	-
3	Electrical motor protection	Short-circuit	-	X	X	X	-	X[b]
3	Electrical motor protection	Overcurrent	-	X	C	X	-	X
3	Electrical motor protection	Internal faults	-	X	C	X	-	X[c]
1	**Transformer/reactor, i.a.**							
7	Transformer, winding temperature	Max	-	X	C	X	X	-
6	Transformer, core temperature i.a.	Max	-	X	C	X	X	-
5	External cooling i.a.							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
1	Electrical protection	Overcurrent	-	X	C	X	-	X
1	Electrical protection	Short-circuit	-	X	C	X	-	X
1	Differential current (not required for reactors)	Max	-	X	C	X	-	X
2	**Convertor**							
8	Mains (input)	Failure	-	X	C	X	-	X[d]
8	Auxiliary supplies and bus systems i.a.	Failure	-	X	-	X	-	-

Table A.1 *(2 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
5	External cooling							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
	Coolant conductivity in case of directly cooled semiconductors	High	X	X	C	X	-	X
2	Semiconductor fuses i.a.	Blown	Indicator device	X	C	X	-	X
6	Output overcurrent	Max	-	X	C	X	-	X
	Harmonic filter i.a.	Failure	-	X	C	X	-	-

X = Required

C = Collective alarm

ECR = Engine Control Room

i.a. = If applicable

If local diagnostic tool is not possible or accessible, independent measurement shall be installed.

Automatic reduction shall be indicated at control station.

[a] Special arrangements for icebreakers are required.

[b] Immediate stop and automatic disconnection of the permanent excited motor. Equipment downstream of the disconnector shall be able to withstand the short-circuit current of the motor for the time required to stop the motor.

[c] Depending on the location of failure, different measures need to be taken to achieve safe status.

[d] Restart possible only from main control station.

Table A.2 – Protection and alarms, synchronous motor *(1 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
3	**Motor**							
9	Bearing oil lubrication							
	Temperature	High		X	C	X	-	X
	Filling level	Low	Inspection glass	X	C	X	-	-
9	Bearing housing temperature	Max	Thermometer	X	C	X	-	X
7	Stator winding temp.	Max	-	X	C	X	X	i.a.
5	External cooling							
	Cooling air temperature	Max	Thermometer	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
4	Speed	Overspeed	-	X	C	X	-	X
4	Locked rotor protection	Active	-	X	C	X	-	X[a]
3	Earth fault monitoring	Min	-	X	C	X	-	-
3	Electrical motor protection	Short-circuit	-	X	X	X	-	X[b]
3	Electrical motor protection	Overcurrent	-	X	C	X	-	X
3	Electrical motor protection	Internal faults	-	X	C	X	-	X[c]
3	Exciter system	Failure	-	X	C	X	-	X
1	**Transformer/reactor, i.a.**							
7	Transformer, winding temperature	Max	-	X	C	X	X	-
6	Transformer, core temperature i.a.	Max	-	X	C	X	X	-
5	External cooling i.a.							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
1	Electrical protection	Overcurrent	-	X	C	X	-	X
1	Electrical protection	Short-circuit	-	X	C	X	-	X
1	Differential current (not required for reactors)	Max	-	X	C	X	-	X
2	**Convertor**							
8	Mains (input)	Failure	-	X	C	X	-	X[d]
8	Auxiliary supplies and bus systems i.a.	Failure	-	X	-	X	-	-

Table A.2 *(2 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
5	External cooling							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
	Coolant conductivity	High	X	X	C	X	-	X
	in case of directly cooled semiconductors							
2	Semiconductor fuses i.a.	Blown	Indicator device	X	C	X	-	X
6	Output overcurrent	Max	-	X	C	X	-	X
	Harmonic filter i.a.	Failure	-	X	C	X	-	-

X = Required

C = Collective alarm

ECR = Engine Control Room

i.a. = If applicable

If local diagnostic tool is not possible or accessible independent measurement shall be installed.

Automatic reduction shall be indicated at control station.

[a] Special arrangements for icebreakers are required

[b] Immediate stop and automatic disconnection of the permanent excited motor. Equipment downstream of the disconnector shall be able to withstand the short-circuit current of the motor for the time required to stop the motor.

[c] Depending on the location of the failure different measures need to be taken to achieve safe status.

[d] Restart possible only from main control station.

Table A.3 – Protection and alarms, asynchronous motor *(1 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
3	**Motor**							
9	Bearing oil lubrication							
	Temperature	High		X	C	X	-	X
	Filling level	Low	Inspection glass	X	C	X	-	-
9	Bearing housing temperature	Max	Thermometer	X	C	X	-	X
7	Stator winding temp.	Max	-	X	C	X	X	i.a.
5	External cooling							
	Cooling air temperature	Max	Thermometer	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
4	Speed	Overspeed	-	X	C	X	-	X
3	Earth fault monitoring	Min	-	X	C	X	-	-
3	Electrical motor protection	Short-circuit	-	X	X	X	-	X
3	Electrical motor protection	Overcurrent	-	X	C	X	-	X
3	Electrical motor protection	Internal faults	-	X	C	X	-	X
1	**Transformer/reactor, i.a.**							
7	Transformer, winding temperature	Max	-	X	C	X	X	-
6	Transformer, core temperature i.a.	Max	-	X	C	X	X	-
5	External cooling i.a.							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
1	Electrical protection	Overcurrent	-	X	C	X	-	X
1	Electrical protection	Short-circuit	-	X	C	X	-	X
1	Differential current (not required for reactors)	Max	-	X	C	X	-	X
2	**Convertor**							
8	Mains (input)	Failure	-	X	C	X	-	X[d]
8	Auxiliary supplies and bus systems i.a.	Failure	-	X	-	X	-	-

Table A.3 *(2 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
5	External cooling							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
	Coolant conductivity	High	X	X	C	X	-	X
	in case of directly cooled semiconductors							
2	Semiconductor fuses i.a.	Blown	Indicator device	X	C	X	-	X
6	Output overcurrent	Max	-	X	C	X	-	X
	Harmonic filter i.a.	Failure	-	X	C	X	-	-

X = Required

C = Collective alarm

ECR = Engine Control Room

i.a. = If applicable

If local diagnostic tool is not possible or accessible independent measurement shall be installed.

Automatic reduction shall be indicated at control station.

[d] Restart possible only from main control station.

Table A.4 – Protection and alarms, DC motor *(1 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
3	**Motor**							
9	Bearing oil lubrication Temperature Filling level	 High Low	 Inspection glass	 X X	 C C	 X X	 - -	 X -
9	Bearing housing temperature	Max	Thermometer	X	C	X	-	X
7	Exciter and compensation winding temperature, i. a.	Max	-	X	C	X	X	i. a.
5	External cooling Cooling air temperature Coolant	 Max Leakage	 Thermometer -	 X X	 C C	 X X	 - -	 - -
4	Speed	Overspeed	-	X	C	X	-	X
4	Locked rotor protection (shunt wound motor only)	Active	-	X	C	X	-	X[a]
3	Earth fault monitoring	Min	-	X	C	X	-	-
3	Electrical motor protection	Short-circuit	-	X	X	X	-	X
3	Electrical motor protection	Overcurrent	-	X	C	X	-	X
3	Electrical motor protection	Internal faults	-	X	C	X	-	X[c]
3	Exciter system	Failure	-	X	C	X	-	X
1	**Transformer/reactor, i.a.**							
7	Transformer, winding temperature	Max	-	X	C	X	X	-
6	Transformer, core temperature i.a.	Max	-	X	C	X	X	-
5	External cooling i.a. Cooling air temperature Coolant	 Max Leakage	 - -	 X X	 C C	 X X	 - -	 - -
1	Electrical protection	Overcurrent	-	X	C	X	-	X
1	Electrical protection	Short-circuit	-	X	C	X	-	X
1	Differential current (not required for reactors)	Max	-	X	C	X	-	X
2	**Convertor**							
8	Mains (input)	Failure	-	X	C	X	-	X[d]
8	Auxiliary supplies and bus systems, i.a.	Failure	-	X	-	X	-	-

Table A.4 *(2 of 2)*

Figure A.1 index	Monitored value	Limiting value	Local diagnostic tool	Indication on ECR control station	Indication on bridge control station if applicable	First step action Alarm	Second step action Reduce	Last Step action stop/trip
5	External cooling							
	Cooling air temperature	Max	-	X	C	X	-	-
	Coolant	Leakage	-	X	C	X	-	-
	Coolant conductivity	High	X	X	C	X	-	X
	in case of directly cooled semiconductors							
2	Semiconductor fuses i.a.	Blown	Indicator device	X	C	X	-	X
6	Output overcurrent	Max	-	X	C	X	-	X
	Harmonic filter i.a.	Failure	-	X	C	X	-	-

X = Required
C = Collective alarm
ECR = Engine Control Room
i.a. = If applicable

If local diagnostic tool is not possible or accessible independent measurement shall be installed.

Automatic reduction shall be indicated at control station.

[a] Special arrangements for icebreakers are required

[c] Depending on the location of the failure different measures need to be taken to achieve safe status.

[d] Restart possible only from main control station.

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