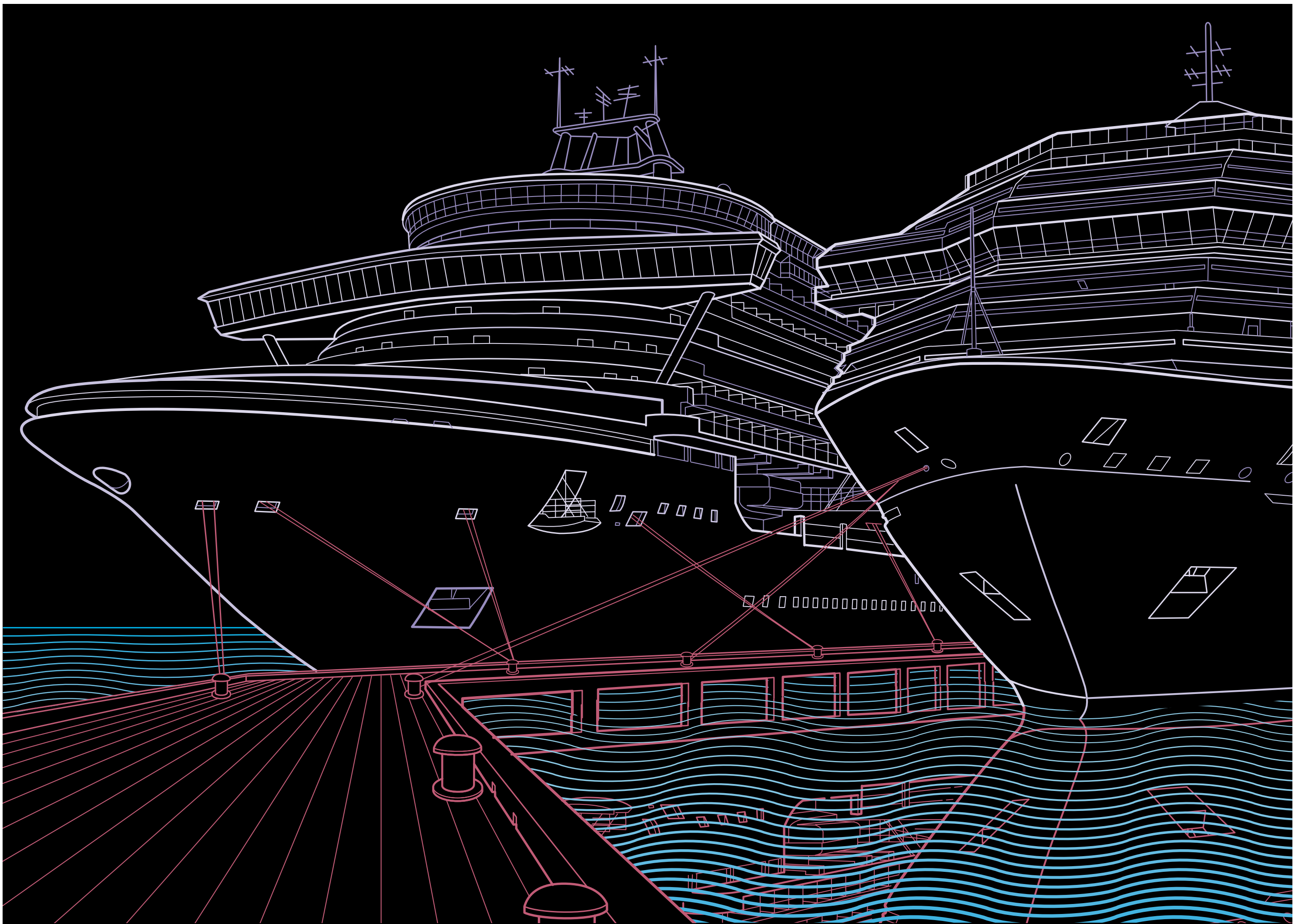


Technical Application Papers No.12
Generalities on naval systems and installations on board

Power and productivity
for a better world™

Generalities on naval systems and installations on board

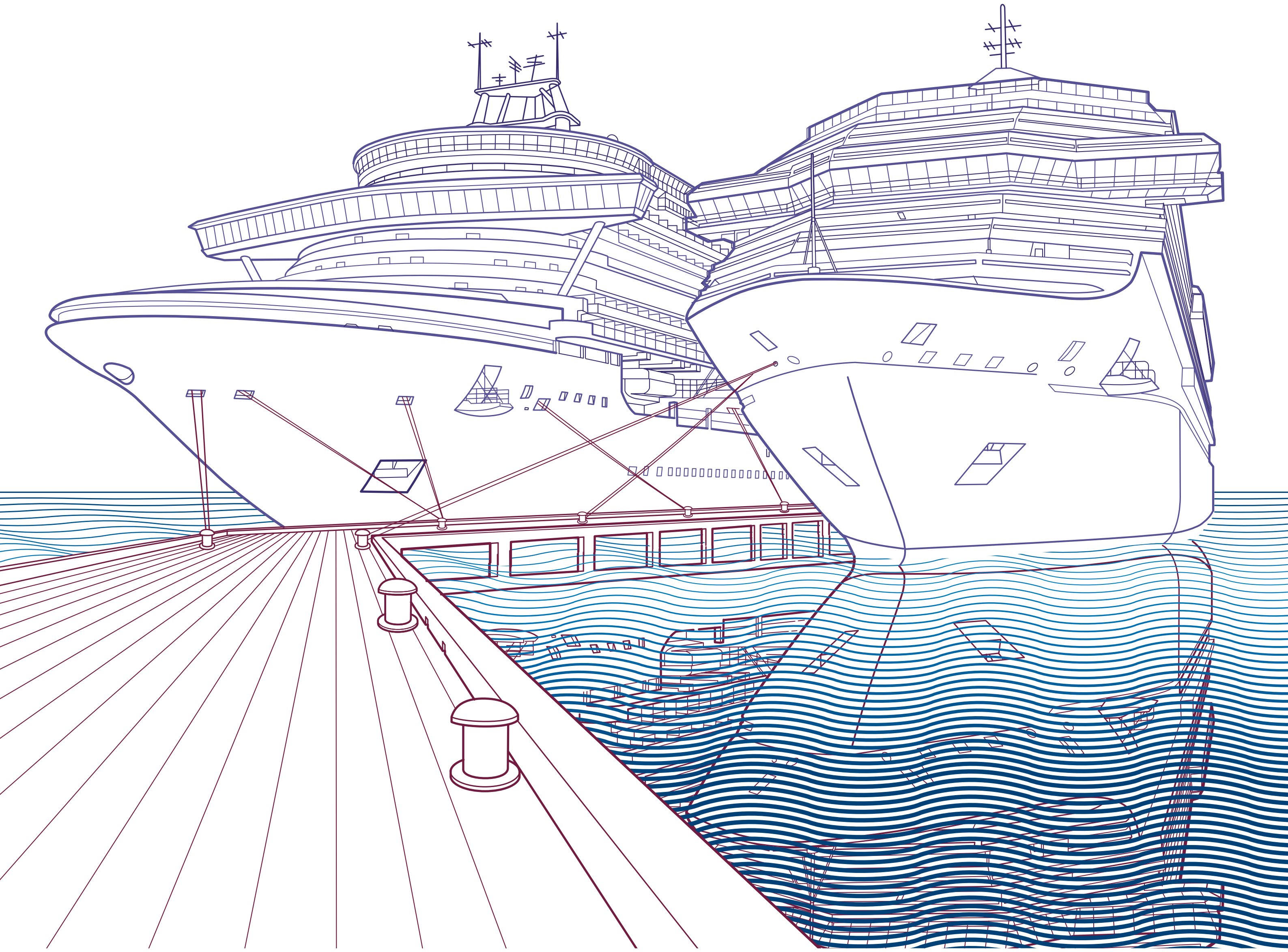
Index

1 Introduction

The purpose of this document is giving some information to help to better understand the structure and the problems linked to a LV electrical installation on board. Starting from a general classification of the main typologies of ships, attention shall be paid to the structure which characterizes the giant cruise ships, giving some hints on electrical power generation on board, on electrical plants and on propulsion systems.
Then, by analyzing the main prescriptions of the Registers of Shipping or of the field Standards, the main parameters required for the selection of the protective devices for LV electrical circuits shall be defined.

To give an idea of the significant presence of ABB in the field of marine installations, considering all applications on board from the mini-yachts up to the cruise ships, going through all the types of vessels, but also all applications relevant to the off-shore platforms, here is a description of the scenario of the products available to cover all the sector demands.

In particular, starting from a thorough analysis of performances, all the necessary information about low voltage switching and protection devices are supplied.



2 Types of ships

Transport of people or goods on water is carried out through means which are commonly identified with the general term “ship”, with no differentiation made. Actually, by going into the details, a more detailed classification is possible, according to the function and type of loading.
A first general and rough distinction can be made by identifying:
- ships intended for handling of materials in a broad sense;
- ships for transport of passengers only;
- ships for combined transport of passengers and wheeled cargo.

Going into details, based on the type of material transported and on the way it is stowed on board, **the ships intended for transportation of materials** can be classified into the following types:
- ships intended for transportation of all types of liquid goods

Among the main types of ships for the transportation of liquid materials the following can be mentioned:
- oil tankers are ships intended to transport prevalently crude oil;
- chemical tankers which are intended for the transport of chemicals;
- tankers for the transportation of nonflammable liquids;
- gas carriers or LNG (liquefied natural gas) tankers (see Figure 1) intended for transportation of liquefied gas (e.g. propane, butane).

Figure 1: Gas carriers or LNG tankers

- ships intended for transportation of dry goods

According to the stowage method - “tidy” stowage (in containers or on pallets) or “in bulk”- the following ship types can be mentioned:
- container ships are ships whose whole cargo consists of metal containers which contain different type of goods and which can be arranged on board in a tidy and modular way (Figure 2) and then easily sorted for distribution on roads or railways;

Figure 2: Container ships

- cargo ships are all those ships of any form and size carrying goods from one port to another; therefore they constitute an essential medium for international trade between different countries.
  They are not structured for tidy and modular transportation, but for carrying differently packaged items, and they can be intended either specifically for the transport of a particular product, or for mixed transport of different products;
- Bulk Carriers are ships intended for the transport of various unpackaged dry material (grain, fertilizers, phosphates) placed in suitable holds (see Figure 3) or for the transport of a single and specific dry type of material, such as for example timber, iron or also livestock and, however, goods not packaged in containers or not palletized.
  All those ships which can package bulk cargo directly on board or while unloading and are identified by the abbreviation BIBO (acronym of Bulk In/Bulk Out or di Bulk In/Bags Out) belong to this category.

Figure 3: Bulk Carriers

Figure 4: Cruise ship

Another important type of ships to be considered is that one specifically designed for the **carriage of passengers**, including pleasure-boats as yachts or mega-yachts, up to the giant cruise ships (see Figure 4).

The **combined transport of passengers/wheeled cargo** (see Figure 5) is carried out by those ships usually called ferries.
These can be used to carry means of transport only, such as for example lorries or cars, and are also known as RO-RO ships with ramps allowing the cargo to be rolled-on and rolled-off, or can be used for the combined transportation of passengers/wheeled cargo; in this case they are known also as RO-PAX (Roll-on/roll-off Passengers).

Figure 5: Transport vessels type RO-RO and RO-PAX

Other types of ships (see Figure 6) which are not for transport but are used for particular activities or services, are military ships, industrial ships (fishing vessels, drill ships, or platforms) and working ships (tugboats, research vessels or cable layers).

Without going into the details of particular rules linked to the type of service carried out by single typology of ships, naval constructions are to meet and comply with the prescriptions established by the Registers of Shipping.

Figure 6

Platform

Icebreaker

Drillship

Cable layer

3 Registers of Shipping

Generally speaking, the origin of the control and classification societies in the naval sector is bound to the need of ship-owners and of marine insurance companies to have a subject “super partes” to assess with the necessary technical competence the design and the building of ships and consequently their reliability.

As from their origin, these societies have had a great structural and technical evolution; nowadays, in a market more and more attentive and demanding, the certification process through which a third party ensures that a product, a service or an organization complies with specified, shared and standardized requirements presents itself as an instrument with great economic and social utility, since it introduces a protection against any possible non-qualified operator. In the naval sector, the certificate of classification is the document which attests that a ship and its components have been designed and built in compliance with the rules and criteria established by the Classification Society and therefore it complies also with the rules defined by the International Maritime Organization, if the classifying body is a member of IMO.
To maintain the requirements initially obtained, the ship shall be subject to periodical – usually annual – surveys and to deeper and more detailed verifications, which are usually carried out every five years.

The approval program of the registers is addressed to all those components and equipment which are installed on board and for which the national or international rules prescribe verification of the homologating authority.
Therefore, also the electrical components and specifically switching and protection devices shall be accompanied by type approval certificates attesting the compliance with all relevant electrical and environmental parameters.
The issue of the certificate is obtained as final result of a verification process which, as a rule, foresees the analysis of the product specification or of the reference standard, the verification of compliance with the design attested through test reports issued by an accredited laboratory, the definition of the controls to be carried out during manufacturing and final inspection. Following up this procedure, according to which the Register attests that under any condition all the requirements have been met, a type approval certificate is issued for the product testifying its suitability for the use in naval applications.
Figure 7 shows, as an example, an extract of the documents (type approval certificate) attesting the approval of some naval Registers for ABB SACE circuit-breakers; in the case considered, for Emax X1 circuit-breaker, reference is made to the certification obtained, among the other ones, by the Norwegian Register Det Norske Veritas and by the English Lloyd’s Register.

Figure 7 : Example of Naval Type Approval Certificate


DNV

DET NORSKE VERITAS
TYPE APPROVAL CERTIFICATE

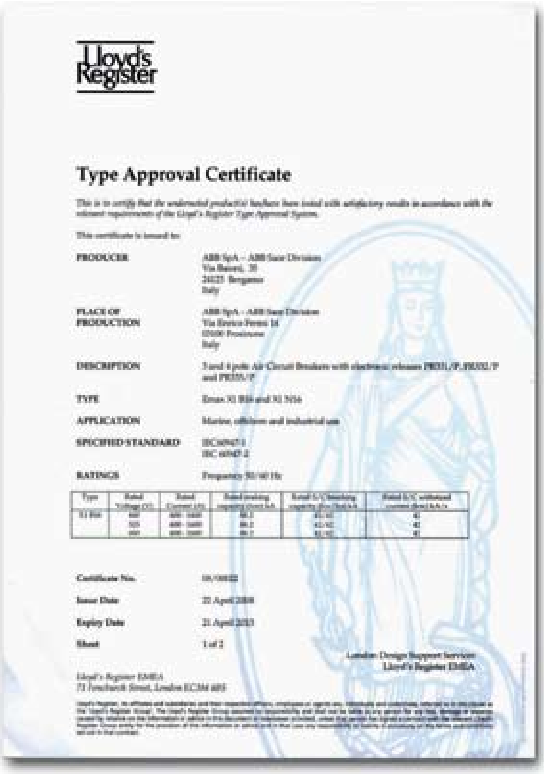
CERTIFICATE NO. E-9148

Circuit Breaker

Emax X1

ABB S.P.A. - ABB SACE DIVISION

BERGAMO BG, Italy


Lloyd's Register

Type Approval Certificate

The story of the naval Registers started in the second half of XVIII century when in 1764 the body which actually is Lloyd's Register was established in London; afterwards, in 1828 the establishment of Bureau Veritas and in 1861 the present RINA S.p.A., which is the society of the Registro Italiano Navale, was founded in Genua.
The concept of classification and regulation in the naval sector became a requirement also in other countries, and therefore many other Registers were established.

To get collaboration and uniformity in the application of the guidelines for the construction of ships, in 1939 the first conference of the main Registers of Shipping - ABS, BV, DNV, GL, LR, NK and RINA - was held; they stipulated agreements aimed at guaranteeing a better co-operation among these societies.

Other meetings followed, with the purpose of sharing and aligning regulations up to 1968, when IACS International Association of Classification Societies was founded to keep high the quality of the service given to the naval industry by ensuring integrity and competence for the services supplied.

The Type Approval Certificate is the document which confirms that a ship has been designed and built in compliance with the rules/criteria established by the Classification Society itself and therefore it is authorized to carry out the activity which it has been intended for.

Table 1 lists the names and the identification logos of the Registers of Shipping currently members of IACS.

Table 1: Logos of the Registers of Shipping members of IACS

Registro Italiano Navale (RINA) : Italy	American Bureau of Shipping (ABS): USA
Bureau Veritas (BV): France	Det Norske Veritas (DNV): Norway
Germanischer Lloyd (GL): Germany	Lloyd's Register of Shipping (LR): United Kingdom
Nippon Kaiji Kyokai (NKK): Japan	Russian Maritime Register of Shipping (RMRS): Russia
CCS China Classification Society: China	IRS Indian Register of Shipping: India
KR Korean Register of Shipping: Korea	

4 Hints on electrical generation on board

The generation of electric power on board is mainly carried out by engine-generator sets (gen-sets), which can be constituted by a generator coupled to a diesel engine or to a turbine which may be a gas, a conventional steam or a nuclear turbine.
The different generation modalities are often linked to the type of ship; for example, the steam turbine with fossil propeller (coal or natural gas) is a generation modality present on warships. Gas turbines are present on different varieties of ships mainly characterized by the requirement of having high speed navigation. As regards loading ships or cruise liners, the generation most commonly used is that which can be obtained by coupling the diesel engine with the generator.
Generally speaking, it can be said that turbines can be easily adjusted, allow a higher overload capacity and from a mechanical point of view they grant smaller dimensions and less vibrations, but they offer lower quickness for tripping and greater fuel consumption in comparison with the diesel groups.
An alternative solution to the above mentioned ones can be that defined as axis generation, in which the generator is coaxial and rotated by the bearing shaft so that a part of the mechanical power produced by the propulsion thermal engine is exploited to produce electric energy.

This solution presents some peculiar characteristics, such as for example the need to have an independent gen-sets as the previous ones, able to supply electric power to the plant on board, when the speed of the propeller is too low and in case of standstill. Moreover, the system presents problems linked to the management of the rpm of the propulsion motor and to the management of the simultaneous production of the two systems (generation board and conventional gen-sets).
Take into consideration a hypothetical naval architecture which, due to the characteristics described below, may represent a standard for cruise ships (see Figure 8).

With the only purpose to give an idea of the quantities to be considered, here are some data to understand better the architecture of these types of ships which can be considered as the largest "vessels" constructed.

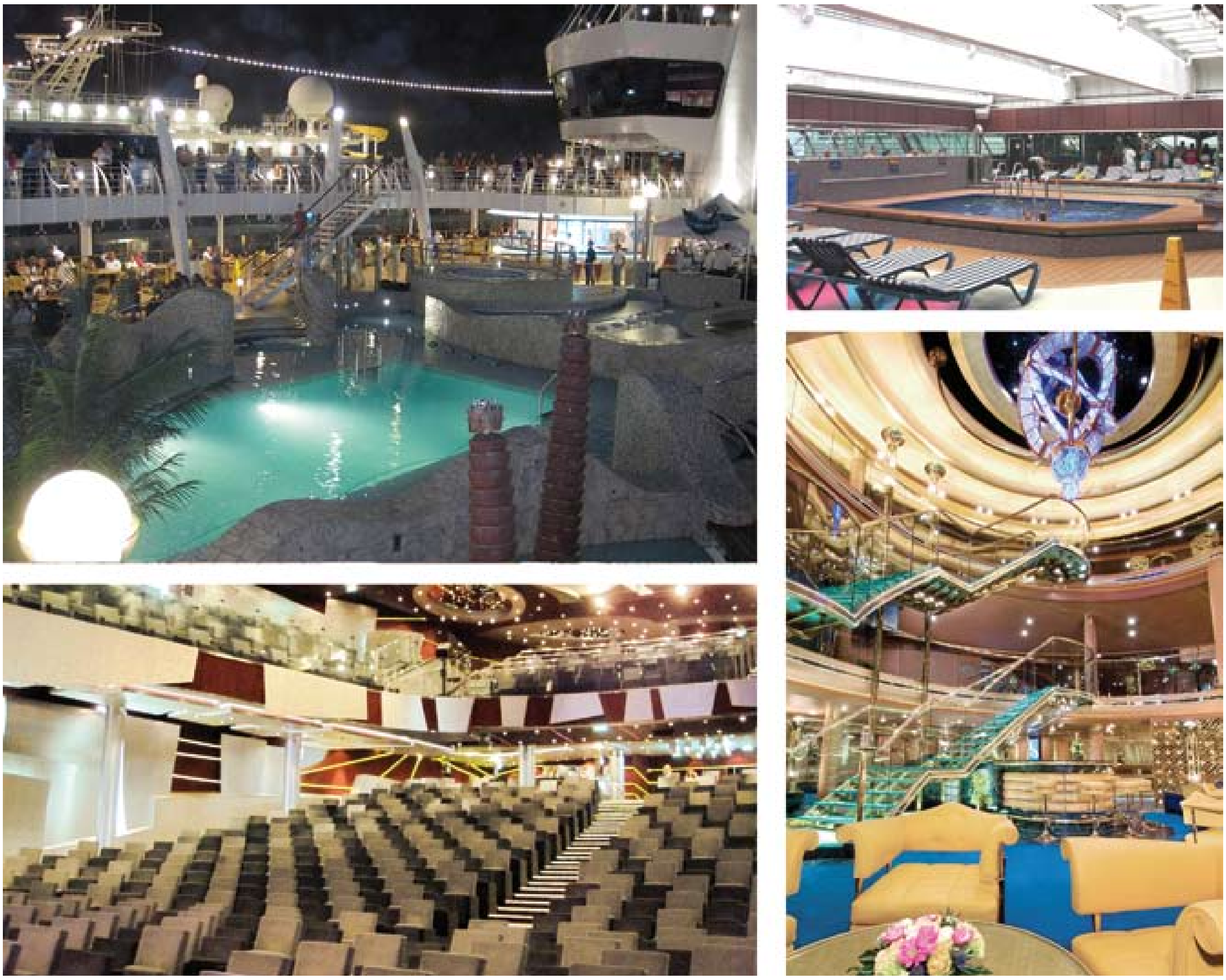
Figure 8: Cruise ship

They can reach a gross tonnage; this parameter is determined by calculations and formulas and defines a capacity index of a ship, comprising the internal volume of a ship, included the spaces of the engine room, of the fuel tanks, of the areas reserved to the crew and it is measured starting from the external surface of the bulkhead. It can range from dozens of thousands of tons up to values close to 100,000 tons, distributed along lengths which can exceed 300m and width of about 50m.
These ships can house some thousands of passengers who can be received and distributed in thousands of cabins, in the big hall with panoramic lifts, numerous bars, restaurants, swimming pools, casinos, discos, ballrooms and fitness centers on dozen of decks.

A cruise ship is all this and the Figure 8 and 9 (overall picture and detailed picture respectively) are much more representative of its elegance and luxury if compared with the short description above.

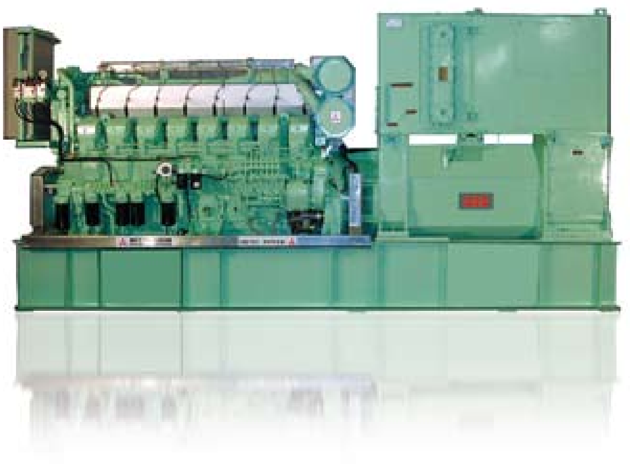
To ensure operation of all the services of this real floating town during navigation, it is necessary to have on board a considerable electric power supply.
First of all, it should be said that the availability of the electrical energy must derive from the equipment present on board; in other words, there must be on board an independent power station able to generate all the power necessary for supply at full load.
The power supply source normally consists of more machines formed by the coupling of a mechanical diesel engine and of an alternator (synchronous generator). Based on the total power absorbed by all the loads of the ship, an incremental coefficient is applied for any possible future increase of loads; besides, a further safety margin is assumed, allowing such increased power to be available also in case of breakdown of one of the diesel-generator sets. As for the calculation of the total power of the installed gen-sets, it should be also considered the maximum power point of the generators, that is their

Figure 9: Example of furniture and finishing on board



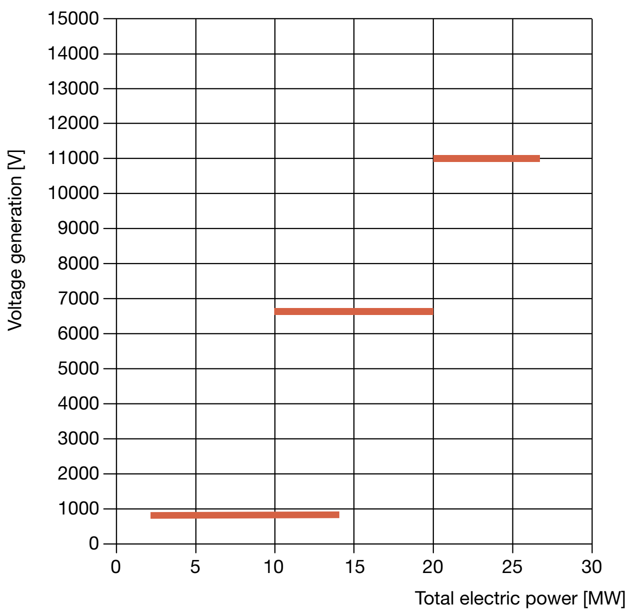
maximum efficiency, which corresponds to 75% of their maximum nominal power.
As already said, the generators on board are devices consisting of a diesel prime engine running a dynamo or a three-phase alternator permanently coupled with it to form a single machine, also defined as gen-set (see Figure 10).
The alternator is rotated by a diesel engine typically having 8 or 12 line or “V” cylinders with powers ranging from 1MW up to 10MW and efficiencies with values of about 95%; it can generate both low as well as medium voltages. In some applications, the alternator may be operated as an alternative also by gas turbines or by a mix of the two types.

Figure 10: Gen-set, diesel engine, alternator in a single machine



As it is known, to operate the alternator, the excitation current necessary to create a magnetic field must be supplied to the inductive winding; this results from a direct voltage auxiliary source which could be an exciting dynamo co-axial to the alternator or, more modernly, a system of static rectifiers converting the alternating voltage produced by the alternator itself into direct voltage.
By means of adjusting devices, which have the function of controlling both the rotation speed of the prime mover by varying the flux of the fuel as well as the excitation parameters, it is possible to keep constant both the supply voltage as well as the frequency generated at varying of the load conditions.
The power generation system of a cruise ship having the above mentioned characteristics normally comprises 6 alternators for a total power in the order of fifty megawatts (to give an idea, enough to supply a town of 50,000 inhabitants).
Generators are usually divided into groups and each group supplies its own busbar.
These machines can be put in parallel and this operation is carried out by a parallel control device; it connects the generator to the main busbars of the switchboard when it has phase and voltage equal and constant enough in comparison with the parameters of the alternators already in service.
Once the parallel connection has been carried out, the load splitter distributes on the gen-sets the power of the different loads according to the demands and to the percentage of load assigned to the single machine. Therefore the automation has the task of managing starting and stopping of generators according to the load.
The gen-sets with the relevant automation, the medium voltage main switchboards and the control devices constitute the power station on board. The main switchboard is generally divided into two or more sections, each of them depending on a gen-set, so that the possibility of a redundant supply for the different loads of the ship is guaranteed.
The value of the primary distribution voltage depends on the total power on board. The MV generation and distribution systems on board of big ships usually provide either 11kV voltage level - when the total power capacity of the generators exceeds 20MW and there are engines with powers over 400kW – or 6.6kV voltage when the total power capacity of the generators ranges from 10MW to 20MW and the engines have maximum power of about 300kW.
For maritime applications with the total power of generators of some megawatts up to about 12MW and therefore small crafts (for example yachts or small size ships), generation and distribution are usually in low voltage and with a voltage value of 440V or 690V. The different voltage level as a function of the total power is summarized in the diagram of Figure 11.

Figure 11: Representation of the rated voltages as a function of the power supply on board



5 Hints on propulsion systems

The propulsive power installed on board varies considerably according to the type of ship and to the particular requirements of service.
Making reference to the standard ships built around the 70's, the propulsion systems consisted of steam turbines or diesel engines either two-stroke (for naval applications only) or four-stroke ones, whose shaft drove the propeller bearing system.

With the increase in the ship burden, and in particular with big-size ships such as passenger liners which have reached dimensions and tonnages well beyond imagination over the last years, a field of application particularly interesting for electric propulsion has been created: it consists in using an electric motor as thruster for the propellers of the ship.
At first, asynchronous motors have been used because of their robustness and constructional simplicity. The further step has been the synchronous motor which, although it has higher overall dimensions and more weight at the same power level and involves more complications to manage starting and reverse operations, allows working, by acting on excitation, at unit power factor with a consequent reduction in the plant sizing.
Moreover, since the slip is null, it is possible to get a constant speed; they are also characterized by the presence of a stator electromotive force at no-load operations, allowing, for the control, the use of converters with natural switching.
Thus, electric propulsion has imposed itself; it consists in using the main engine of the ship to run an electrical generator, whose current supplies a synchronous motor which runs the propellers.
A ship, with the characteristics initially assumed, has usually two motors, each of them with power in the order of about ten MW, able to grant to the unit an average navigation speed of about 20 knots. Therefore, total propulsion powers ranging from 15MW to 30MW can be reached, which are necessary to handle navigation in the open sea (see Figure 12).

If compared with the absolute values of power, the electrification coefficient $K_{P/T}$ may result more significant; it can be defined as the ratio between the total electric power on board and the ship tonnage which can typically take values in the range from 0.15 to 0.25 kW/T.

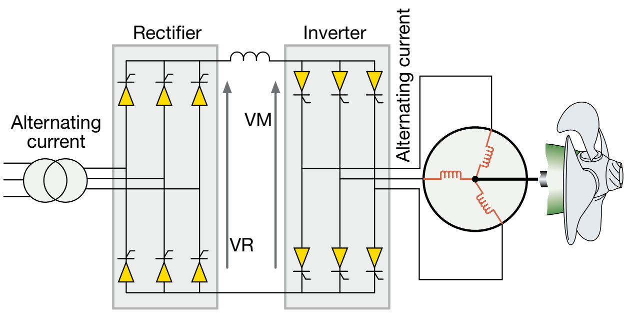
The energy necessary to supply the electrical motors originates by the MV power plant on board from which derives also the electrical supply for the whole ship.
Big line cruisers are normally equipped with two synchronous motors typically supplied at 6.6kV which rotate the fixed or steerable blade propeller according to the adopted type of static converter.
To guarantee a certain propulsion capacity also in case of a partial damage of the windings, each electrical engine can be constituted by two different three-phase windings with power equal to half the total power of the motor instead of by a single full-power winding.
To drive a machine through voltage and frequency control, some static frequency converters named Synchroconverter or "Load Commuted Inverter LCI" are used;

Figure 12: Open sea navigation

they handle the conversion of the electrical energy from an alternating network at fixed frequency to an alternating network with variable frequency from zero to the rated value, verifying also that the voltage/frequency ratio keeps constant.
The converter used and shown in Figure 13 is of indirect type and as a first step carries out the conversion from alternating to direct electrical quantities through a bridge rectifier with six-phase reaction totally controlled by thyristors.

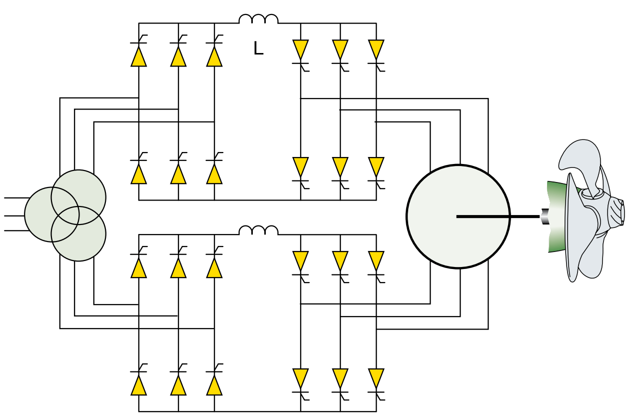
This DC section guarantees, for the propulsion motor, the availability of an excitation system necessary for the operation of the synchronous motor.
In the DC intermediate step there is also present an inductance "L" in series with the function of stabilizing the current at the inverter input. In the subsequent step, called impressed current (Current Source Inverter), the conversion from direct to multiphase alternating electrical quantities at variable frequency is carried out by means of another controlled three-phase bridge rectifier which operates as inverter at natural switching, with switching depending on the load, that is by the synchronous motor.
Without going into the details of theoretic treatments, the operation principle of the Synchroconverter, can be summarized as follows: at the output terminals of the three-phase bridge functioning as rectifier and at the input terminals of the three-phase bridge functioning as inverter two voltages are present, VR and VM (with VR > VM since the apparatus controlled is a motor and not a generator).
VM results to be proportional to the rotation speed and to the excitation of the synchronous motor.
The difference of potential allows controlling of the current which passes through the inductor and periodically through two of the three phases of the stator, thus creating a rotating field with direction and frequency required by the control system.
The rotor, duly excited, starts to rotate and tries to reach the same synchronous speed of the rotating magnetic field.

Figure 13: Synchroconverter



In the diagram of Figure 14, there are two ac/ac converters (each of them consisting of an alternating/direct inverter and by a direct/alternating inverter) because the stator of the synchronous motor is made of two different three-phase windings, each of them supplied by its own alternating/alternating inverter.
This system allows realizing an ac/ac converter at 12 impulses with the advantage of reduction in the harmonics and pulsating torque.
Moreover, nowadays the tendency to provide for the use of filters makes unnecessary the use of a rectifier with a higher number of impulses so that the harmonic contribution is reduced.

Figure 14: Synchroconverter for double-wound motor

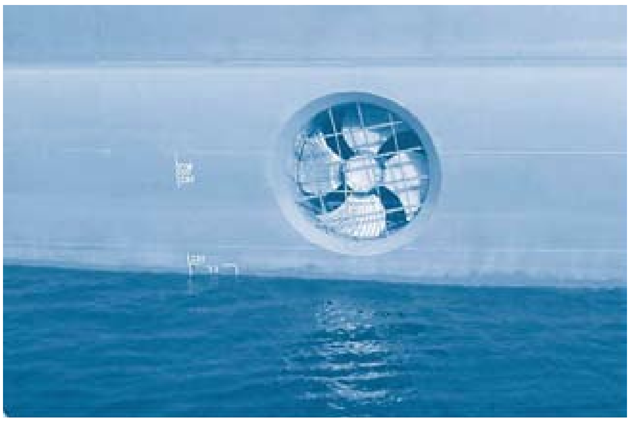


From the description of the two propulsion typologies it is evident how the electrical propulsion is more complex than the mechanical one and requires the use of two machines (inverter and electric motor) in addition to oversizing of the electric generator, however present in both cases to supply the distribution system.
As a consequence, when considering volume, weight and cost, it could seem less convenient, but other elements, pointed out hereunder, have led to the success of electric propulsion.
In spite of a bigger apparent total volume, electric diesel engine allows optimization of spaces since there are few positioning bonds because the electric engine can be placed closer to the propeller.
Thus it is possible to reduce the mechanical limits related to the alignment and dimensioning of the shaft which constitutes the transmission component between mechanical diesel propulsor and propeller.
Besides, electric diesel engines ensure a great flexibility in motor handling.
The use of electronic technologies introduces unquestionable advantages in terms of efficiency and maintenance; this in comparison with the mechanical devices necessary to bring the rotation speed of the diesel engines

to the lowest number of revolutions which characterize functioning of the propellers.
The presence of an automatic control, which allows adaptation to the different operating conditions by making easier and improving maneuverability, speed adjustment and direction handling, optimizes the total efficiency with a reduction in consumptions and in polluting emissions. Besides, also noise and vibrations result to be reduced.

Other modalities for propulsion are coming up, in particular the use of permanent magnet synchronous motors is being considered with interest thanks to their peculiar characteristics: for example the high power density which can be reached, the reduction in copper losses with a consequent increase in efficiency, the increase in reliability (there is no excitation winding, which involves the elimination of all the relevant problems such as mechanical and electrical severities placed in the manifold and due to the wear and tear of brushes), or the high noiselessness when considering the comfort.
As regards harbour manoeuvring or, generally speaking, in restricted waters, ships use a system with propellers, which produce a transversal thrust; it is usually built into the bow and the stern area.
Such system is normally known as "bow-thruster" or "stern-thruster" and must not be mistaken for, or associated to, the main propulsion system.
The propeller can be rotated either clockwise or anticlockwise on a plane parallel to the longitudinal axis of the ship, generating a transverse thrust to the right or to the left. The typical solution, represented in Figure 15, foresees that the generator is enclosed in a tube open at its ends and built into the hull.

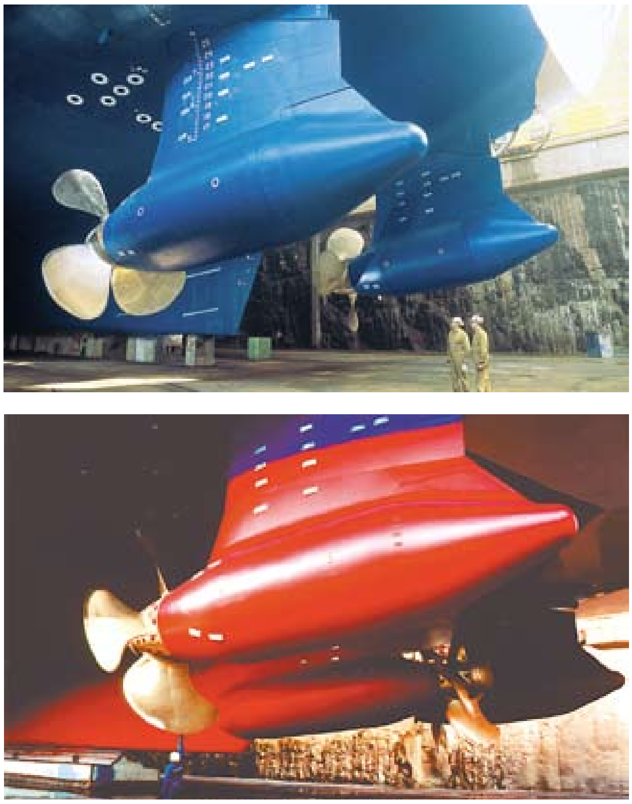
Figure 15: Thrusters built into the hull



A revolutionary and innovative propulsion system allowing the most demanding requirements on board to be satisfied and maneuverability to be improved is the Azipod system, made in the first '90 by Asea Brown Boveri (ABB) and by the Finnish Kvaerner Masa Yards (KMY).

As shown in Figure 16, it consists of an adjustable "podded" unit, placed under the submerged part of the hull, fore or abaft, basically according to the type of ship (e.g. for icebreakers it is fore).

Figure 16: Azipod



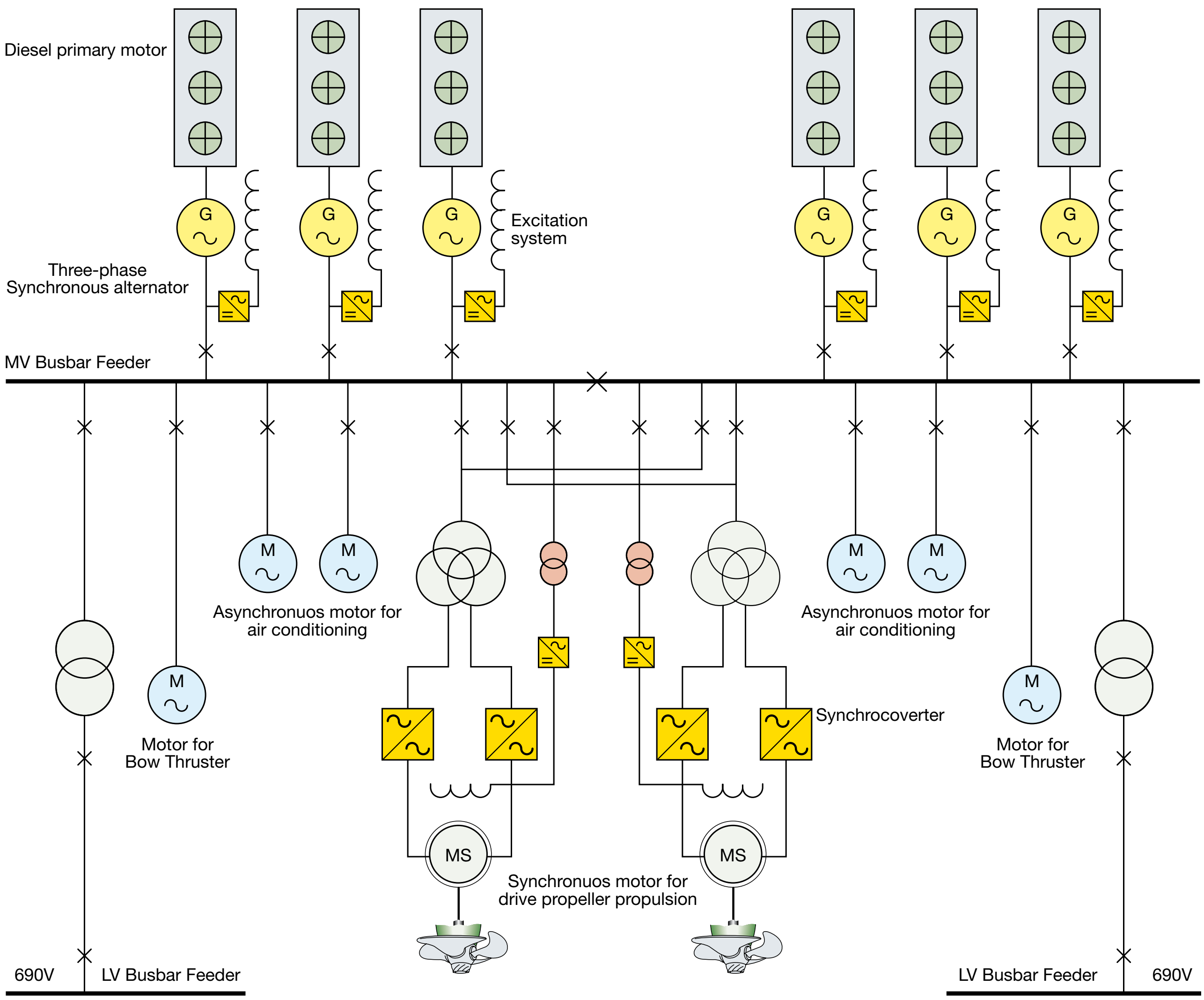
The pod, which shall have good hydrodynamic characteristics, incorporates a permanent magnet motor whose speed and torque are controlled by a frequency converter. A propeller is driven through a short shaft; it is generally a fixed-pitch propeller which can be mounted to one of the two ends of the nose cone according to the requirement for a pulling propulsion, typical for ships with quite high speeds, or a pushing action with low speed and high thrust (tugboats).
This device can azimuth through 360°, thus making it possible to exploit the full power in either direction and giving the ship a great advantage as regards maneuverability and efficiency in comparison with the traditional system, therefore making unnecessary rudder and maneuver transverse thrusters.
Azipod system allows for high efficiency, with fuel economy up to 10-15% in comparison with conventional propellers and a consequent improvement of the environmental impact thanks to a reduction in the emissions of CO_2.
Azipod also ensures a reduction in noise and vibrations and an optimization of the spaces on board.

6 Generalities on electrical systems on board

Without going into the details of the management modalities of the electric distribution or of the layout that an electrical system on board may have, it is possible to describe it in short, however giving the possibility to understand its structure and complexity.
In the plants on board of big ships, or however in the most modern ships, such as for example line cruisers, the generation of electric energy occurs, as already said, in the power station on board, which, in some cases, can be divided into two parts, one placed astern and the other at the bow.
Medium voltage distribution (see Figure 17) starts from the main switchboard which consists of two sections, each of them connected to one gen-set.
These bars are usually connected through a bus-tie which allows the power to be handled according to the specific needs, always with the point of view of keeping, even if reduced, such an efficiency that a good degree of safety and stability is ensured for the ship.
The medium voltage main busbar system or some distribution sub-switchboards deliver power, directly or through control devices (e.g. electronic converters) to:
1) essential high power loads (e.g. the propellers or the thrusters for transverse motion);
2) big power motors, for example for air-conditioning or for the typical functions linked to particular vessel typology;
3) various substations in the service areas intended to supply LV power to all the power loads, small power loads or lights provided for that area.

Therefore, the secondary power supply of the LV switchboards starts from the substations, through MV/LV transformers; these switchboards often offer the pos-

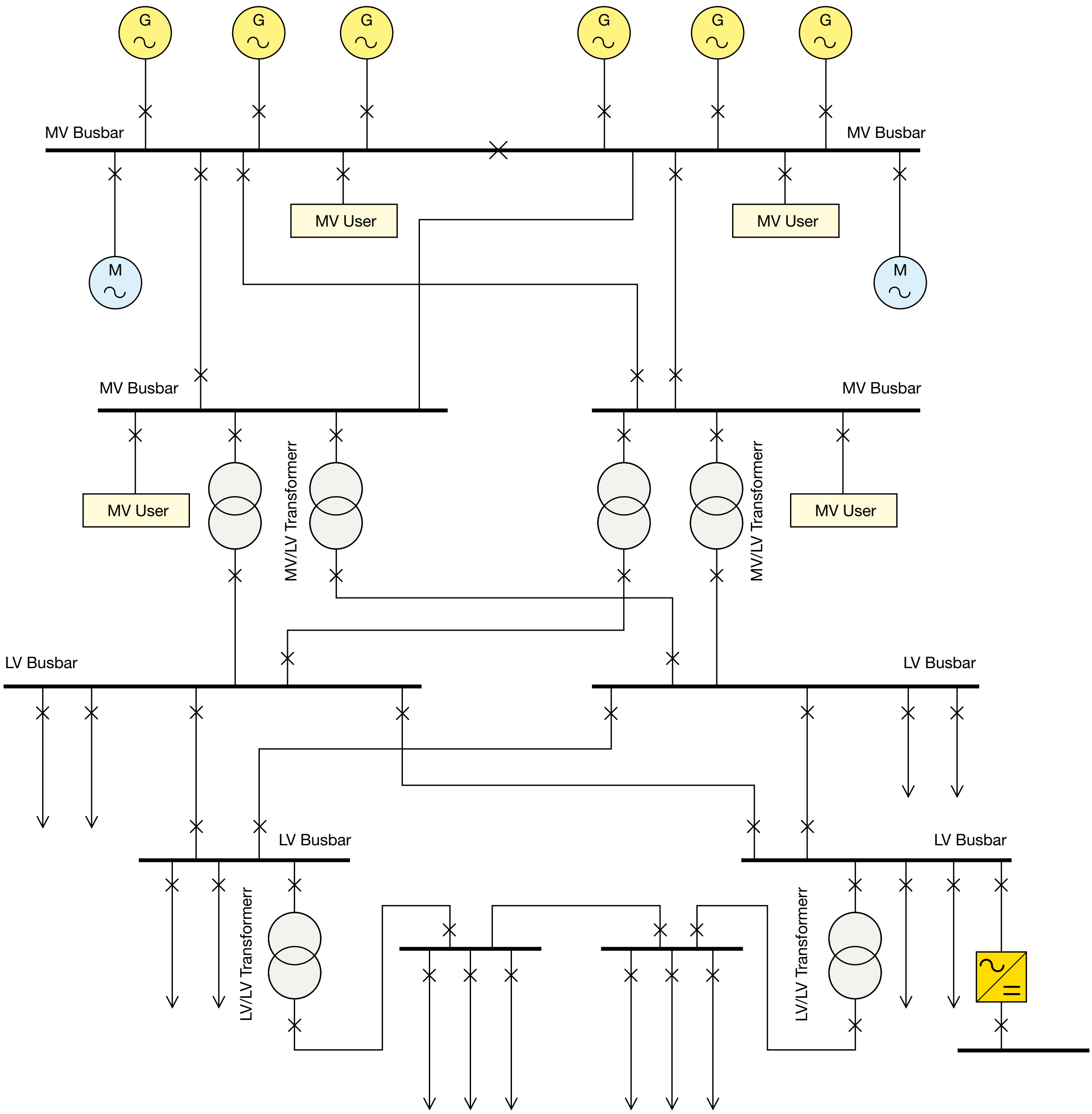
Figure 17: General representation of the modalities of generation and MV supply



sibility of having redundant supply coming from other MV switchboards supplied in turn by the other half-busbar of the main MV switchboard.
From the LV switchboards a complex distribution network (see Figure 18) is originated and it supplies the different types of LV loads on board, such as the rudder, the winches or the essential auxiliaries of the motor and, moreover, the lightning plant, the entertaining, comfort and performance facilities, as well as the accommodation structures with kitchens and laundries.

The plant must always guarantee service continuity; therefore, switchboards with two incoming feeders deriving from other separate switchboards are provided. In case of fault, putting out of service, as fast as possible, only the load involved or the section affected by the breakdown is important, thus realizing high selectivity for all the loads.

Figure 18: General diagram relevant to MV and LV distribution on board



In the previous paragraph, the MV generation voltage values have already been mentioned. Instead, as regards the distribution levels of the LV plant, till some years ago the standard value was 440V.
Due to the continuous increases of the tonnage and consequently of the power required on board, for the difficulty in handling the higher and higher rated currents and the short-circuit current values, the voltage supply has been changed and passed to 690V and in some rare and particular cases to 1000V.
This has implied some advantages, such as a partial reduction of the fault current values, a reduction of the cross sectional areas of the cables and consequently of weights and overall dimensions, a reduction of voltage drops and bigger admissible lengths of cables and an increase in the power of the motors which can be directly connected to the primary network and generally of all the loads of the Main Switchboard.

Low voltage final distribution is carried out at lower voltages (400V/230V), obtained through LV/LV transformers. The frequencies most commonly used are 50Hz or 60Hz according to different aspects, such as for example the type of naval construction and the country of origin. For special loads, or more simply in the military field, dedicated circuits are required in the presence of 400Hz. Typically, the direct current has voltage values of 48V, 110V or 125V are maintained for those particular circuits, for example, where devices for battery recharging or for automation auxiliary circuits are provided.

Electrical naval plants are subject to particular and typical project specifications which can be distinguished for some details from those of earth plants because of a totality of aspects and necessities linked to the characteristics of the environment to be considered and which can be found on each type of naval unit. In fact, the network on board constitutes an island system characterized by short distances between the energy source and the loads. The total power installed can be very high with high short-circuit values and electrodynamic forces which must be managed safely; this requires particular attention when designing such systems.
An earth distribution system is divided into different separated sub-systems, whereas for a plant on board there are fewer possibilities of integration and management.
The total power of the generators can be compared with the total power installed, considering the safety factor, and the rated power of some loads can be compared with that of the single generators.
Therefore, on board there are no busbars with infinite power, that is with power available clearly exceeding the power required by the loads, as it happens instead with earth generation systems.

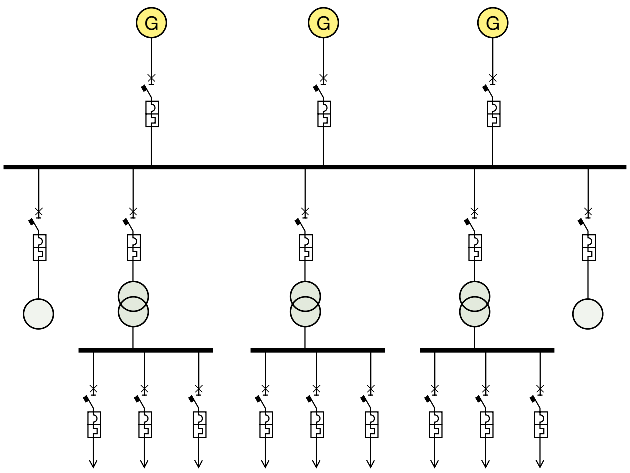
As a consequence, the division of the supply and use powers must allow starting of bigger asynchronous motors with the minimum possible number of generators running and without causing such a high voltage drop such as to perturb the distribution system.
The possible types of fault, from overload to short-circuit, are in common with fixed electric plants. The operation modalities and the fault consequences could be more serious and complicated to deal with, always due to the particular environmental and operating conditions on board, with limited escape routes and spaces often restricted.
To obtain high performances in terms of electric safety on board, for example, the cables to be used shall be able not to propagate fire, therefore of flame retardant type, with the purpose of getting the event under control and with characteristics of fume and vapor emissions the least toxic as possible for passengers' safety.
Various safety systems, e.g. sophisticated fire-prevention installations must be provided.

As already said, also the lack of supply for the fundamental utilities must be avoided for safety on board. Therefore the distribution system shall provide for the possibility of a redundant supply; this can be obtained usually through an open ring system, for example dividing the MV main busbar, which closes if needed, so that the power supply to the electric propulsion engines is ensured in order not to jeopardize the ship maneuverability, or for LV switchboards to provide the possibility of a double supply deriving from other switchboards, or also through adequate designing of the emergency power station.
Electrical plants on board are typically in alternating current since they result to guarantee a better management in terms of costs and reliability in comparison with direct current ones.

The MV primary distribution network generally consists in a three-phase system with three conductors without neutral. Such system is usually managed with the neutral of the star point isolated from earth or connected with earth through a resistance or a Petersen coil, thus allowing a reduction in the values of leakage and short-circuit currents. In this way, a first fault with insulation loss does not represent a hazard and allows the system to be maintained in service without the intervention of the protection.
Obviously the fault must be signaled and standard service conditions must be immediately restored so that it can be avoided that the first fault turns into a double fault to earth, which is extremely dangerous in IT systems.
Once, when onboard installations were not very wide and the powers involved quite small, the secondary

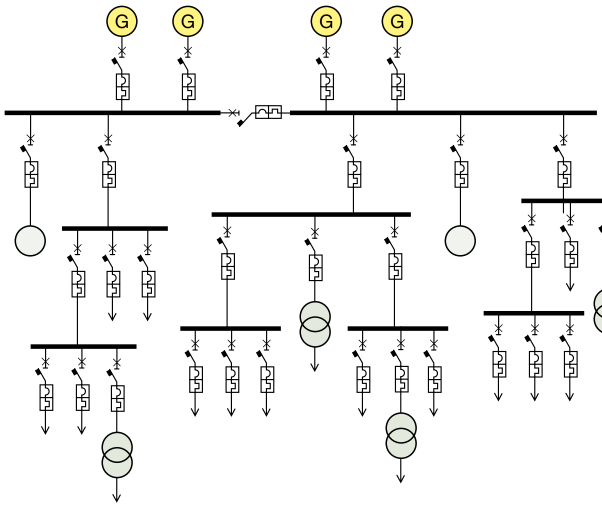
distribution system consisted in a single-phase network with two insulated conductors or three conductors with the medium point of the transformer connected to earth. Nowadays, since the powers involved have remarkably increased, it is preferred to use a four-wire three-phase system, that is with distributed neutral and in the most cases not connected with earth, with the possibility of disposing easily of the line-to-line and of the phase voltages.
Generally, the secondary distribution network is radially distributed with the possibility of double switchboard supply through two different lines, thus realizing the reserve connection to the load. The choice of using one type or the other depends on the plant conditions and it is carried out either by means of a switch or of interlocked circuit-breakers.
MV main distribution networks have a different structure according to the type of ship and to the installed power. They can be of simple radial type with substations or sub-switchboards.
The simple radial diagram (see Figure 19) includes a main switchboard with a single busbar, from which the output feeders for all the LV power consumers start. This configuration results to be particularly critical since a fault on the main switchboard may jeopardize the reliability of the services on board.

Figure 19: Diagram of principle for radial distribution



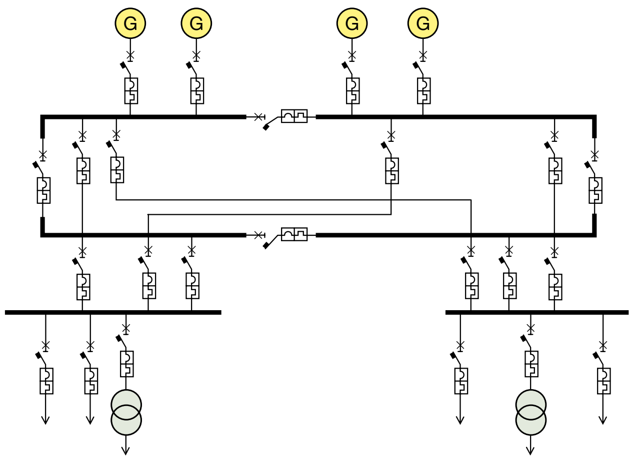
The compound radial diagram (see Figure 20) is fitter than the previous one for the realization of medium power plants and comprises a main switchboard with one or more main busbars and some sub-switchboards, which provide solely for the power supply delivery from the main switchboard to the distribution switchboards differently placed. With this configuration there is a remarkable reduction in the number of the circuits derived from the main switchboard and therefore of the devices installed in the switchboard.

Figure 20: Diagram of principle for compound radial distribution



Instead, as regards the service continuity of the users derived from different distribution sub-switchboards, a remarkable importance is represented by the correct sizing of the chain of circuit-breakers positioned at the different levels of the distribution system so that it is possible to obtain the tripping of the circuit-breaker affected by the fault only, thus guaranteeing power supply for the other loads and sub-switchboards.
To ensure power supply continuity, the radial system is often structured with a reserve ring (Figure 21) intended for the supply of the substations having the main line interrupted, or even the whole substation group in case of a serious fault on the semi-busbar of the main switchboard usually supplying them. In this case, which is to be considered very heavy and hard, only half the generators results to be available and consequently half the energy power installed.
The ring shall be sized to provide for the needs of the plant foreseen for this operation situation, which, as it is evident, is of extreme emergency.

Figure 21: Diagram of principle for distribution with ring circuit



The plant on board may be divided into three main parts, represented by:

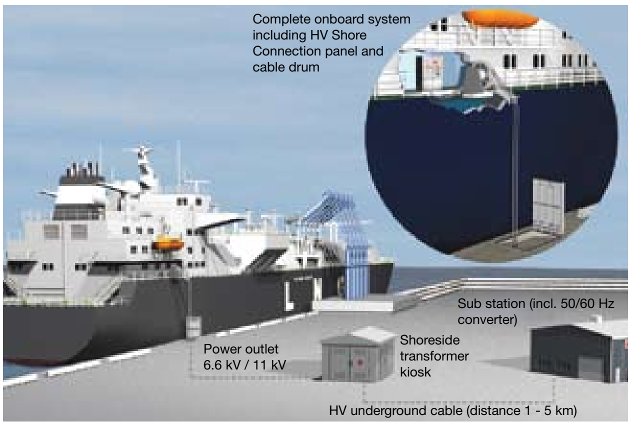
- the main plant, consisting of the essential services of the ship, such as the propulsion or the circuits intended for priority functions on board, each of them characteristic of the ship typology (e.g. the circuits intended for gas pumping or compression for a gas carrier, or the circuits intend for the control of the devices for load handling on shipping containers);
- the auxiliary circuits which include power production and distribution systems for lightening and auxiliary motive force;
- the special installations for which a particular technology has been developed (e.g. telephone installations, electronics devices for different uses, telegraphs, torquemeters, integrated navigation systems, fire warning devices).

Another main difference concerns the distinction which can be made between essential and non-essential loads, which influence the distribution system which supplies them. The first ones are those for which supply and proper operation are to be guaranteed also under emergency conditions, since they carry out functions indispensable to the safety of the vessel. Among them, first of all the propulsion system, the control systems of motors, helms and stabilizer paddles, the fire-prevention systems, the alarms, the communication and auxiliary systems for navigation, the emergency lightening.
Also those loads which contribute to create the best comfort or a better safety for passengers' life on board, such as the air-conditioning or water-aspiration system, are to be considered essential.

The electrical system, in compliance with the Naval Registers' rules, provide also an emergency electrical station positioned in another area with respect to the power station on board, usually on one of the high decks and however over the waterline. The power station consists of an autonomous LV diesel-generator set (440V or 690V), in the order of some MW.
The diesel engine under consideration shall be able to start also when the main network cannot deliver energy and this is usually obtained by means of a connection to the UPS system. A set of capacitors is present to guarantee energy availability also during the starting time of the emergency generator. Under standard operating conditions, that is in the presence of voltage on the mains, a rectifier shall have the task of delivering to the capacitor banks the energy necessary to keep the maximum charge.
In case of malfunctioning of the main station, an automatic control sequence provides for switching to the emergency switchboard the power delivery of the part of the plant to which the priority loads, which must work also in emergency case, are connected (e.g. emergency lightning, fire pumps, steering devices and auxiliary equipment indispensable for the machinery systems, communication and signaling networks and other circuits).

Besides, due to environmental constraints, in harbors ships must turn their diesel engines off thus interrupting electric generation; then they must connect to the onshore grid, normally to a LV source, or in the most modern solutions to a MV tap made available in the port.
This procedure, defined High-Voltage Shore Connection (HVSC) finds favor with the harbor management authorities worldwide, allows for a reduction in the polluting emissions of ships at berth, improving air quality in the port areas and in the surrounding ones.
HVSC technology (Figure 22) allows power supply directly from the wharf to the vessel to ensure operation of the machinery systems and installations on board (refrigerators, illumination, heating and air-conditioning) and allow the diesel engines normally used to supply electrical generators on board to be turned off.
This operation in parallel, which is necessary for onboard electrical power supply must not cause problems of power quality to the onshore distribution grid.
To give an idea of the environmental impact, a big line cruiser at berth for 10 hours, if using onshore power supply, avoids burning of up to 20 metric tons of fuel, which is equivalent to 60 metric tons of carbon dioxide not emitted into the atmosphere, which is the annual emission of 25 cars.

Figure 22: High-Voltage Shore Connection (HVSC)



7 Selection conditions for low voltage equipment: Standards' prescriptions and Registers' rules

7.1 Switching and protection circuit-breakers

7.1.1 Suitability for environmental conditions

Environmental conditions on board are very critical; in fact the marine environment, with its high humidity levels and installation conditions in restricted spaces, at operating temperatures which could easily reach values above norm and the presence of mechanical stresses, such as for example vibrations due to the proper movement of the ship or of mechanical origin (prime movers), contributes to the creation of an extremely heavy and aggressive environment.
These conditions require the use of particularly resistant electrical materials.
With regard to all aspects relevant to the applications of electrical components for marine installations, the rules of the different Registers of Shipping give the necessary prescriptions for the tests and the parameters required in terms of performances with which such equipment shall comply.
Besides, they require all the technical documentation consisting of the test reports relevant to the "type tests" certifying the compliance of the apparatus with the product standards, which in case of circuit-breakers are IEC 60947-1 and IEC 60947-2.
Table 2 below summarized the main verifications to which the apparatus must be subject according to the rules of the main Registers of Shipping.

As the Table below shows, the rules are prevalently aligned. The following main parameters are usually required by the Registers of Shipping for the testing of electrical components to recognize their suitability to marine applications.
For ships classed for unrestricted navigation, the reference air temperature for enclosed spaces ranges from +5°C up to +45°C, for ships classed for service in specific

Table 2: Parameters of some tests prescribed by the Registers of Shipping

Registers	Vibrations	Power supply variation	Damp heat
Lloyd's Register	Frequency range: 5-13.2 Hz Displacement: 1mm. Frequency range: 13.2-100 Hz Acceleration: 0.7 g.	Voltage variation (permanent) % +10/-10 Voltage transient (duration 1.5s) +20/-20 Frequency variation (permanent) % +5/-5 Frequency transient (duration 5s) +10/-10	T rise form 20° to 55°C. Keep T=55°C for 12h (RH 90-100%) Treduction to 20°C . keep T=20°C for not less 6h (RH 80-100%) 2 cycles
RINA	Frequency range: 5-13.2 Hz Displacement: 1mm. Frequency range: 13.2-100 Hz Acceleration: 0.7 g.	Voltage variation (permanent) % +6/-10 Voltage transient (duration 1.5s) +20/-20 Frequency variation (permanent) % +5/-5 Frequency transient (duration 5s) +10/-10	IEC 60068-2-30 test Db T rise T=55°C Keep T=55°C for 12h (RH 95%) Cycles: 2 (2x 12+12h)
DNV	Frequency range: 5-13.2 Hz Displacement: 1mm. Frequency range: 13.2-100 Hz Acceleration: 0,7 g. Sweep rate max 1 octave/minute	Voltage variation (Permanent) % +10/-10 Voltage transient (duration 1.5s) +20/-20 Frequency variation (Permanent) % +5/-5 Frequency transient (duration 5s) +10/-10	IEC 60068-2-30 test Db T rise T=55°C. Keep T=55°C for 12h (RH 90-96% at 55°C) Cycles: 2 (2x 12+12h)
ABS	Frequency range: 5-13,2 Hz Displacement: 1mm. Frequency range:13.2-100 Hz Acceleration: 0,7 g. Sweep rate max 1 octave/minute	Voltage variation (Permanent) % +6/-10 Voltage transient (duration 1.5s) +20/-20 Frequency variation (Permanent) % +5/-5 Frequency transient (duration 5s) +10/-10	IEC 60068-2-30 test Db T rise:T=55°C, RH=95% Cycles: 2 cycles (12+12h)
BV	Frequency range: 5-13,2 Hz Displacement: 1mm. Frequency range:13.2-100 Hz Acceleration: 0.7 g.	Voltage variation (permanent) % +10/-10 Voltage transient (duration 1.5s) +20/-20 Frequency variation (permanent) % +5/-5 Frequency transient (duration 5s) +10/-10	IEC 60068-2-30 test Db T rise:T=55°C, RH=95% Cycles: 2 cycles (12+12h)
GL	Frequency range: 5-13.2 Hz Displacement: 1mm. Frequency range: 13.2-100 Hz Acceleration: 0.7 g.	Voltage variation (permanent) % +6/-10 Voltage transient (duration 1.5s) +20/-20 Frequency variation (permanent) % +5/-5 Frequency transient (duration 5s) +10/-10	IEC 60068-2-30 test Db T rise:T=55°C, RH=95% cycles: 2 Cycles (12+12h)

zones (e.g. for ships operating outside the tropical belt) the maximum ambient air temperature may be assumed as equal to 40°C.
The standard rules for humidity prescribe the value of 95% at 55°C.
The vibration levels vary in relation to the location of the electrical components. For installations inside command and control stations, on exposed decks or in accommodation spaces on board, the verification field required to comply with in the frequency range from 2Hz to 13.2Hz is 1mm displacement amplitude and from 13.2Hz to 100Hz is an acceleration amplitude of 0.7g (1g=9.8m/s^2).
Some prescriptions are given also for the quality of the power delivered by the station on board as regards the voltage, frequency and harmonic distortion parameters with which all electrical components shall comply to operate satisfactorily.
The accepted voltage and frequency variations are respectively from +6% and -10% and +/- 5%. As for the harmonic distortion of systems without priority loads controlled by static converters and supplied through synchronous generator, the total voltage harmonic distortion admitted shall not exceed 5% and the single harmonic shall not exceed 3% of the fundamental. In the presence of loads controlled by static converters the single harmonic shall not exceed 5% of the nominal voltage up to the 15th harmonic of the nominal frequency and the total harmonic distortion shall not exceed 10%.
As regards the presence of those devices allowing diffusion or transfer of the signals through electromagnetic waves, for radar installations or for radio links, the Registers of Shipping prescribe also verifications for the aspects linked to the phenomena which are generally defined of electromagnetic compatibility and which include immunity tests against radiated and conducted disturbances as well as for conducted and radiated emissions.

Dry heat test	Immunity to radiated radio frequency fields	Immunity to conducted high frequency field
IEC 60068-2-2 Tests Bb-Bd T rise T=70°C (RH=50% at 35°C, equivalent to 9% at 70°C) Duration 16h at 70°C	Frequency range 80MHz-2GHz Modulation 80% at 1000Hz Field strength 10 V/m Frequency sweep not exceeding 1.5x10^{-3} decades/s, or 1% /second	IEC 61000-4-6 Frequency range 150kHz-80MHz Amplitude 3V rms Modulation 80% at 1000Hz Frequency sweep not exceeding 1.5x10^{-3} decades per second, or 1% /second
IEC 60068-2-2 T rise T=55°C or T=70°C Duration 2h at 70°C or 16h at 55°C	IEC 61000-4-3 Frequency range 80MHz-2GHz Modulation 80% at 1000Hz Field strength 10 V/m Frequency sweep not exceeding 1,5x10^{-3} decades/s, or 1% /second	IEC 61000-4-6 Frequency range 150kHz-80MHz Amplitude 3V rms Modulation 80% at 1000Hz Frequency sweep Not exceeding 1.5x10^{-3} decades per second, or 1% /second
IEC 60068-2-2 Tests Bb-Bd T rise - Duration 16h at 55°C+2h at 70°C (RH max 55%) Class B	IEC 61000-4-3 Frequency range 80MHz-2GHz Modulation 80% at 1000Hz Field strength 10 V/m Frequency sweep not exceeding 1.5x10^{-3} decades/s, or 1% /second	IEC 61000-4-6 Frequency range 150kHz-80MHz Amplitude 3V rms (10Vrms for bridge and deck zone) Modulation 80% at 1000Hz Frequency sweep Not exceeding 1,5x10^{-3} decades per second, or 1% /3s (according to level 2 severity standard)
IEC 60068-2-2 Tests Bb-Bd T rise - Duration 16h at 55°C or 2h at 70°C	IEC 61000-4-3 Frequency range 80MHz-2GHz Modulation 80% at 1000Hz Field strength 10 V/m Frequency sweep Not exceeding 1,5x10^{-3} decades/s, or 1% /3s (according to level 3 severity standard)	IEC 61000-4-6 Frequency range 150kHz-80MHz Amplitude 3V rms Modulation 80% at 1000Hz Frequency sweep not exceeding 1.5x10^{-3} decades per second, or 1% /3s (according to level 2 severity standard)
IEC 60068-2-2 Tests Bb-Bd Trise - Duration 16h at 55°C or 2h at 70°C (70°C to be performed on equipments not located in air-conditioned spaces)	IEC 801-3 Frequency range 80MHz-2GHz Field strength 10 V/m	Not present
IEC 60068-2-2 T rise: 55°C 16h (RH max=50%) installed in areas without increased heat stress Duration: 70°C 16h (RH max=50%) installed in areas with increased heat stress or on the open deck	IEC 61000-4-3 Frequency range 80MHz-2GHz Modulation 80% at 1000Hz Field strength 10 V/m Frequency sweep not exceeding 1.5x10^{-3} decades/s, or 1% /3s	IEC 61000-4-6 Frequency range 150kHz-80MHz Amplitude 3V rms Modulation 80% at 1000Hz Frequency sweep not exceeding 1.5x10^{-3} decades per second, or 1% /3s (according to level 2 severity standard)

7.1.2 Parameters for circuit-breaker selection

The electrical characteristics which can be defined on the basis of the values of voltage, rated current, and fault current of the plant section considered are the main parameters to be compared with the electrical features of the switching and protection device to be installed.
Starting from the fault conditions, the short-circuit current calculation shall be carried out, as indicated also in the rules of the Registers of Shipping, in compliance with the prescriptions of the Std. IEC 61363 "Electrical installations of ships and mobile and fixed offshore units - Part 1: Procedures for calculating short-circuit currents in three-phase a.c."
According to what mentioned in the clauses about electrical plants on board, it is evident that the plant consists of different typologies of electrical machines, such as generators, synchronous and asynchronous motors and drives and transformers.
Besides, the presence of automatic regulators and the nonlinearity of some components may condition the calculations and, in order to take into consideration the contribution of the electrical system as a whole, a calculus simulator should be used.
For the calculation of the short-circuit current, the maximum number of generators which can be simultaneously connected and the total number of motors usually connected to the grid at the same time must be considered.

The calculation of the short-circuit current in compliance with the Std. IEC 61363 prescribes the determination of the aperiodic component Iac(t), which is characterized by the subtransient, transient and synchronous or steady state contribution.
As for the determination of the characteristic parameters of the protective device, the T/2 half-cycle value (10ms at 50Hz) can be taken as reference.
Taking into account also the contribution linked to the aperiodic component Idc (component of the current present in a circuit immediately after the short-circuit) the following relation

$$i_p = \sqrt{2} \times I_{ac}(t) + i_{dc}(t)$$

allows determining the peak value of the short-circuit current depending on the pre-charge conditions and on the typical parameters of the generator.
The Standard accepts considering the peak value calculated for T/2.
Attention shall be paid to the fact that the electrical systems on board are characterized by the presence of big generators installed in a confined area and consequently the short-circuit current may also take peak values exceeding the standard ones due to the nonlinearity and to the time-varying nature of the impedance of the active components during the short-circuit and due to the presence of cables with large cross-sectional areas and reduced lengths deriving from the structure of the plant (reduced distances between the generator and the main fault points).
With standard power factor, as indicated in Table 3 below, it is meant the value reported by the Stds. IEC 60947-1 and IEC 60947-2, which refer to the general rules for LV switchgear and controlgear (Part 1) and in particular to circuit-breakers (Part 2).

Table 3: Values of power factor corresponding to the test currents and value "n" of the ratio between current peak and r.m.s. value

Test Current	Power factor	Peak factor
[A]	cosφ	n
I ≤ 1500	0.95	1.41
1500 < I ≤ 3000	0.9	1.42
3000 < I ≤ 4500	0.8	1.47
4500 < I ≤ 6000	0.7	1.53
6000 < I ≤ 10000	0.5	1.7
10000 < I ≤ 20000	0.3	2
20000 < I ≤ 50000	0.25	2.1
50000 < I	0.2	2.2

Therefore, when identifying the breaking and making capacity, it is necessary to pay great attention to the value taken by the power factor of the plant and in particular to the peak factor, with respect to the equivalent parameters required by the product Standard.
To summarize, all the typologies of circuit-breakers used on board shall be chosen based not only on the rated current and voltage values which should exceed the relevant parameters of the plant, but also on the basis of the performances under short-circuit conditions according to the following limits:
- a rated making capacity under short-circuit conditions "Icm" referred to the operating voltage; it shall not be lower than the peak calculated complying with the prescriptions of the Std. IEC 61363 at the installation point of the device itself. Therefore Icm > Ip;
- a rated breaking capacity under short-circuit conditions "Icu" or "Ics" referred to the operating voltage; it shall not be lower than the value calculated for the alternating current Iac(t) at T/2. Therefore either Icu > Iac(T/2) or Ics > Iac(T/2);
- a peak factor at the fault point which shall not be lower than the one to which the performances of the circuit-breaker referred, assessed as already said, in compliance with the product Standard.

Besides, with reference to the values of the breaking capacity, it is necessary to remember that the Registers of

Shipping, excepted for particular cases and for particular agreements with the certifying body, do not accept the back-up protection between two circuit-breakers, thus confirming that it shall be either Icu > Iac(T/2) or Ics > Iac(T/2).

As regards the choice of the breaking capacity, the Registers of Shipping introduce a further specification indicating the typology of circuits for which the circuit-breaker is to be chosen according to its Icu or Ics value.
As regards the circuits of the non-essential services or the redundant circuits of the essential services, the circuit-breaker can be chosen making reference to the Icu value. In practice, only the circuit-breakers for the generators and those ones for which a duplicated supply is not provided are chosen making reference to Ics.
As regards the selection of circuit-breakers with the possibility of guaranteeing an intentional tripping delay, that is circuit-breakers suitable for selectivity, the selection of the device shall be made with reference to the Icw value.

7.2 Protection modalities of on board electrical components

Electrical installations on board are to be protected against overcurrents due to short-circuits or accidental overloads.
The selection of the protective devices shall take into consideration the problems typical of naval applications, for example, in order to adapt as far as possible the same circuit-breaker - according to the characteristics of the cable provided - to any possible replacement of the controlled load (e.g. for an increase in power) it would be advisable to foresee circuit-breakers with adjustable protection functions.
Moreover, in order to make easier any possible operation of replacement, control and maintenance, it is preferable the use of withdrawable or plug-in devices (Figure 23); in addition to ensuring better safety for the personnel, these versions make these operations easier since there are often non-optimal operating conditions due to installation in enclosed spaces.

Figure 23: Fixed part and interruptive part of Emax withdrawable version

The performances of the different protective devices have to guarantee protection and coordination in order to ensure as far as possible:
- the elimination of the effects of the fault current, so that damages to the electrical system and fire hazards are reduced;
- service continuity, in case of fault, through the selection of devices resulting selective at the different levels of the adopted distribution system.

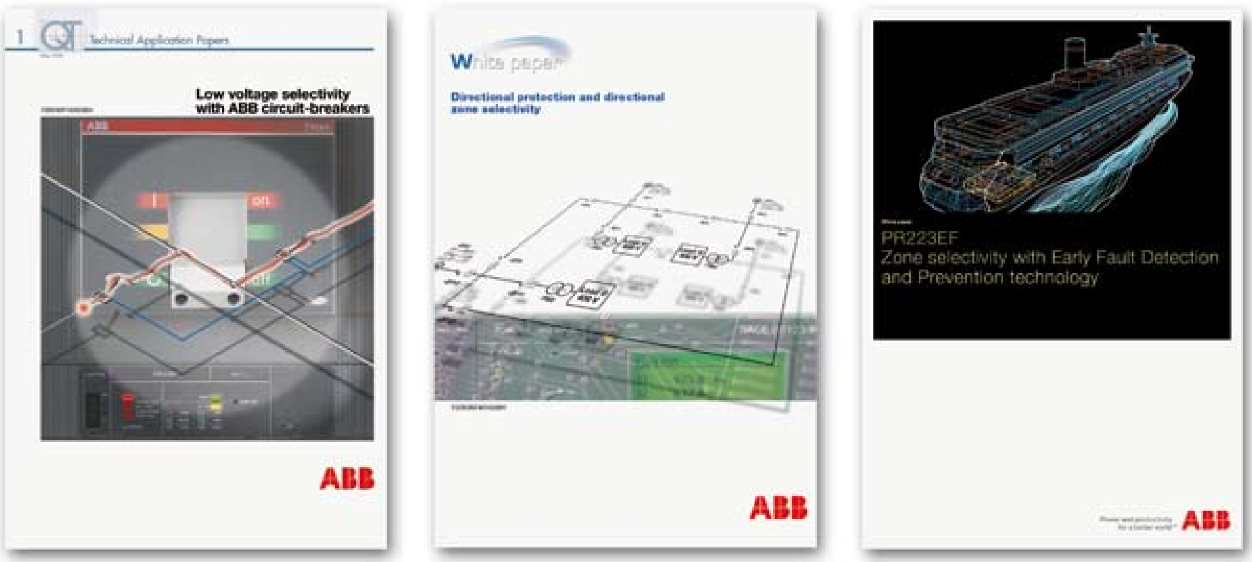
With their rules, the Registers of Shipping give detailed prescriptions as regards the modalities of protection against the overcurrents of the different electrical components on board. Here are reported some of the main and most important prescriptions to be followed, but reference shall be made to the rules of the different Registers for more detailed indications specific for the different components.
Every insulated distribution system, for power, heating or lighting, whether primary (directly supplied by generators) or secondary (supplied by transformers) shall be provided with a device capable of continuously monitoring the insulation level to earth and of giving a visual and audible alarm to indicate low or anomalous insulation values.
In the systems connected to earth directly or through a low impedance, the circuit affected by the fault shall be automatically disconnected.
The electrical protection is to be located as close as possible to the origin of the protected circuits and shall ensure short-circuit and overload protection for each non-earthed conductor; on the contrary, the earthed conductors are not to be interrupted.

Different rules can be given for the supply circuits of particular loads, as for example for the main or auxiliary control or supply circuits for the rudders, for them only the short-circuit protection shall be provided.
As regards generators, the short-circuit protection is to be set to instantaneously trip the circuit-breaker at an overcurrent less than the steady current and the overload protection to trip at an overload value between 10% and 50% of the rated current; in correspondence of 1.5xInG and excepted for particular cases, the tripping time shall not exceed 2 minutes.
The protection of the motor circuits shall provide a thermal protection suitable to the starting typologies, and the magnetic protection shall allow the presence of high currents during the transitory starting phase.
The transformers are designed to withstand without damages and for 2 seconds the thermal and mechanical effects caused by a fault on the secondary winding. The primary winding of the transformer (usually dry-type with air-cooling) shall be protected by an overload and short-circuit protective device. Such device shall ensure selectivity towards the circuits supplied by the secondary winding of the transformer.

As regards service continuity, selectivity between the different circuit-breakers of the incoming and outgoing feeders to other loads is required and is to be obtained so that only the part of the plant under failure can be isolated without jeopardizing or causing the loss of any other essential services.
ABB offers different solutions: without dwelling on the classical selectivity techniques (time-current or energy) here are some hints about zone selectivity, which can be obtained for molded-case circuit-breakers through the PR223EF trip unit.
Zone selectivity allows selectivity by using two circuit-breakers of the same size (T4L T5L T6L) and an interlock protocol running through a cable which, properly connected, links the device on the load side with the one on the supply side.
This allows the circuit-breaker size not be differentiated - as instead it is usually done in order to obtain selectivity – with consequent economical and dimensional savings.

Another selective function which could result particularly useful with meshed or ring networks is directional zone selectivity which can be obtained between air circuit-breakers equipped with protection trip units type PR123-PR333; these devices are capable to manage the lock signals and vary the tripping times according to the direction of the current flowing through them. These circuit-breakers, characterized by high current performances and consequently suitable to manage low voltage main distribution which in marine applications is usually carried out through two busbars and a bus-tie, allow the plant to be operated keeping only one half-busbar functioning in case of failure of the other.
For a detailed analysis of these selectivity techniques reference should be made to the dedicated documentation (see Figure 24), that is: the Technical Application Paper No. 1 “Low voltage selectivity with ABB circuit-breakers”, the White Paper “Directional protection and directional zone selectivity” and the White Paper on PR223EF, “Zone selectivity with Early Fault Detection and Prevention technology”.

Figure 24: ABB technical documents



8 Low voltage products' offer and availability of approvals

8.1 Switching and protection circuit-breakers

Low voltage molded-case circuit-breakers series **Tmax T** (T1-T2-T3-T4-T5-T6-T7-T8) and **SACE Tmax XT** (XT1-XT2-XT3-XT4), together with the air circuit-breakers series **Emax** (X1-E1-E2-E3-E4-E6) ensure an extremely high level of performances in comparison with their reduced overall dimensions, easy installation and an ever increasing safety for operators. In addition to complying with the various operating prescriptions for the different distribution systems, ABB offer is the most complete as regards the protection of the electrical components on board thanks to the use of circuit-breakers with dedicated trip units or dedicated protection functions.
The circuit-breakers of Tmax T and SACE Tmax XT series are particularly indicated to be used in secondary distribution applications, industrial installations in direct current (except for T7 and T8) and alternating current, for motor protection in motor control centers and for different final users.
Emax air circuit-breakers can be used both as general protection circuit-breakers, as well as protective circuit-breakers for electrical machinery.
In addition to the protection performances, ABB circuit-breakers offer communication availability (see Figure 25), which is particularly suitable for automation, measures, grid analysis and energy saving.
These functions allow the complete monitoring of the load and energy generation conditions and, through an interaction with the control systems of the ship, they allow an adjustment of the settings according to the different navigation trims.
Through programmable contacts and thanks to the communication functions it is possible to obtain an efficient and decentralized automation capable to react in a good time to the variations and to all the perturbations of the electrical system.

Figure 25: Communication through ABB circuit-breakers

In the range of molded-case circuit-breakers there are solutions for:

- Motor protection. Carried out by circuit-breakers with magnetic only trip units coordinated with thermal trip units and contactors, up to the most sophisticated electronic trip units for motor protection, which integrate also dedicated protection functions, such as phase unbalance (U) or rotor blocked (R) or protection against overtemperature through PTC, in addition to the traditional protection functions against overload and short-circuit.
- Generator protection. Carried out by trip units with protection functions against short-circuit with low thresholds, meeting the particular demands of this type of users.

In the range of Emax air circuit-breakers, equipped with protection trip units in their most evolute versions, it is possible to have an advanced and performing protection system allowing the implementation of advanced control functions which are particularly suitable for the management of particularly critical applications. The main advanced control functions available are:

- the function called "double S", available on PR123 and PR333, allows two thresholds to be set independently and activated simultaneously; this is particularly useful to improve selectivity conditions also under highly critical conditions;
- the function called "dual setting", available on PR123 and PR333, allows programming on the trip unit two different sets of parameters and through an external command to switch from one set to the other according to the installation requirement; this occurs for example when switching from the main supply to that of the emergency generator, or when protecting systems which result supplied with a reduced number of generators in comparison with those usually provided. In parallel with this function, it is to be taken into account also the availability of the load control function to favour supply to the essential loads in case of a reduction in the power supply;
- the already mentioned zone selectivity (PR122-PR123-PR332-PR333) and directional zone selectivity (PR123-PR333) functions to manage selectivity in more complex grids;
- the function called "double G", available on PR123 and PR333 trip units, allow restricted earth fault protection to be implemented by acting on the protective device on the medium voltage side.

Moreover, it is possible to meet particular requirements through dedicated protection functions, such as:

- "start up" function which allows operation of the protections S, I and G during the starting phase with higher trip thresholds than the set values (for motors, transformers and all the loads with high inrush current);
- thermal memory for functions L and S and phase unbalance (U) for motor protection;
- reverse power (RP), undervoltage (UV), overvoltage (OV), residual voltage (RV), underfrequency (UF), overfrequency (OF) for optimum generator protection of generators;
- phase rotation: for the protection of shore connection circuit-breakers;
- directional short-circuit function with adjustable delay (D), for the protection of generators and bus ties.

The trip units for molded-case circuit-breakers type Tmax T and SACE Tmax XT and air circuit-breakers type Emax, properly equipped with the suitable measuring module, make available also the measuring functions useful to monitor the main electrical parameters of the plant (current, voltage, power, energy and harmonic calculation). For further modalities on the operation modalities reference must be made to the relevant technical documents.

Tmax T family

Tmax T circuit-breakers are available in 8 sizes with rated currents of the trip units in the range from 1A to 3200A and thermal-magnetic or electronic protective trip unit according to the size.
In particular, to satisfy all the application requirements of the naval sector, a range of automatic circuit-breakers for alternating current up to 690V (see Table 4) is available.

SACE Tmax XT family

As for the new SACE Tmax XT family of molded-case circuit-breakers 4 sizes are currently available, with rated currents of the trip units in the range from 1A to 250A and thermal-magnetic or electronic protective trip unit according to the size.
In particular, to satisfy all the application requirements of the naval sector, a range of automatic circuit-breakers for alternating current up to 690V (see Table 5) is available.

Emax family

Emax air circuit-breakers are currently available in six sizes when considering also X1 circuit-breaker; the rated currents of the trip units are in the range from 400A to 6300A and they are equipped with electronic protective trip unit.

In particular, to satisfy all the application requirements in the naval sector, the following product ranges are available:

- Automatic circuit-breakers for alternating current power distribution up to 690V (Table 6);
- Switch-disconnectors for direct current power distribution up to 1000V (Table 7);
- Automatic circuit-breakers for direct current power distribution up to 1000V (Table 8).

As for the applications in the naval field, practically the whole range of products results to be approved by the main above mentioned Registers of Shipping.

For detailed information about the availability of the approval referred to each single circuit-breaker please contact ABB SACE. Tables 4-5-6-7-8 in the following pages summarize the main electrical parameters of standard circuit-breakers.

Tmax T family

SACE Tmax XT family

Emax family

Table 4: Tmax T circuit-breakers for applications up to 690V

		T1			T2				T3	
Rated uninterrupted current Iu	[A]	160			160				250	
Poles	[Nr.]	3/4			3/4				3/4	
Rated service voltage Ue (AC) 50-60 Hz	[V]	690			690				690	
Rated impulse withstand voltage Uimp	[kV]	8			8				8	
Rated insulation voltage Ui	[V]	800			800				800	
Test voltage at industial frequency for 1 min.	[V]	3000			3000				3000	
Rated ultimate short-circuit breaking capacity Icu @ V		B	C	N	N	S	H	L	N	S
220-230V 50-60Hz	[kA]	25	40	50	65	85	100	120	50	85
380-400-415V 50-60Hz	[kA]	16	25	36	36	50	70	85	36	50
440V 50-60Hz	[kA]	10	15	22	30	45	55	75	25	40
500V 50-60Hz	[kA]	8	10	15	25	30	36	50	20	30
690V 50-60Hz	[kA]	3	4	6	6	7	8	10	5	8
Rated service short-circuit breaking capacity Ics @ V		B	C	N	N	S	H	L	N	S
220-230V 50-60Hz	[kA]	100%	75%	75%	100%	100%	100%	100%	75%	50%
380-400-415V 50-60Hz	[kA]	100%	100%	75%	100%	100%	100%	75% (70kA)	75%	50% (27kA)
440V 50-60Hz	[kA]	100%	75%	50%	100%	100%	100%	75%	75%	50%
500V 50-60Hz	[kA]	100%	75%	50%	100%	100%	100%	75%	75%	50%
690V 50-60Hz	[kA]	100%	75%	50%	100%	100%	100%	75%	75%	50%
Rated short-circuit making capacity Icm @ V (peak value)		B	C	N	N	S	H	L	N	S
220-230V 50-60Hz	[kA]	52.5	84	105	143	187	220	264	105	187
380-400-415V 50-60Hz	[kA]	32	52.5	75.6	75.6	105	154	187	75,6	105
440V 50-60Hz	[kA]	17	30	46.2	63	94.5	121	165	52,5	84
500V 50-60Hz	[kA]	13.6	17	30	52.5	63	75.6	105	40	63
690V 50-60Hz	[kA]	4.3	5.9	9.2	9.2	11.9	13.6	17	7.7	13.6
Trip units		TMD			TMD - MA - ELT				MA - TMD	
Versions		F			F-P				F-P	
Utilization category (IEC 60947-2)		A			A				A	

T4					T5					T6					T7				
250/320					400/630					630/800/1000					800/1000/1250/1600				
3/4					3/4					3/4					3/4				
690					690					690					690				
8					8					8					8				
1000					1000					1000					1000				
3500					3500					3500					3500				
N	S	H	L	V	N	S	H	L	V	N	S	H	L	V**	S	H	L	V*	X***
70	85	100	200	200	70	85	100	200	200	70	85	100	200	200	85	100	200	200	170
36	50	70	120	200	36	50	70	120	200	36	50	70	100	150	50	70	120	150	170
30	40	65	100	180	30	40	65	100	180	30	45	50	80	120	50	65	100	130	170
25	30	50	85	150	25	30	50	85	150	25	35	50	65	85	50	50	85	100	75
20	25	40	70	80	20	25	40	70	80	20	22	25	30	40	30	42	50	60	75
N	S	H	L	V	N	S	H	L	V	N	S	H	L	V**	S	H	L	V*	X***
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	75%	100%	100%	100%	100%	100%	100%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	75%	80% (120kA)	100%	100%	100%	100%	100%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	75%	83% (100kA)	100%	100%	100%	100%	100%
100%	100%	100%	100%	100%	100%	100%	100%	100% 75% 630A	100% 50% 630A	100%	100%	100%	75%	76% (65kA)	100%	100%	75%	100%	100%
100%	100%	100%	100%	100%	100%	100%	100% 75% 630A	100% 50% 630A	100% 50% 630A	75%	75%	75%	75%	75%	100%	75%	75%	75%	100%
N	S	H	L	V	N	S	H	L	V	N	S	H	L	V**	S	H	L	V*	X***
154	187	220	440	660	154	187	220	440	660	154	187	220	440	440	187	220	440	440	374
75.6	105	154	264	440	75.6	105	154	264	440	75.6	105	154	220	330	105	154	264	330	374
63	84	143	220	396	63	84	143	220	396	63	73.5	105	176	264	105	143	220	286	374
52.5	63	105	187	330	52.5	63	105	187	330	52.5	46	105	143	187	84	105	187	220	165
40	52.5	84	154	176	40	52.5	84	154	176	40	46	52.5	63	84	63	88.2	105	132	165
MA - TMD - TMA - ELT					TMA - ELT					TMA - ELT					ELT				
F-P-W					F-P-W					F-W					F-W				
A					B Icw = 5kA (400A) A (630A)					B Icw = 7.6kA (630A) B Icw =10kA (800A) A (1000A)					B Icw = 20kA (S,H,L) B Icw = 15kA (V)				

** Available for 630A e 800A

* Not available for 1600A

*** Available for 800A

Table 5: SACE Tmax XT circuit-breakers for applications up to 690V

		XT1					
Rated uninterrupted current Iu	[A]	160					
Poles	[Nr.]	3/4					
Rated service voltage Ue (AC) 50-60 Hz	[V]	690					
Rated impulse withstand voltage Uimp	[kV]	8					
Rated insulation voltage Ui	[V]	800					
Rated ultimate short-circuit breaking capacity Icu @ V		B	C	N	S	H	N
220-230V 50-60Hz	[kA]	25	40	65	85	100	65
380V 50-60Hz	[kA]	18	25	36	50	70	36
415V 50-60Hz	[kA]	18	25	36	50	70	36
440V 50-60Hz	[kA]	15	25	36	50	65	36
500V 50-60Hz	[kA]	8	18	30	36	50	30
525V 50-60Hz	[kA]	6	8	22	35	35	20
690V 50-60Hz	[kA]	3	4	6	8	10	10
Rated service short-circuit breaking capacity Ics @ V		B	C	N	S	H	N
220-230V 50-60Hz	[kA]	100%	100%	75%(50)	75%	75%	100%
380V 50-60Hz	[kA]	100%	100%	100%	100%	75%	100%
415V 50-60Hz	[kA]	100%	100%	100%	75%	50%(37,5)	100%
440V 50-60Hz	[kA]	75%	50%	50%	50%	50%	100%
500V 50-60Hz	[kA]	100%	50%	50%	50%	50%	100%
525V 50-60Hz	[kA]	100%	100%	50%	50%	50%	100%
690V 50-60Hz	[kA]	100%	100%	75%	50%	50%	100%
Rated short-circuit making capacity Icm @ V (peak value)		B	C	N	S	H	N
220-230V 50-60Hz	[kA]	52.5	84	143	187	220	143
380V 50-60Hz	[kA]	36	52.5	75.6	105	154	75.6
415V 50-60Hz	[kA]	36	52.5	75.6	105	154	75.6
440V 50-60Hz	[kA]	30	52.5	75.6	105	143	75.6
500V 50-60Hz	[kA]	13.6	36	63	75,6	105	63
525V 50-60Hz	[kA]	9	13.6	46.2	73.5	73.5	40
690V 50-60Hz	[kA]	4.5	6	9	13.6	17	17
Trip units		TMD					
Versions		F-P					
Utilization category (IEC 60947-2)		A					

XT2				XT3		XT4				
160				250		160/250				
3/4				3/4		3/4				
690				690		690				
8				8		8				
1000				800		1000				
S	H	L	V	N	S	N	S	H	L	V
85	100	150	200	50	85	65	85	100	150	200
50	70	120	200	36	50	36	50	70	120	150
50	70	120	150	36	50	36	50	70	120	150
50	65	100	150	25	40	36	50	65	100	150
36	50	60	70	20	30	30	36	50	60	70
25	30	36	50	13	20	20	25	45	50	50
12	15	18	20	5	8	10	12	15	20	25
S	H	L	V	N	S	N	S	H	L	V
100%	100%	100%	100%	75%	50%	100%	100%	100%	100%	100%
100%	100%	100%	100%	75%	50% (27)	100%	100%	100%	100%	100%
100%	100%	100%	100%	75%	50% (27)	100%	100%	100%	100%	100%
100%	100%	100%	100%	75%	50%	100%	100%	100%	100%	100%
100%	100%	100%	100%	75%	50%	100%	100%	100%	100%	100%
100%	100%	100%	100%	75%	50%	100%	100%	100%	100%	100%
100%	100%	100%	75%	75%	50%	100%	100%	100%	100%	75% (20)
S	H	L	V	N	S	N	S	H	L	V
187	220	330	440	105	187	143	187	220	330	440
105	154	264	440	75.6	105	75.6	105	154	264	330
105	154	264	330	75.6	105	75.6	105	154	264	330
105	143	220	330	52.5	84	75.6	105	143	220	330
75.6	105	132	154	40	63	63	75.6	105	132	154
52.5	63	75.6	105	26	40	40	52.5	63	75.6	110
24	30	36	40	8.5	13.5	17	24	30	40	52.5
TMD - TMA - ELT				TMD		TMD - TMA - ELT				
F-P-W				F-P		F-P-W				
A				A		A				

Table 6: Emax circuit-breakers for applications up to 690V

		X1			E1	
Rated service voltage Ue (AC) 50-60 Hz	[V]	690			690	
Rated impulse withstand voltage Uimp	[kV]	12			12	
Rated insulation voltage Ui	[V]	1000			1000	
Poles	[Nr.]	3/4			3/4	
Rated uninterrupted current Iu		B	N	L	B	N
	[A]	630	630	630	800	800
	[A]	800	800	800	1000	1000
	[A]	1000	1000	1000	1250	1250
	[A]	1250	1250	1250	1600	1600
	[A]	1600	1600			
	[A]					
	[A]					
Rated ultimate short-circuit breaking capacity Icu @ V		B	N	L	B	N
220-230-380-400-415V 50-60Hz	[kA]	42	65	150	42	50
440V 50-60Hz	[kA]	42	65	130	42	50
500V 50-60Hz	[kA]	42	55	100	42	50
690V 50-60Hz	[kA]	42	55	60	42	50
Rated service short-circuit breaking capacity Ics @ V	[kA]	B	N	L	B	N
220-230-380-400-415V 50-60Hz	[kA]	42	50	150	42	50
440V 50-60Hz	[kA]	42	50	130	42	50
500V 50-60Hz	[kA]	42	42	100	42	50
690V 50-60Hz	[kA]	42	42	45	42	50
Rated short-circuit making capacity Icm @ V (peak value)		B	N	L	B	N
220-230-380-400-415V 50-60Hz	[kA]	88.2	143	330	88.2	105
440V 50-60Hz	[kA]	88.2	143	286	88.2	105
500V 50-60Hz	[kA]	88.2	105	220	88.2	105
690V 50-60Hz	[kA]	88.2	105	132	88.2	105
Rated short-time withstand current (1s) Icw [kA]	[kA]	42	42	15	42	50
Utilisation category (IEC 60947-2)		B	B	A	B	B
Versions		F-W		F-W	F-W	

E2				E3					E4			E6	
690				690					690			690	
12				12					12			12	
1000				1000					1000			1000	
3/4				3/4					3/4			3/4	
B	N	S	L	N	S	H	V	L	S	H	V	H	V
1600	1000	800	1250	2500	1000	800	800	2000	4000	3200	3200	4000	3200
2000	1250	1000	1600	3200	1250	1000	1250	2500		4000	4000	5000	4000
	1600	1250			1600	1250	1600					6300	5000
	2000	1600			2000	1600	2000						6300
		2000			2500	2000	2500						
					3200	2500	3200						
						3200							
B	N	S	L	N	S	H	V	L	S	H	V	H	V
42	65	85	130	65	75	100	130	130	75	100	150	100	150
42	65	85	110	65	75	100	130	110	75	100	150	100	150
42	55	65	85	65	75	100	100	85	75	100	130	100	130
42	55	65	85	65	75	85	100	85	75	85	100	100	100
B	N	S	L	N	S	H	V	L	S	H	V	H	V
42	65	85	130	65	75	85	100	130	75	100	150	100	125
42	65	85	110	65	75	85	100	110	75	100	150	100	125
42	55	65	65	65	75	85	85	65	75	100	130	100	100
42	55	65	65	65	75	85	85	65	75	85	100	100	100
B	N	S	L	N	S	H	V	L	S	H	V	H	V
88.2	143	187	286	143	165	220	286	286	165	220	330	220	330
88.2	143	187	242	143	165	220	286	242	165	220	330	220	330
88.2	121	143	187	143	165	2220	220	187	165	220	286	220	286
88.2	121	143	187	143	165	187	220	187	165	187	220	220	220
42	55	65	10	65	75	75	85	15	75	100	100	100	100
B	B	B	A	B	B	B	B	A	B	B	B	B	B
F-W				F-W					F-W			F-W	

Table 7: Emax switch-disconnectors for direct current applications up to 1000V

		E1../E MS		E2../E MS		E3../E MS		E4../E MS	
Rated impulse withstand voltage Uimp	[kV]	12		12		12		12	
Rated insulation voltage Ui	[V]	1000		1250		1250		1250	
Rated uninterrupted current Iu		B		N		H		H	
	[A]	1250		2000		3200		4000	
Rated service voltage Ue (DC)	[V]	750	1000	750	1000	750	1000	750	1000
Poles		3 - 4	4	3 - 4	4	3 - 4	4	3 - 4	4
Rated short-time withstand current (1s) Icw [kA]	[kA]	20 - 25	20	25 - 40	25	40 - 50	40	65	65
Rated short-circuit making capacity Icm @ Vac (peak value)	[kA]	20 - 25	20	25 - 40	25	40 - 50	40	65	65
Versions		F-W		F-W		F-W		F-W	

The breaking capacity Icu, by means of external protection relay, with 500ms of maximum trip time delay, is equal to the value of Icw (1s).

Table 8: Emax circuit-breakers for direct current applications up to 1000V

		E2		E3		E4		E6
Rated service voltage Ue (DC)	[V]	1000		1000		1000		1000
Rated impulse withstand voltage Uimp	[kV]	12		12		12		12
Rated insulation voltage Ui	[V]	1000		1000		1000		1000
Poles	[Nr.]	3/4		3/4		3/4		3/4
Rated uninterrupted current Iu		B	N	N	H	S	H	H
	[A]	800	1600	800	1600	1600	3200	3200
	[A]	1000		1000	2000	2000		4000
	[A]	1250		1250	2500	2500		5000
	[A]	1600		1600		3200		
	[A]			2000				
	[A]			2500				
Rated short-time withstand current (0.5s) Icw [kA]	[kA]	B	N	N	H	S	H	H
500V DC (III)		35	50	60	65	75	100	100
750V DC (III)		25	25	40	40	65	65	65
750V DC (IV)		25	40	50	50	65	65	65
1000V DC (IV)		25	25	35	40	50	65	65
Utilization category (IEC 60947-2)		B	B	B	B	B	B	B
Versions		F-W		F-W		F-W		F-W

The Icu values could change with reference to the rated voltage and the DC network type (isolated from earth, one polarity connected to earth, middle point connected to earth). In order to know the Icu value for different condition please referred to the dedicated technical catalogue.

8.2 Switch-disconnectors and switch-disconnectors with fuses

This product family consists of a complete range of switch-disconnectors and switch-disconnectors with fuses; they are approved by the main above mentioned Registers of Shipping, although the switch-disconnectors with fuses are rather used in the industrial and tertiary sector than in the naval field.
All the series of apparatus are characterized by remarkable technical performances and by particular constructional characteristics which ensure the maximum operational safety.
They have a wide range of accessories at their disposal (mechanical interlocks, motor operators, conversion kits, etc.), as well as adjustable shafts and metallic and plastic handles.
For detailed information about the availability of the approval referred to each single apparatus please contact ABB SACE. Tables 9-10-11-12-13 in the following pages summarize the main electrical parameters of the switch-disconnectors and switch-disconnectors with fuses.

8.2.1 Switch-disconnectors OT and OETL series

The power switch-disconnectors without fuse holders belonging to OT family are available in the versions from 16A to 2500A and thanks to those ones belonging to OETL family it is possible to cover applications up to 3150A.
These devices offer high performances with reduced overall dimensions.
User-friendly and flexible, they are suitable for different applications such as, for example, in motor control centers, in switchboards and as main switches in various equipment and machines; moreover, through the combined switch-disconnectors or switch-disconnectors with double position, they are suitable for those applications where it is necessary to control the change-over, by-pass or reversing.

They are mountable on DIN rails, base plates or on doors, both by snap-on and screw fitting. Besides they offer the possibility of snap-on mounting for the accessories.

OT family

Table 9: Switch-disconnectors OT16 – OT160

			OT16	OT25
Rated insulation voltage and rated operational voltage with utilization category AC20/DC20. Pollution degree 3		[V]	750	750
Dielectric strength 50 Hz 1min.		[V]	6	6
Rated impulse withstand voltage		[V]	8	8
Rated thermal current and rated operational current with utilization category AC20/DC20 Minimum copper conductor cross section	T ambient of 40°C in open air	[A]	25	32
	T ambient of 40°C in enclosure	[A]	25	32
	T ambient of 60°C in enclosure	[A]	20	25
	Scu	[mm²]	4	6
Rated operational current, AC-23A	up to 415V	[A]	16	20
	440V	[A]	16	20
	500V	[A]	16	20
	690V	[A]	10	11
With reference to the rated conditional short-circuit current Ik (r.m.s.) to the voltage and to the max fuse size and type, the maximum allowed cut-off current Ip is given	Ik (r.m.s.) 50kA < 415V	[A]	6.5	6.5
	Max OFA fuse size : gG/aM	[A]	40/32	40/32
	Ik (r.m.s.) 50kA < 500V	[A]	---	---
	Max OFA fuse size : gG/aM	[A]	---	---
	Ik (r.m.s.) 10kA < 690V	[A]	---	---
	Max OFA fuse size : gG/aM	[A]	---	---
	Ik (r.m.s.) 50kA < 690V	[A]	4	4
	Max OFA fuse size : gG/aM	[A]	25/16	25/16
Rated short-time withstand current Icw x1s (rms)	690V	[A]	0.5	0.5
Rated short circuit making capacity Icm (peak)	690V / 500V	[A]	0.705	0.705

Table 10: Switch-disconnectors OT200E – OT800

			OT200E	OT250
Rated insulation voltage and rated operational voltage with utilization category AC20/DC20. Pollution degree 3		[V]	1000	1000
Dielectric strength 50 Hz 1min.		[V]	10	10
Rated impulse withstand voltage		[V]	12	12
Rated thermal current and rated operational current with utilization category AC20/DC20 Minimum copper conductor cross section	T ambient of 40°C in open air	[A]	200	250
	T ambient of 40°C in enclosure	[A]	200	250
	Scu	[mm²]	95	120
Rated operational current, AC-23A	<500V	[A]	200	250
	690V	[A]	200	250
	1000V	[A]	135	135
With reference to the rated conditional short-circuit current Ik (r.m.s.) to the voltage and to the max fuse size and type, the maximum allowed cut-off current Ip is given	Ik (r.m.s.) 100kA 500V	[A]	40.5	40.5
	Max OFA fuse size : gG/aM	[A]	315/315	315/315
	Ik (r.m.s.) 80kA 690V	[A]	40.5	40.5
	Max OFA fuse size : gG/aM	[A]	355/315	355/315
Rated short-time withstand current Icw x1s (rms)	690V	[A]	8	8
Rated short circuit making capacity Icm (peak)	690V	[A]	30	30

OT32	OT45	OT63	OT100	OT125	OT160
750	750	750	750	750	750
6	6	6	6	6	10
8	8	8	8	8	12
40	63	80	115	125	200
40	63	80	115	125	160
32	50	63	80	100	125
10	16	25	35	50	70
23	45	75	80	90	135
23	45	65	65	78	125
23	45	58	60	70	125
12	20	20	40	50	80
6.5	13	13	16.5	16.5	---
40/32	100/80	100/80	125/125	125/125	---
---	17	17	---	---	30
---	100/80	100/80	---	---	200/250
---	---	---	8.2	8.2	---
---	---	---	125/100	125/100	---
4	11	11	10	10	24
25/16	80/63	80/63	63/63	63/63	200/250
0.5	1	1.5	2.5	2.5	4
0.705	1.4	2.1	3.6	3.6	12

OT315	OT400	OT630	OT800
1000	1000	1000	1000
10	10	10	10
12	12	12	12
315	400	630	800
315	400	630	800
185	185	2x185	2x240
315	400	630	800
315	400	630	800
200	200	400	400
61.5	61.5	90	90
500/450	500/450	800/1000	800/1000
59	59	83.5	83.5
500/500	500/500	800/1000	800/1000
15	15	20	20
65	65	80	80

Table 11: Switch-disconnectors OT1000 – OETL3150

			OT1000	
			E	X
Rated insulation voltage and rated operational voltage with utilization category AC20/DC20. Pollution degree 3		[V]	1000	1000
Dielectric strength 50 Hz 1min.		[V]	10	10
Rated impulse withstand voltage		[V]	12	12
Rated thermal current and rated operational current with utilization category AC20/DC20 Minimum copper conductor cross section	T ambient of 40°C in open air	[A]	1000	1000
	T ambient of 40°C in enclosure	[A]	1000	1000
	T ambient of 60°C in enclosure	[A]	---	---
	Scu	[mm²]	2x300	2x300
Rated operational current, AC-23A	<500V	[A]	800	1000
	690V	[A]	650	1000
With reference to the rated conditional short-circuit current Ik (r.m.s.) to the voltage and to the max fuse size and type, the maximum allowed cut-off current Ip is given	Ik (r.m.s.) 50kA < 415V	[A]	---	100
	Max OFA fuse size : gG/aM	[A]	---	1250/1250
	Ik (r.m.s.) 50kA < 500V	[A]	---	106
	Max OFA fuse size : gG/aM	[A]	---	1250/1250
	Ik (r.m.s.) 50kA < 690V	[A]	---	---
	Max OFA fuse size : gG/aM	[A]	---	---
Rated short-time withstand current Icw x1s (rms)	690V	[A]	150	150
Rated short circuit making capacity Icm (peak)	415V	[A]	---	---
	500V	[A]	---	---
	690V	[A]	110(3p) 92(4p)	110(3p) 92(4p)

OT1250		OT1600		OT2000	OT2500	OETL1250M	OETL3150
E	X	E	X	---	---	---	---
1000	1000	1000	1000	1000	1000	1000	1000
10	10	10	10	10	10	8	8
12	12	12	12	12	12	8	8
1250	1250	1600	1600	2000	2500	1250	3150
1250	1250	1600	1600	---	---	1250	2600
---	---	---	---	---	---	1000	2300
2x400	2x400	2x500	2x500	3x500	4x500	2x(80x5)	3x(100x10)
1000	1250	1000	1250	---	---	---	---
650	1250	650	1250	---	---	800	---
---	100	---	100	---	---	105	140
---	1250/1250	---	1250/1250	---	---	---	---
---	106	---	106	---	---	105	140
---	1250/1250	---	1250/1250	---	---	---	---
---	---	---	---	---	---	105	105
---	---	---	---	---	---	---	---
150	150	150	150	55	55	50	80
---	---	---	---	---	---	105	176
---	---	---	---	---	---	105	140
110(3p) 92(4p)	110(3p) 92(4p)	110(3p) 92(4p)	110(3p) 92(4p)	176	176	105	105

8.2.2 Switch fuses OS

The switch-disconnectors with fuse holders type OS are available in the versions from 16A from 1250A. They are easy to install and offer great adaptability to different types of cubicle designs.

A wide selection of accessories and the availability of a motorized version (OSM) improve the usability of the switch fuses.
Moreover, 6 and 8-pole, change-over, by-pass and mechanically interlocked switch combinations can be built up by means of conversion kits.
The switch fuses are available for all types of fuse links, DIN, BS, NFC, UL, CSA. OS switch fuses ensure safe

OS family

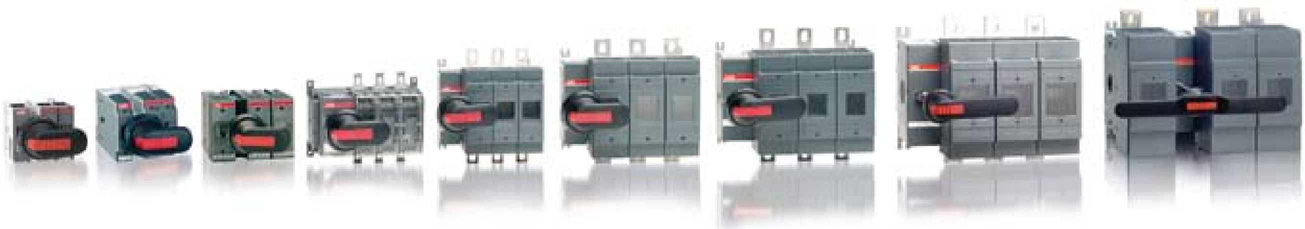


Table 12: Switch fuses OS16 – OS160

			OS Mini 16	OS Mini 20
Rated insulation voltage and rated operational voltage with utilization category AC20/DC20. Pollution degree 3		[V]	1000	1000
Dielectric strength 50 Hz 1min.		[V]	10	10
Rated impulse withstand voltage		[V]	12	12
Rated thermal current and rated operational current with utilization category AC20/DC20 Minimum copper conductor cross section	T ambient of 40°C in open air	[A]	16	20
	T ambient of 40°C in enclosure	[A]	16	20
	Scu	[mm²]	2.5	2.5
Rated operational current, AC-23A	up to 500V	[A]	16	20
	690V	[A]	16	20
With reference to the rated conditional short-circuit current Ik (r.m.s.) to the voltage and to the max fuse size and type, the maximum allowed cut-off current Ip is given	Ik (r.m.s.) 80kA < 415V	[A]	9	9
	Max. OFA_ fuse size gG / aM	[A]	---	---
	Ik (r.m.s.) 100kA < 500V	[A]	8	8
	Max. OFA_ fuse size gG / aM	[A]	---	---
	Ik (r.m.s.) 50kA < 690V	[A]	7	7
	Max. OFA_ fuse size gG / aM	[A]	---	---
	Ik (r.m.s.) 80kA < 690V	[A]	7.5	7.5
	Max. OFA_ fuse size gG / aM	[A]	---	---
Rated short-time withstand current Icw x1s (rms)	690V	[A]	1	1

Table 13: Switch fuses OS200 – OS1250

			OS200	OS250
Rated insulation voltage and rated operational voltage with utilization category AC20/DC20. Pollution degree 3		[V]	1000	1000
Dielectric strength 50 Hz 1min.		[V]	10	10
Rated impulse withstand voltage		[V]	12	12
Rated thermal current and rated operational current with utilization category AC20/DC20 Minimum copper conductor cross section	Tambient of 40°C in open air	[A]	200	250
	T ambient of 40°C in enclosure	[A]	200	250
	Scu	[mm²]	95	120
Rated operational current, AC-23A	up to 500V	[A]	200	250
	690V	[A]	200	250
With reference to the rated conditional short-circuit current Ik (r.m.s.) to the voltage and to the max fuse size and type, the maximum allowed cut-off current Ip is given	Ik (r.m.s.) 80kA 415V	[A]	35	40.5
	Max. OFA_ fuse size gG /aM	[A]	250/200	355/315
	Ik (r.m.s.) 100kA 500V	[A]	37.5	37.5
	Max. OFA_ fuse size gG /aM	[A]	250/200	250/250
	Ik (r.m.s.) 80kA 690V	[A]	25	32.5
	Max. OFA_ fuse size gG /aM	[A]	160/---	200/250
	Ik (r.m.s.) 50kA 415V	[A]	28	28
	Max. BS fuse size gG /gM	[A]	200/200M315	250/200M315
	Ik (r.m.s.) 80kA 690V	[A]	28	28
	Max. BS fuse size gG /gM	[A]	200/200M250	250/200M250
Rated short-time withstand current Icw x1s (rms)	690V	[A]	8	8

operation, and offer total protection of people and equipment eliminating the risks of electrical accidents.
Form this point of view, there are some important characteristics to be pointed out:

- the fuse covers cannot be opened while the switch fuse is in "ON" position and can be blocked in closed position;
- the double insulated external operating handle eliminates the risk of touching live parts outside the box;
- the handle indicates the position of the contacts with the maximum reliability under all circumstances.

OS Mini 25	OS Mini 32	OS Mini 35	OS Mini 40	OS32	OS50	OS63	OS100	OS125	OS160
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
10	10	10	10	10	10	10	10	10	10
12	12	12	12	12	12	12	12	12	12
25	32	35	40	32	50	63	100	125	160
25	32	35	40	332	50	63	100	125	160
4	6	10	10	6	10	16	50	50	70
25	32	35	40	32	50	63	100	125	160
25	32	35	40	32	50	63	100	125	160
9	9	9	9	17	17	17	23	29	29
---	---	---	---	100/100	---	100/100	125/160	125/160	125/160
8	8	8	8	17	17	17	22	22	22
---	---	---	---	100/100	---	100/100	125/160	125/160	125/160
7	7	7	7	13	13	13	16	16	16
---	---	---	---	100/80	---	100/80	100/125	100/125	100/125
7.5	7.5	7.5	7.5	12	12	12	18.5	18.5	18.5
---	---	---	---	63/63	---	63/63	100/125	100/125	100/125
1	1	1	2.5	2.5	2.5	2.5	5	5	5

OS315	OS400	OS630	OS800	OS1250
1000	1000	1000	1000	1000
10	10	10	10	10
12	12	12	12	12
315	400	630	800	1250
315	400	570	720	720
185	240	2x185	2x240	2x400
315	400	630	800	1250
315	400	630	800	1250
---	59	77	77	89
---	500/500	800/800	800/800	1250/1250
---	63.5	83	83	105
---	500/500	800/800	800/800	1250/'---
---	46	55	55	88
---	315/400	---/630	---/630	1000/1000
44	44	---	---	---
400/400M500	400/400M500	---	---	---
48	48	55	55	109
400/400M500	400/400M500	---	---	1250/'---
14	14	18	18	40

9 Overview of ABB offer

ABB leadership in the marine application field is based on the deep knowledge and on the great experience achieved in different applications as well as in technological innovation.

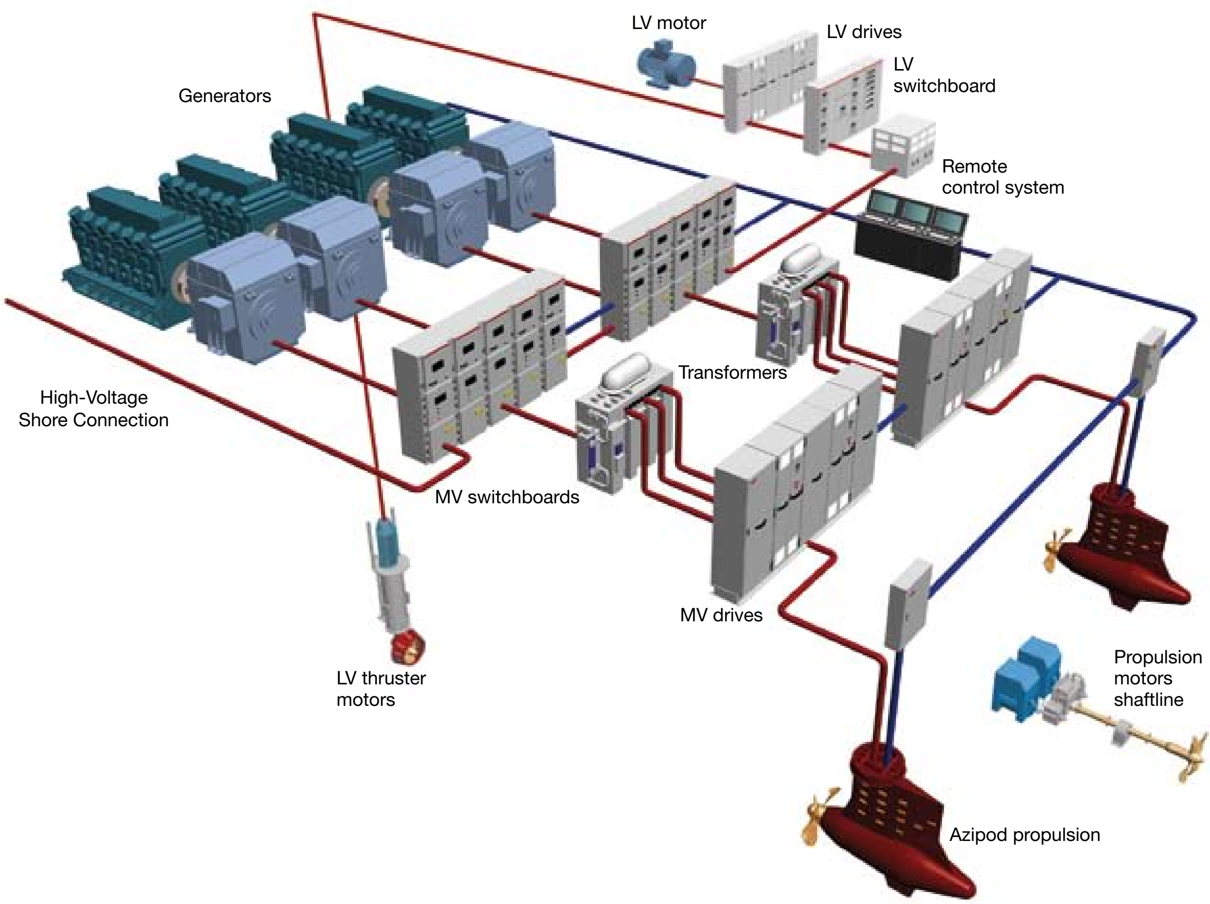
The systems and services made available for electric power systems, design and engineering products, installations, delivery and put into service with testing and after-sale support offer a wide range of solutions capable of fulfilling the market demands and to be suitable for all vessel typologies and marine applications.
ABB experience in this field contributes to the construction of ships more and more modern and innovative from the technological point of view, since it ensures high quality and competence in this field at global level.

Figure 26 shows the wide range of products that ABB offers to realize the complex electrical power distribution network on board. A brief description of the main characteristics of these products is given hereunder.

- Synchronous motors and generators

High efficiency and robust construction make ABB synchronous motors and generators ideal for the marine industry.
They are designed and built to be used in uninterrupted working cycles for very long periods and demanding environments.
High level mechanical design (see Figure 27) and construction techniques result in considerable savings over their lifetime both as for maintenance as well as service.
They are mainly used as propulsion motors and as main, auxiliary and shaft generators. They are suitable for coupling with turbines or diesel prime movers in a wide range of vessel types.
Medium voltage motors range up to 50MW and synchronous generators, available also for LV, from 11kW to 50MVA. A high degree of standardization enables shorter delivery times and greater versatility in all applications.
Reliability and high efficiency of these machines result

Figure 26: Typical lay-out of electrical equipment and components typically required for onboard machinery (schematization)



in considerable savings over their lifetime.
Precise torque control with ABB frequency converters makes zero-speed starting and even the most demanding conditions easy to handle in propulsion drives.

Figure 27: Medium voltage synchronous generator

- Induction motors

ABB medium voltage induction motors constitute a comprehensive range of asynchronous motors with power up to 18MW.
These reliable and high-efficiency motors are built around modular and cast iron platforms (see Figure 28). They can meet all the specific requirements of each installation and are designed for demanding conditions, including special and hazardous environments.
Induction motors are used in applications such as compressors, pumps, winches, fans, blowers, propulsion systems and ship thrusters.
They are accurately tested and are certified to the major classification Standards.

Figure 28: Induction motor

- Low voltage motors

ABB offers a comprehensive range of low voltage motors (Figure 29) capable of fulfilling the most different application requirements (propulsion-lifting-air circulation), also in special or hazardous environments.
Low voltage motors are available with aluminum, steel and cast iron structure and output power from 0.09 to 1200 kW.
ABB motors for marine applications are certified in compliance with the main international certification bodies. They are high-efficiency motors which fulfill all the energy saving requirements of fundamental importance in marine applications.
Low voltage motors are used for air or liquid treatments, therefore for fans, pumps, compressors, blowers, oil separators, or for motion transmission, and therefore propellers, steering devices, winches, lifters and applications for machinery rooms.

Figure 29: Range of low voltage three-phase asynchronous motors

- Dry-type transformers for marine applications

ABB range of transformers for marine applications is based on several design models and offers the ideal solution for all types of marine applications; moreover, customers can take advantage of the service support and of the wide experience in putting into service.
Generally, the transformers used for power distribution are two-winding AN-cooled transformers; they are mainly used to supply loads, such as pumps, fans, winches and other onboard systems.
These transformers, produced with RESIBLOC® technology (epoxy resin insulation of windings), together with vacuum cast coil dry-type ones (see Figure 30) are the typologies of machinery most commonly used for naval distribution.
These transformers feature very robust mechanical design; they are non-explosive and maintenance-free and are suitable to withstand vibrations or shocks on board ships.

The transformers produced with RESIBLOC® technology are ideal for the wide range of variable speed marine drives.
Marine propulsion transformers are usually three-winding transformers designed with ratings up to 30MVA or even more, often with special phase shifting to limit network harmonic distortions.
Air-to-water cooled transformers, often with special redundant fan-cooling systems, make possible high reliability and protection classes and a more compact construction.

Figure 30: Vacuum cast coil dry-type transformer

- Low voltage and medium voltage distribution

ABB medium and low voltage switchboards (see Figure 31) meet the requirements of every marine applications, ranging from power distribution on board to offshore platforms; they ensure the maximum safety and availability according to the highest standard thanks to solutions focused on air-insulated switchgear, arc-proof version, characterized by low total cost, high reliability, minimum maintenance and increased safety for personnel.

ABB low voltage switchgear MNS type is a reliable and safe solution, type-tested according to Stds. IEC 60439-1/IEC 61439 and arc-proof in compliance with IEC 61641. The design is flexible and compact and can be tailored according to specific needs, with ratings up 5200A at 690V; therefore it is suitable for generator switchgear, main switchgear and motor control center (MCC) both for marine as well as offshore applications, where the reliability and integrity of the distribution system are essential for power supply continuity.
Medium voltage switchboards are one of the most important link in the power distribution chain.
ABB UniGear ZS1 is an internal arc-proof switchboard (50kA for 0.5s) extremely safe and reliable and meets all installation requirements; for example, it is used as main switchgear and motor control center.
The single unit and the double-level solution make available a compact unit ensuring highly effective use of space.
This switchboard can be equipped with both vacuum as well as gas circuit-breakers (e.g. HD4 type) thus ensuring safety, reliability and high performances.
UniGear ZS1 switchgear has been tested according to the most demanding international Standards IEC and to the rules of the major Registers of Shipping.

Figure 31: ABB switchgear and controlgear

- Low voltage control products

This classification includes a very wide range of ABB products, which, thanks to their high performances and reliability, are often used for marine industry applications by switchboard, panel and console manufacturers.

These products are, as shown in Figure 32, the devices for motor switching and protection (contactors, thermal relays) or the devices for soft motor starting (softstarters); other products to be considered here are control and automation devices or process and safety control and monitoring systems, such as the arc guard system TVOC. Other components are also available for automation, operation, switching and control through the connection to local networks or fieldbuses (multiplicity of standard communication protocols).

Figure 32: Low voltage control devices

In the last few years a lot of users have underlined the question of safety in electrical assemblies with reference to one of the most severe and destructive electrophysical phenomenon: the electric arc.
Such phenomenon generates internal overpressures and results in local overheatings which may cause high mechanical and thermal stresses.
An active protection system to limit these effects consists in installing some devices which sense the light flux associated with the electric arc phenomenon.
ABB Arc Guard System for low and medium voltage applications is TVOC-2 (Figure 33). By means of optical sensors installed in the critical areas of the assembly, TVOC-2 sends a tripping signal to the controlled circuit-breaker.

Figure 33: Arc Guard System TVOC-2

- Low voltage miniature circuit-breakers (MCBs)

ABB offers a wide range of thermal-magnetic and residual current circuit-breakers (Figure 34), particularly suitable for circuit protection in marine applications.

In particular, the thermal-magnetic circuit-breakers of series S200 (6 kA), S200 M (10 kA), S200 P (25/15 kA) and S280 UC (10/6 kA) are type-approved by the main international Registers of Shipping (marine offshore application and industrial use).
For more demanding uses, where high breaking capacities are required for miniature circuit-breakers, ABB offers S800 S series with 50kA breaking capacity also approved in compliance with the Rules of the Registers of Shipping.
When only residual current protection is needed, ABB provides F200 series of residual current-circuit breakers; if, in addition, also protection against overcurrent is required, ABB offers DS202C M series of compact residual current circuit-breakers with overcurrent protection and 10kA breaking capacity.

In particular, DS202C M RCBOs series ensure the above mentioned protection functions on two poles; that is why they result particularly suitable for naval applications where the final distribution plant is typically two-phase and where they are particularly appreciated for the reduced dimensions.
DS202C M series is approved and certified by RINA.

Figure 34: Low voltage miniature circuit-breakers

- Low voltage and medium voltage drives for marine applications

As regards drives, ABB gives a series of products to be used for naval propulsion, for floating structures and for auxiliary applications, thus making more efficient and performing, from the point of view of performances and energy efficiency, the advantages offered by electric propulsion.
The Variable Speed Drive VSD interests both medium as well as low voltage.
The Direct Torque Control DTC is an interesting motor control system for AC drives; it allows accurate control of both the motor speed and torque, without the need of monitoring shaft position or speed.

ABB low voltage variable speed drives (see Figure 35) offer powerful and accurate performance for any application in a power range from 0.55kW to 5600kW.
They are used in main propulsion systems, rudder control, propellers, compressors, pumps, fans, winches and many other systems on board. ABB AC drives, with asynchronous or permanent magnet synchronous motors, combine environmental advantages with reduced operating costs.

These drives, tested and approved in compliance with the major classification societies, fulfill the requirements of the marine and offshore field, ensuring compact solutions and reliable and economical operation under all conditions.

Figure 35: Variable Speed Drives VSD

ABB medium voltage drives (see Figure 36) with their modularity, energy efficiency and superior performance, are the perfect solution for modern marine requirements in the power range up to 28000kW; they are used in advanced propulsion systems and auxiliary applications for all types of vessels and floating structures.
ABB multi-level topology makes possible the realization of an intrinsically less complex, more efficient and highly reliable medium voltage converter. Its compact construction results in small overall dimensions and lightweight design, offering greater flexibility to ship designers and making more space available for other purposes.
The modular platform is extremely versatile, providing a basis for marine certified standard single drives, transformerless solutions, multi-motor-drives and systems with built-in redundancy.

Figure 36: Enclosures for medium voltage drives

- Solutions for power quality

Capacitor banks for power factor correction and filters for reduction of harmonic distortion are the ideal solution to ensure good power quality in the supply systems on board.
These products not only guarantee compliance with the main power quality specifications required by the classification societies but also ensure high efficiency and trouble-free operation in both new installations and retrofit applications.
This can help to reduce running costs and cut CO_2 emissions.
Dynacomp series products (see Figure 37) are dynamic response compensators consisting of capacitors and reactors switched on the network by solid-state power circuit-breakers; they allow extremely fast and accurate power factor correction, thus optimizing the working conditions for cables, transformers and generators in installations with low power factor.
They also contribute to stabilizing the supply voltage when there are fast varying load demands.
They are applications used mainly with motors or converters.
PQF active filters eliminate the risk of equipment breakdown due to harmonic pollution (they are suitable for harmonic filtering up to order 50); moreover they allow reactive power compensation and load balancing, thus contributing to a reduction in the running costs.

Figure 37: Dynamic response compensators (Dynacomp) and PQF filters

- Frequency converters

PCS 6000 frequency converters are an economical and effective solution for converting the public grid frequency - usually 50Hz – to the appropriate frequency needed on board (typically 60Hz), thereby allowing ships to be connected to harbor grid (thus making possible for ships the shift from fossil fuel to electric power supply while at berth; this results in improved quality as regards pollution).

PCS6000 unit is particularly competitive in terms of installation time and space requirements (Figure 38). High efficiency and low maintenance ensure low operation costs. Other benefits are grid stabilization through voltage control, harmonic filtering and reactive power compensation.

Figure 38: PCS6000 frequency converters

Technical Application Papers

QT1
Low voltage selectivity with ABB circuit-breakers

QT2
MV/LV trasformer substations: theory and examples of short-circuit calculation

QT3
Distribution systems and protection against indirect contact and earth fault

QT4
ABB circuit-breakers inside LV switchboards

QT5
ABB circuit-breakers for direct current applications

QT6
Arc-proof low voltage switchgear and controlgear assemblies

QT7
Three-phase asynchronous motors Generalities and ABB proposals for the coordination of protective devices

QT8
Power factor correction and harmonic filtering in electrical plants

QT9
Bus communication with ABB circuit-breakers

QT10
Photovoltaic plants

QT11
Guidelines to the construction of a low-voltage assembly complying with the Standards IEC 61439 Part 1 and Part 2

QT12
Generalities on naval systems and installations on board

Contact us

ABB SACE
A division of ABB S.p.A.
L.V. Breakers
Via Baioni, 35
24123 Bergamo - Italy
Phone: +39 035 395 111
Fax: +39 035 395 306-433
www.abb.com

1SDC007111G0201 - 04/2011 - 5.000