Ships Electrical System

- Rene Borstlap, Hans ten Katen

Introduction

Electrical installations in ships cover every aspect of an independent installation, from power generation, switch-gear and distribution, to every type of consumer on board.
They include all types of automation and remote control, as well as internal and external communication, navigation and nautical equipment. The basic difference with shorebased electrical installations is that ships have to be self-supporting. Ships have to have either the personnel and necessary spares on board, or the required redundancy to be able to reach the next port in case of a failure of a single system or component.
Some applications of ships and offshore systems require this redundancy, not only in case of an electrical or mechanical failure, but also in case of other events such as fire or flooding of a space.
It is also essential to know the way in which an installation is operated in order to appraise the situation like:

- manned or unmanned engine room,
- computerized control systems,
- one man on the bridge (Class notation).

All these considerations influence the basic design, inclusive of the location of equipment and cable routing.
Application of high-tech control and communication equipment and high-powered semiconductor drives requires knowledge of electromagnetic compatibility (EMC) and the application of EMC measures.

This book is intended for those readers who have a basic knowledge of electrical installations and who would like to widen their knowledge of the principles of electricity as well as the specific requirements of electrical installations in ships.
Every paragraph will be accompanied by a short foreword or summary for ease of use.

The total of these summaries has been published as chapter 13 in the book SHIP KNOWLEDGE, a widely used encyclopaedia for people involved in the shipping world or shipbuilding industry.

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In the completion period of this book the originator, **René Borstlap**, sadly passed away.
He will be remembered for his effort and knowledge in creating this book.

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1. PREFACE

Ships, in one form or the other, have probably been around as long as there are people on this planet, but only since the end of the 19th century electricity got on board.

First in a simple form with some lights on DC power, later with more power to drive systems using alternating current (AC).
Nowadays we cannot be without electricity on ships as it has penetrated every system on board like pumps, control and automation, navigation equipment and sophisticated communication equipment.

Every year thousands of new-built ships, from very small to very large, are made around the world and thousands of repairs, modifications and revamps to existing ships take place. Practically all of these projects require electrical design and installation in one form or another.
This book has been written with the intent to help all those involved with decision-making, design, installation, testing and maintenance of electrical systems on board ships. This to gain better understanding of the subjects involved to make the correct choices from a number of options.

Shipbuilding is a global business and involves shipowners with their financiers, shipyards, equipment manufacturers and many related service and knowledge providers. All in all thousands of workers may be involved in a project and they could be all over the world. This requires a lot of planning and coordination and early agreement of the standards and goals for the project.

Chapter 3-basic design criteria- will address some of these issues together with the fundamental requirements to work on the electrical design.

We kick off with Chapter 1 -basics of electricity- for those who are not familiar with these or to revitalise knowledge for those who should know.

The other chapters are organised in such a way that they follow the development of the design of the electrical installation.

The following groups can be recognised:

Fundamental design
04 One-line diagram
05 Load balance
06 Mains voltage selection
07 Short-circuit calculation

All these chapters will normally be addressed by the shipowner and the shipyard with the aid of specialists.
The results will be part of the technical specification.
As we will explain in Chapter 3, Basic Design criteria, it may require some recalculations or iterations when the fundamental design progresses as one result may influence the other.

Basic equipment selection
08 Circuit breakers, contactors and selectivity
09 Type approved equipment
10 Equipment protection Ex/IP ratings

Chapter 8, Circuit breakers, contactors and selectivity, can only be addressed when the fundamental design is completed.
The other two chapters are determined by Class requirements as defined in the specification. These chapters will primarily be addressed by the lead electrical engineer.

Power sources
11 AC sources,
12 Emergency power
13 Switchboards
14 Synchronizing and parallel operation

The basic selections for chapters 11 and 12 will have been made by the shipyard following the fundamental design and be part of the specification.
Based on this information the electical engineers will work on the detail designs which will include items 13 and 14.

Main power consumers
15 Motors and starting devices
16 Transformers and converters
17 Electromagnetic compatibility

Again the basic selections for chapters 15 and 16 will have been made by the shipyard following the fundamental design and be part of the specification.
However, the electrical engineer will have to work on the detail design. When large converters are part of the electrical installation special attention should be given to chapter 17, Electromagnetic compatibilty to avoid disturbances in the installation.

Installation requirements
18 Electrical cabling

This gives information on the cable installation and connection and will be used by the electrical engineers to plan and organise the installation on board.

Primary systems
19 Automatic control systems
20 Alarm and monitoring systems
21 Navigation and nautical systems
22 Communication systems
23 Safety systems
24 Lighting systems

All these chapters will normally be applicable to any ship and the basic requirements will have been addressed in the specification. The electrical engineers will complete the systems in detail design.

Special systems
25 Dynamic positioning systems
26 Special systems

Chapter 25 will much of the time be applicable to special types of vessels like offshore cranes, pipelayers, diving support ships, etc. and the basics will be laid down in the specification.
Chapter 26 will address a number of special systems such as helicopter facilities, emergency propulsion systems and the like.
Chapter 27 will address testing.

Vessel completion and operation
27 Testing, commissioning and classification
28 Maintenance

Chapters 27 deals with the completion of the vessel and bringing it into operation.
These items are primarily for the owner to verify that the electrical installation has been built in accordance with the contract, to maintain the vessel in operation (28) and to have it surveyed by Class on a regular basis.

Additional information
29 Appendixes
30 Useful internet links
31 Index
32 Credits

These chapters provide quick access to useful information.

Marine projects
Each project will require a different focus on the content of this book.

New-building projects
For new-building projects all of the chapters 03 to 24 probably will be required.
A new to be built passengership would require special attention for chapter 23 Safety systems and chapter 24 Lighting systems.

Modifications to existing ships
Modifications to existing ships may require more electrical power by adding generator capacity due to for instance the addition of extra cargo-handling gear or a bow-thruster.
This would mean that the chapter 04 One line diagram, 05 Load balance and 07 Short-circuit calculation, has to be updated and reviewed.

Special ships
There are many special ships in the world fleet.
Some were custom-made, others are modified existing ships.
Special ships are for instance large offshore cranes, pipelaying vessels, stone- dump vessels, diving support vessels, survey vessels, dredgers, etc.

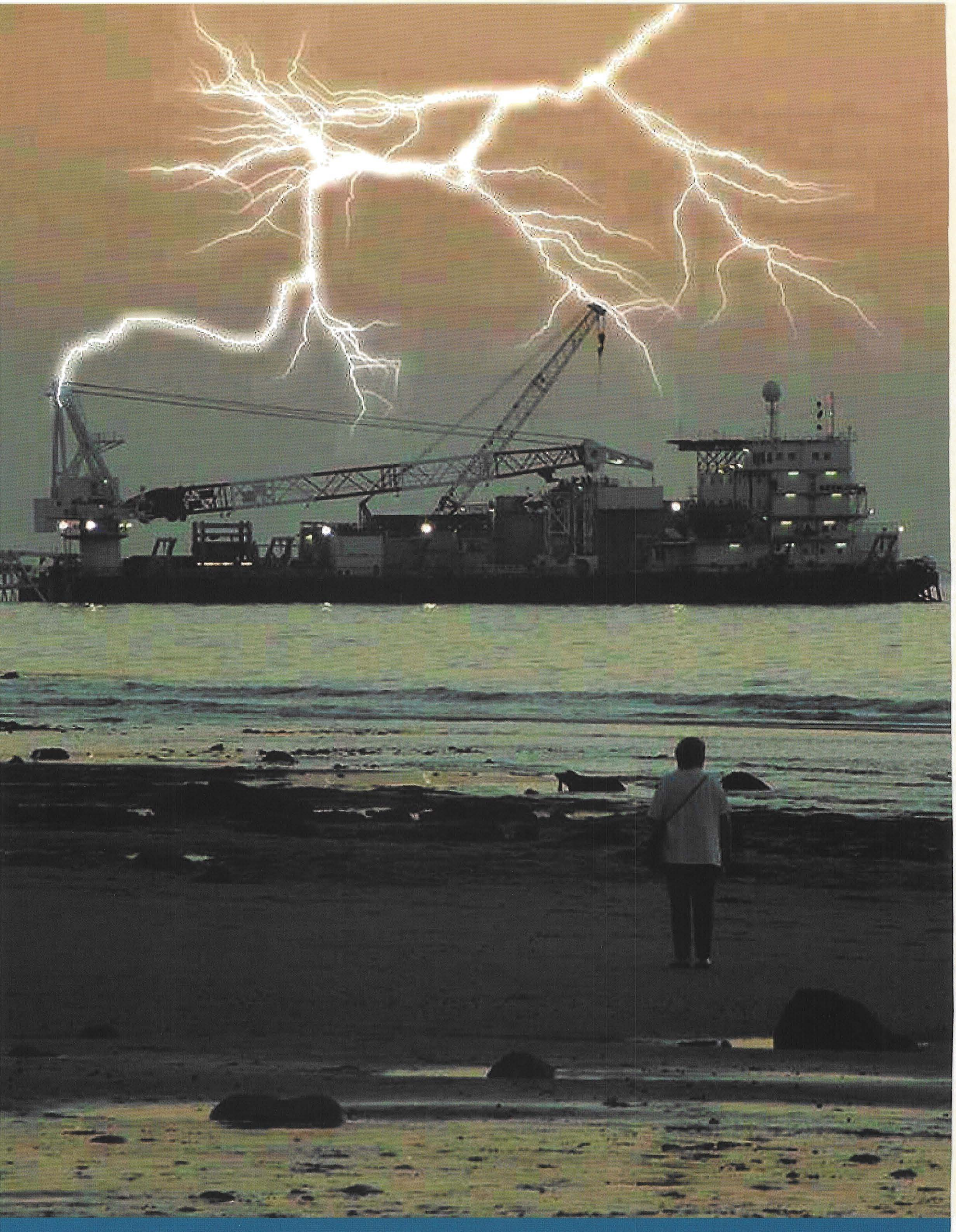
Most of these vessels are equipped with a dynamic positioning system and sophisticated electronic systems to aid operations. For these projects chapters 25 Dynamic positioning systems and 26 Special systems will particularly apply.

Offshore projects
Offshore projects such as drilling-rigs in any shape or size are not covered by this book. The Rules and Regulations differ quite substantially from those for ships.

Moreover many offshore systems are unique and dealing with these in this book would make it over-complicated.

Having said this it is also true that the first four groups of this book, dealing with the basics of the electrical design, may safely be used for offshore-related projects.

Instructions for use
This book is for guidance only and the user should always refer back to the contract and the technical specification and the class requirements for the legal binding rules and regulations.
For the Class requirements it should be clearly established that the latest information is available for which the web-page of the applicable class may be a good source.



2. BASICS OF ELECTRICITY

This section defines and explains the different types of **electricity** and their purpose.
A dictionary gives for "electricity" the following definition:
Fundamental property of matter, associated with atomic particles, whose movements, free or controlled, lead to the development of fields of force and the generation of kinetic or potential energy.

The definition looks complicated but electricity is a clean distribution medium to transport power.
It does not smell, it does not pollute if spoiled and is relatively safe.

Electricity is not a purpose but a medium for the distribution of power which can be done with relatively simple equipment. It can easily be converted into mechanical forces, light or heat. In very small portions it can be used to distribute information.

Any accumulation of one kind of electricity in excess of an equivalent of the opposite kind is called a charge and is measured in appropriate units:
- a charge fixed at one point or within a circumscribed field of force is static electricity;
- a charge which flows through a conductor is current electricity.

Static electricity is usually undesirable.
For example: Voltage created by the flow of liquid through the cargo hoses when loading a tanker could lead to a static high voltage and there after to a spark.

Current electricity comes in two basic types:
- Direct Current (DC)
- Alternating Current (AC).

1. Direct Current (DC)

DC power can be produced in various ways;
- a chemical process in batteries or fuel cells
- a dynamo converting mechanical energy
- an AC to DC converter.

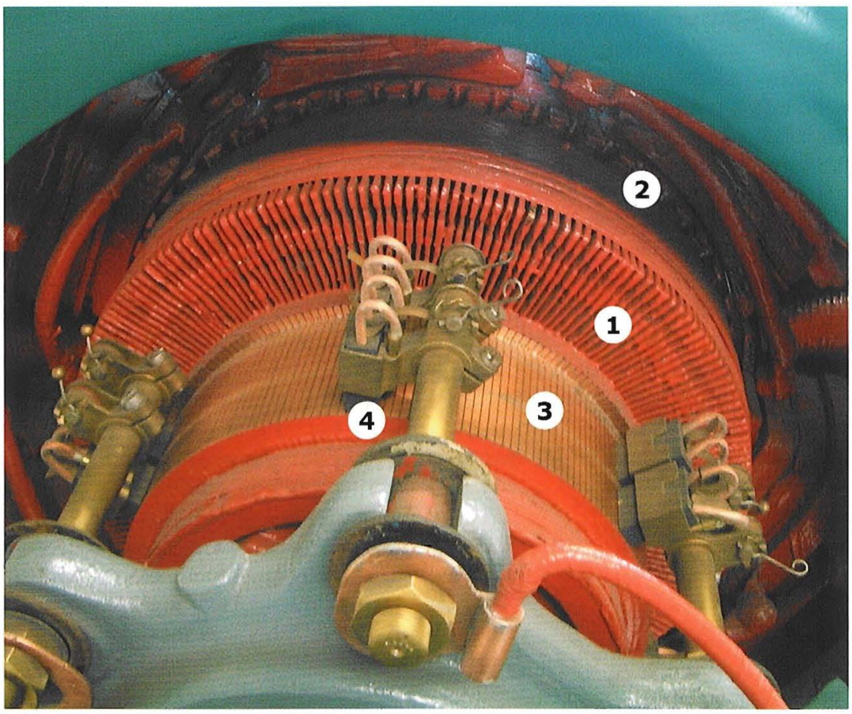
DC can be stored in an accumulator and later retrieved when required.
An example is a conventional diesel electric submarine, where the electric energy is produced by a diesel generator during operation at the surface or just underwater at snorkel depth and stored in batteries. The propeller is driven by an electromotor both at the surface or when submerged.

In modern ships, DC systems are limited to small installations or transitional sources of power.

Uninterrupted Power Supply units (UPS units) are a combination of a battery, storing the DC power, a battery charger and a converter to make AC from the DC power.
These units are often used for computer power supplies where an uncontrolled shutdown would lead to loss of information or crash of the program. Small units are also used in transitional lighting fixtures.

Battery box

A disadvantage of DC systems is that the generators with collectors and brushes, complex switch-gear and motors with collectors and brushes, all require a lot of maintenance and get more complicated when the size increases.
A further disadvantage of DC systems is that switching off DC circuits must be fast to reduce the effects of possible harmful arcs.

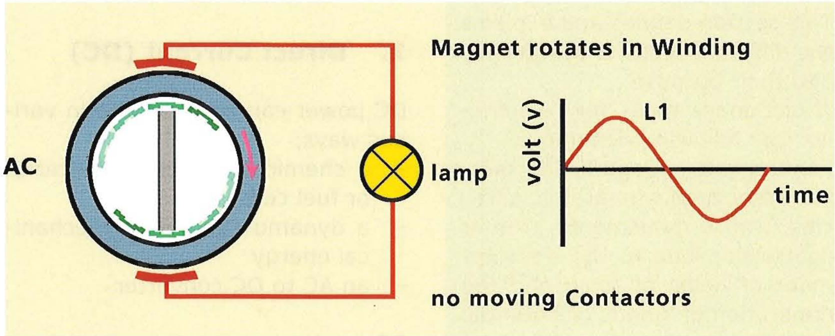


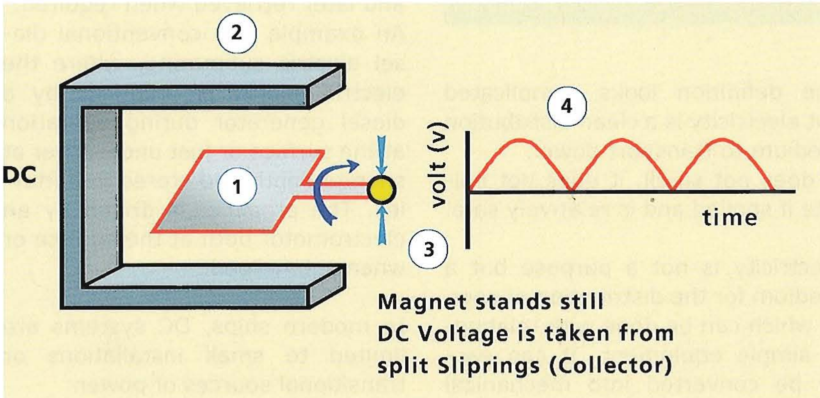
DC Dynamo or motor with the complicated brushes and collector
1. Rotating coil
2. Fixed coil
3. Collector
4. Brushes

2 Alternating Current

Alternating current **(AC)** allows simple switchgear as the current goes down to zero every cycle and the arc extinguishes by itself when the voltage is zero, provided the distance between the open contacts is large enough to prevent re-ignition in the next cycle.
Pictures of the extinguishing of an arc in a circuit breaker are shown in chapter 8, circuit breakers.

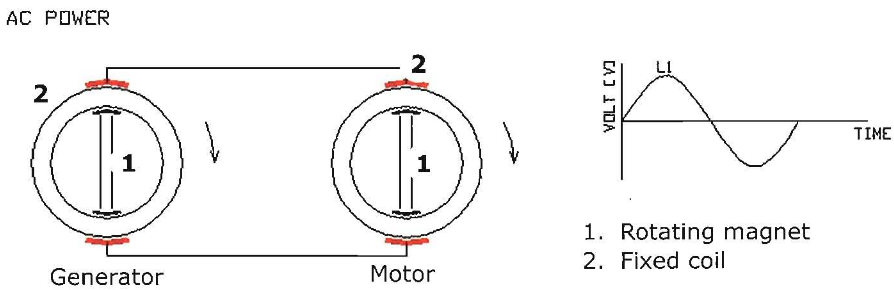
The diagram on this page, of the generator and motor, shows a single-phase alternating current system with the physical location of the magnets and rotating field.
AC is a very suitable transport medium of energy for lighting and control signals. The conversion of AC single-phase into rotating energy requires an auxiliary winding to define the direction. Thus, small electric motors need to have a starting or auxiliary winding. Large motors are seldom single-phase.

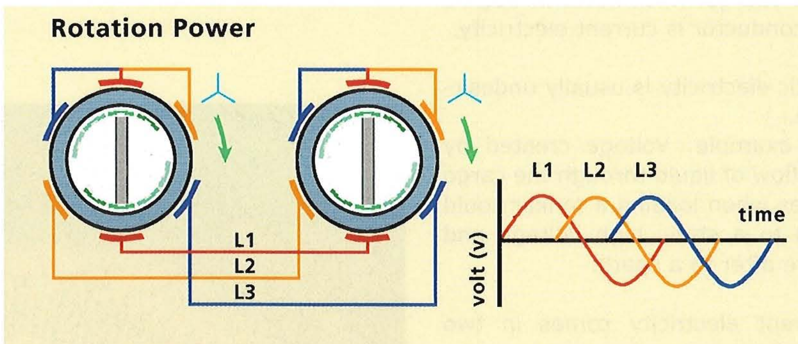




3 Rotating Current (RC)

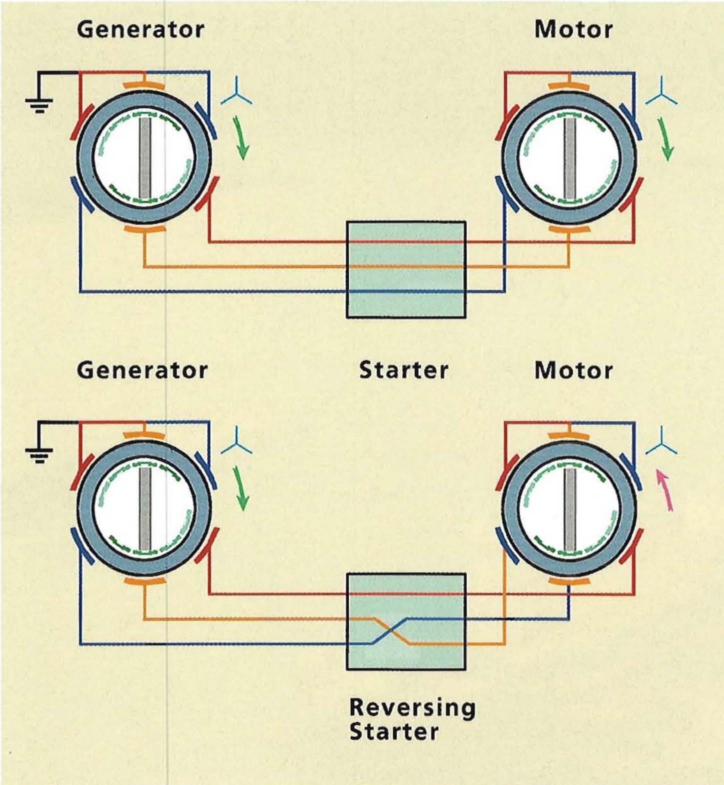
A logical evolution after the single-phase AC system is the three-phase AC or rotating current system.
The permanent magnet of the generator rotates within three windings, physically located 120 ° from each other, creating an AC voltage/current in sequence in each of these windings.
This rotating voltage/current makes it possible to power a simple AC squirrel cage motor (see chapter 15) having the same three windings similarly spaced.
Reversing the direction of rotation is done by changing two phases.
A further advantage of this three-phase system is that when the load is equally distributed over the phases, the sum of the three-phase current is zero. In that case the zero or star-point-conductor can be deleted or at least reduced in size. This effective distribution system is the most commonly used system on ships and shore installations.



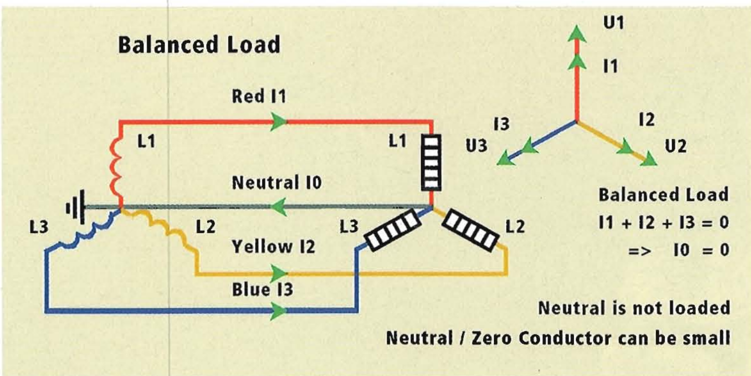


4 Ships' Electrical Systems

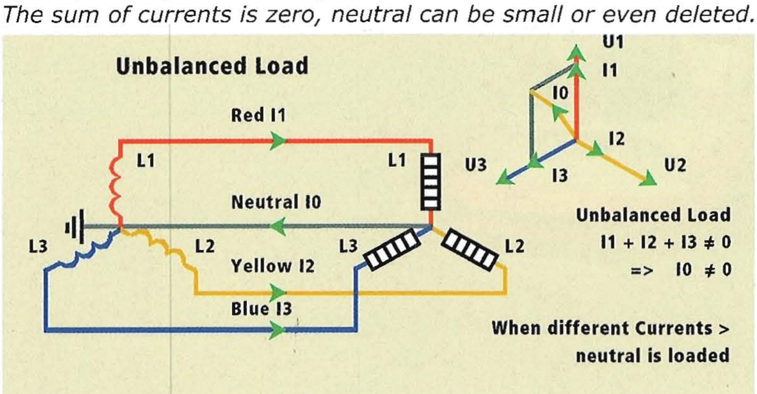
Electrical systems on board ships have become increasingly complicated over the years.
From relatively small systems with poor quality materials these systems have evolved to complicated large systems which require careful design, particularly with the choice of distribution system.
More on this can be found in Chapter 3 Section 8.



Reversing AC motor by changing two wires



Three-phase system with equal loads.
The sum of currents is zero, neutral can be small or even deleted.



Three-phase system with different loads.
The sum of currents is not zero, neutral is loaded.

4 Relation Voltage, Power and Current

Relation between voltage, power and current in DC and single-phase AC systems:

$$I = \frac{U}{R}$$

$$I = \frac{P}{U}$$

$$P = U \times I \times \cos\varphi$$

Relation between voltage, power and current in three-phase AC systems:

$$P = U \times I \times \sqrt{3} \times \cos\varphi$$

Cos φ is the power factor and is determined by the load.
For resistive loads such as lighting, heating and cooking equipment the cos φ is normally 1, unless electronic devices or capacitors are included.

The design power factor of generators is normally 0.8.
Power factors for motors vary with the load and size between 0.6 for a small motor or a low-loaded larger motor to 0.9 for a full-loaded large motor.

Voltage: U (V = Voltage)
Current: I (A = Ampère)
Power: P (W = Watt)
Resistance: R (Ω = Ohms)

In general in most countries the following voltages will be used:

- phase to neutral 230V
- 3-phase line voltage for 50Hz 400V
- 3-phase line voltage for 60Hz 440V

When the required electric power is known the current can be calculated from:

$$I = \frac{P}{U \times \sqrt{3} \times \cos\varphi \times \eta}$$

Depending on the value of the current, the cable and circuit breaker or fuse can be selected.

3. BASIC DESIGN CRITERIA

Establishing the **Basic Design Criteria** is the first step towards a successful project.
The content and clarity of these criteria will aid all those involved in the design, preparation, installation, testing, commissioning and delivery of the project. These criteria should be clearly identified if possible by the Owner when preparing the contract specification but otherwise by the shipyard, in consultation with the Owner.

1 Introduction

A ship's electrical system in a small ship can be simple, with a small power source like a battery and a solar panel, but more often it will involve a large number of sometimes complicated systems. Modern vessels may have close to a hundred different systems. These could range from power generation to large distribution systems and from large control systems to satellite communication with remote diagnostic systems via satellite for onboard computer systems.

Being involved in the electrical design for a ship can therefore be a challenge as you would be working with the owner and shipyard representatives, numerous suppliers, specialists, installation workers and commissioning engineers.

Establishing the basic design criteria is the essential first step before any other design activity can start. Going carefully through the basic design criteria at the start of a project can avoid costly changes later in the project.

2 Project management

Every project, small or big, should be managed throughout the project on five essential criteria which are to be anchored at the start of the project in a written project plan:

2.1 Quality

This basically is what to expect from the end result on delivery of the project. Don't make a Rolls Royce when you were asked for a Volkswagen. The basis for this is put down in the contract specification where there will also be the reference to the required class notation. When the contract specification is not clear on all points this should be addressed at the start of the project and rectified.

2.2 Contract price

This is the agreed price for the work under contract. Normally the shipyard will hold the main contract with the ship-owner and will subcontract parts to other parties. Any change of the contract specification may be subject to a price adjustment of the main contract.

2.3 Planning

This is the agreed time scheduled for the work under contract. Most of the time this will also include so-called milestones which are anchors for the project on which all parties can focus their own activities. Again any change to the planning may be subject to a price adjustment on the main contract.

2.4 Organisation

This is to show the relation between the parties involved and their level of authority to make decisions. The resulting organisation chart helps to identify the key players and their role in the project. Changes in the organisation chart during the project, especially on management levels, should be avoided as it would also drain knowledge from the project.

2.5 Information

This is the way all those involved communicate with each other. It may range from the distribution of e-mails with primary communicators (read and reply) and secondary communicators (read only) to the way the drawings and documents are coded.
The electrical design will be part of the bigger project structure and will follow the same management structure. It should always be realised that projects are made by people and that good communications are essential.

It may help to think SMART with all activities which means:
S - Specific i.e. not fuzzy or unclear
M - Measurable i.e. quantified in agreed standard units
A - Agreed i.e. all involved have discussed and will comply
R - Realistic i.e. do not ask for the impossible
T - Time dependent i.e. relate the subject to a beginning and end plan.

It is obvious that, when a ship is part of a series, only the first ship will require most effort in establishing the basic design criteria. A one-off design for vessels of some complexity will probably require more effort to prepare the basic design criteria.

3 Definitions

The basic design criteria should be made at the start of the project preferably by the owner when the ship's design is made. This is not always possible as the Owner may not have sufficient resources and expertise to do so. In that case ship owners will have specialized ship design bureaus involved. With a more standard ship the owner may go directly to a shipyard.

The basic design criteria will start with the owner's description of the purpose of the ship and its type of service based on expectations of the commercial market the vessel will work in.

The purpose of the vessel could be a general-cargo ship, a passenger-ship, an oil tanker, a support vessel, a drill ship, etc. with a description of its capacity and operational limits like unrestricted service, coastal service or inland waterways service.

Then the type of operation by the ship's staff will be defined like a manned or unmanned engine-room and the level of automation. At the same time the basic design for the bridge will be made with the level of integration.

The redundancy criteria will determine how much equipment may fail before the operation of the ship cannot be continued.

Options for redundancy levels are:
Class 1, standard single failure mode for all ships
Class 2, for DP (Dynamic Position) ships, single failure mode
Class 3, for DP (Dynamic Position) ships, extra precautions against fire and flooding

There is a logical order in which the design stages follow each other. When the one-line diagram and the load balance are available the main voltage can be selected after which the short-circuit calculation can be made.
The values from the shortcircuit calculation are the basis for the circuit breaker selection, selectivity and main switchboard design. With the fundamental design figures determined, the main electrical components can be ordered and production of for instance the main switchboard started.

When all the items of the basic design criteria have been addressed the result has to be submitted to the classification society for appraisal. The basic design criteria will be verified against the requested class notation of the ship.

For the electrical installation the submission of the basic design criteria will be supported by information such as:
- short-circuit calculations,
- selectivity diagrams,
- lists of primary materials,
- lay-out drawings

In case of a new or unusual design the submission must also include an operational description.

The various subjects of the basic design criteria are further explained below and further detailed in separate chapters.

It should be noted that when drafting the basic design criteria for a new-design vessel, one decision may influence another. When insufficient data are available the basic design will be based on assumed values but these values should be validated as soon as possible with detailed design. When more accurate data is available, earlier made calculations should be redone to verify if the outcomes are still within the set limits. Especially with the design of a "one-off" vessel more than one recalculation may be required before final results are obtained.

4 Type of service

Unrestricted service.
No help is to be expected from shore. The requirements for redundancy, battery time, and emergency generator capability are maximal as per SOLAS (Safety of Life at Sea) rules.
Restricted service.
Any ship especially designed for a certain location or short service, like ferries between The United Kingdom and the continent.
Coastal service
Ships with a "Coastal Service" notation are allowed to operate in a limited area, which in general is covered by a local communication station and some sort of service organization.
Again, the requirements for battery rating, communication equipment and redundancy are limited as assistance is available at short notice.
Inland Waterway
Operational area: rivers, canals, harbours, etc. These types of ships are limited in their operational area. Assistance by a fire brigade or tugs is more likely available. The requirements for fire pumps, emergency battery capacity rating or fuel tank contents for an emergency generator set, are less than the requirements for unrestricted service.

Tanker for unrestricted service, coastal service ship, inland waterway ship and a restricted service tug

5 Type of operation, engine room and bridge

5.1 Manned / unmanned engine room.

Manned engine-rooms are rare nowadays. Modern automation systems such as remote control and alarm and monitoring systems make it possible to operate most engine-rooms unmanned, at least part of the time.
In day-time engineers can execute planned maintenance and repairs or replacement of defective parts.
Because engine-rooms are usually warm, damp and noisy, an unmanned engine-room is advantageous.
For ships with simple electrical installations it may be feasible to design a manned engine-room and delete the expensive and complicated automation for remote control, alarm and monitoring systems, fire-detection systems, fuel leakage detection, etc.
Automatic starting of a stand-by generator set, automatic closing of a dead bus bar after failure of the running set and automatic starting of all essential electric consumers is a SOLAS requirement for all ships, including those with a manned engine-room.

5.2 Unmanned (UMS) notation.

On ships with notation UMS there is no need for a person permanent on watch in the engine-oom. These ships (UMS) are required to have additional warning systems such as:

- a fire-detection system
- automatic safety systems and remote-control systems for machinery
- automatic control systems for air compressors alarm and monitoring system
- automatic starting of stand-by pumps for propulsion auxiliaries such as:
    - seawater pumps
    - freshwater pumps
    - lubricating-oil pumps
    - fuel-oil pumps
    - propeller hydraulic pumps when not directly engine-driven

These systems have to be arranged in such a way that under normal operating conditions no manual intervention by engineers is required. Alarm and monitoring functions must be independent from safety systems.

Alarms that are not acknowledged in the space within a predetermined time must be automatically relayed to the engineer on duty via the engineer's call system. When the engineer on duty fails to act within a predetermined time the alarms will be relayed to other engineers.
When on patrol in the unmanned engine-room the duty engineer will activate the operator fitness system. This system consists of start/stop panels at the entrances to the engine-room and timer-reset panels in the engine-room. When the timer, normally set at 30 minutes, runs out and is not reset, an alarm will be given on the bridge and in the accommodation.

5.3 One-man-on-bridge

Periodic operation of a ship at sea (coastal, restricted or unrestricted service) under the supervision of a single watch-keeper on the bridge is becoming normal practice.
Similar to an engine-room with one man on watch, the basic requirements are as follows:
Alarm and warning systems associated with navigation equipment are centralised for efficient identification, both visible and audible.

The following alarms have to be provided :

- Closest Point of Approach (CPA) from the radars
- Shallow depth from the echo-sounder
- Waypoint approach if auto-track is installed
- Off-course alarm from a device independent from autopilot or gyro-compass
- Off-track alarm if auto track is provided
- Steering alarms
- Navigation-lights alarms
- Gyro-compass alarms
- Watch safety-system failure alarm
- Power-supply failure alarms of nautical distribution panels and, if dual, both for normal as well as back-up supply circuits. All alarms have to be fail-safe, so that failure of the device or power supply to the device triggers an alarm.

Failure of the power supply to the bridge-alarm system shall be monitored by the engine-room alarm and engine-room monitoring system.
A watch safety system to monitor the well-being and awareness of the watch-keeper is provided. The watch-keeper confirms his well-being by accepting a warning at a maximum 12 minutes interval.
When the watch-keeper fails to respond to accept the warning within 30 seconds or fails to accept a bridge alarm within 1 minute, a fixed installed system initiates a watch alarm to the captain's cabin and to the back-up navigator's cabin. The flag-states, however, do not accept a single watch-keeper on the bridge for passenger-ships, so this bridge always has to be manned by at least two officers when underway with passengers.

Engine control room

5.4 Integrated bridge

Other possibilities for the notation of navigation functions are **Integrated Bridge Navigation Systems.** This configuration requires, in addition to the one-man-on-bridge requirements:
- duplicated gyro-compasses,
- GPS system,
- route-planning capabilities,
- auto track capability
- electronic chart display (ECDIS).

6 Load balance

Location of essential electrical equipment as well as an estimate of how much electric power is required during operations, is the key-issue in the basic design.
A detailed General Arrangement plan is generally used to show the locations of the essential electric generators and large consumers.
A load balance estimates the total electric loads during the various conditions of operation.
This gives a figure for the required electric generator capacity for each condition. A detailed load balance for the total load in a specific location gives a design figure for the local switchboard and feeder cables.
The load balance must also determine the required load under emergency conditions. This figure can then be used to select a suitable sized emergency diesel generator with fuel tank or, in smaller systems, the emergency batteries with charger.

Wheelhouse console

A bird's eye view analysis of the location of main power consumers in a dredger might reveal that the best **location for the Main (HV) Switchboard** would be in the fore-ship close to large consumers such as big dredging pumps and the bow thruster(s). When the generators, which would normally be in the main engine-room in the aft ship, would be connected to this switchboard, the extra long cables would require special fault protection.
Differential protection is obligatory for machines with a rating above 1500 kVA, it is not very cost increasing.
Space is sufficiently available in the forward part of a dredger and weight is not critical there as the heavy main engines are located aft.

7 Maintenance criteria

- Self-supporting
- Shore-based maintenance

The above parametres affect the basic design, including:
- load balance,
- a one-line diagram,
- basic cable-routing requirements,
- basic location of essential electrical equipment,
- automation requirements.

The type of operation determines which spare parts have to be on board and the required level of knowledge of the ship's staff.
When operations cannot stop, as in the case of a pipe-laying vessel or a diving-support vessel, the ship has to be fully self-supporting with all the necessary spares on board.
In other cases, where a ship makes regular port calls, such as a ferry, most spares can be kept ashore where also knowledge can be easily hired in.

Symbols and phase colours: electrical drawings contain standardized symbols and sometimes use phase colours like those in this chapter. More details on this can be found in chapter 29.

8 Type of distribution system

8.1 Introduction on grounding, bonding and safety

Ever since AC generation and distribution has been introduced on a large scale on ships around 1950, there has been debate about the type of distribution system. The main focus with the type of distribution system is the treatment of the systems neutral with respect to grounding.

When selecting the grounding method the primary factor with the selection is the safety of people and secondly the safety of equipment. But loss of vital equipment can endanger a ship's safety and this in turn can reduce the safety of the crew.

The main cause of faults on board of a ship are ground faults which occur when live conductors come into contact with the "ground". The "ground" on a ship is basically the metal structure.

When an electrical system is "ungrounded" this means that the neutral of the power supply is insulated from the ship's metal structure. In an "ungrounded" system a ground fault will be detected but not removed automatically on the first fault. This allows a service to remain in operation, which can be a big advantage for vital services such as those for DP operations.

Although "ungrounded" there will still be a fault current flowing due to the capacitance of the cables and interference suppression capacitors fitted inside equipment. In large installations with many cables this fault current can be substantial.
To find a first ground fault in an "ungrounded" system can be some task as these are normally not self-revealing and would involve switching on and off circuits in distribution panels until the fault disappears. Only when a more sophisticated system is installed with core-balance current transformers in the distribution panels automated fault-finding can be obtained but this can be an expensive addition.

When an electrical system is "grounded" this means that the neutral of the power supply is connected to the ship's metal structure. In a "grounded" system a ground fault will in most cases be removed by the automatic opening of a circuit breaker or the melting of a fuse in the faulty circuit.
A live conductor can touch the metal case of a piece of equipment which then would become a hazard to the crew.
Bonding all metallic enclosures of electrical equipment to the ship's hull will ensure that these are on the same voltage level and will not cause electric shock. Furthermore the bonding of equipment will make paths available for fault currents to allow protection devices or detection devices to react. Bonding thus ads greatly to safety.
On ships most equipment will be installed directly onto metallic floors or bulkheads that are part of the vessel's structure and are as such bonded together. When this is not the case, like for instance with equipment on skids with anti-vibration mounts, additional grounding arrangements must be in place.
These arrangements must be suitably sized flexible ground wires connected to ground bosses welded to the ship's structure.

In an "ungrounded" system the voltage levels of the remaining phases will rise to 1.732($\sqrt{3}$) of the nominal value.
When the fault is not solved this higher voltage level will cause the insulation of wires and cables to deteriorate. That is why most classification bureaus have set a limit to the total time per year that ground faults may occur in a system.
When a wire is loose and re-strikes ground, which is likely to happen on a ship in service, this can cause transient over-voltages which may permanently damage equipment.
In general there is no single "best method" for grounding the electrical system. It is to the engineers to select a system that is best fitted in relation to safety, cost and operation.
The result could be to use a number of restricted grounded systems for specific services such as domestic, hotel and galley via dedicated transformers.

Essential services, such as DP and propulsion related, could then be supplied from insulated systems. By splitting systems over different supplies and applying redundancy these systems can be further optimized.

8.2 Primary methods of grounding on ships

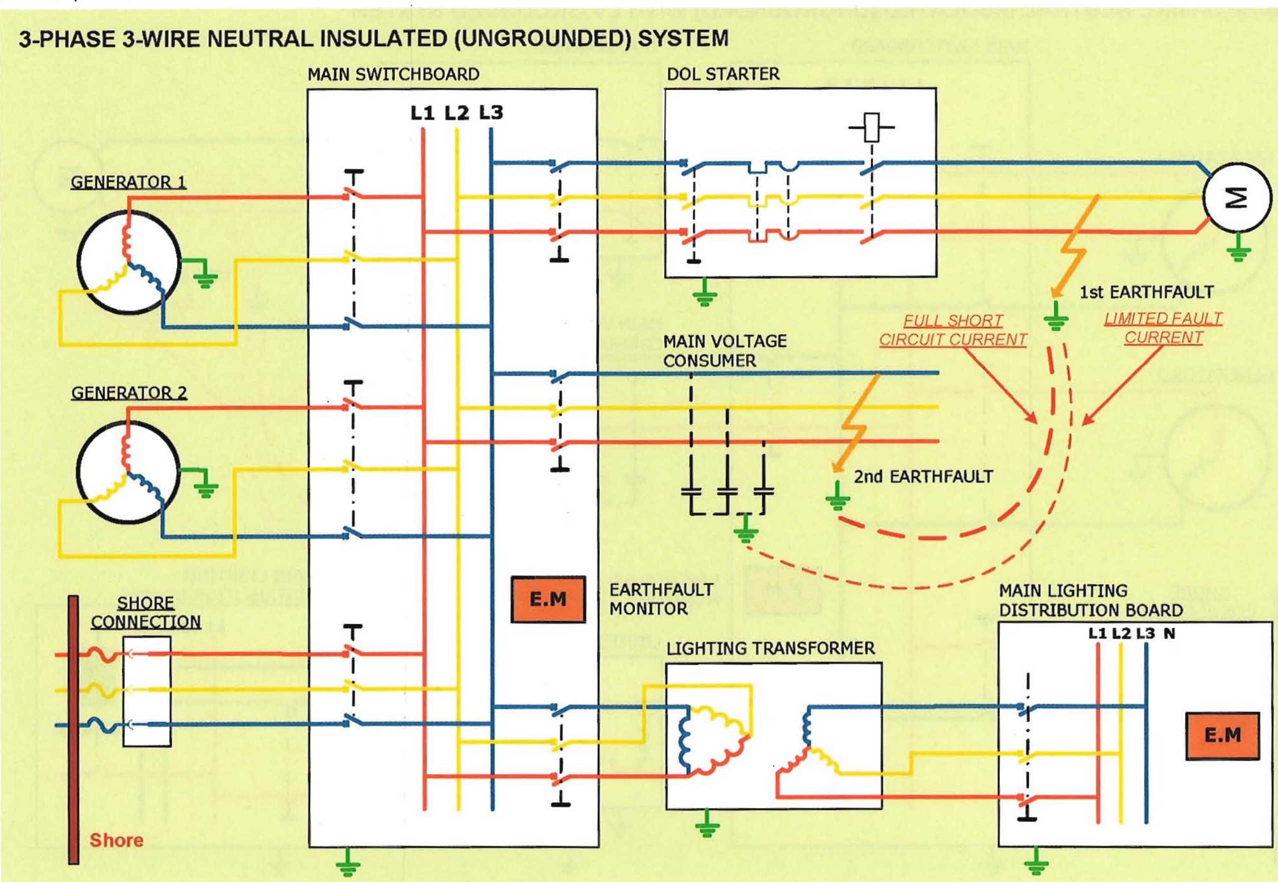
There are generally three methods of grounding which are used:
- Insulated neutral (ungrounded)
- Solid and low impedance
- High impedance

8.2.1 Insulated neutral (ungrounded) systems

The main advantages are:
- Continuity of service on a ground fault
- Ground fault currents can be kept low

The main disadvantages are:
- High level of insulation may be necessary.
- High transient over-voltages may occur
- Grounded circuit detection may be difficult

In the latest edition of **IEC 60092-502 TANKERS** both insulated and earthed distribution systems are permitted, however, systems with a hull return are not permitted. Return via the ship's construction is only acceptable in limited systems, such as diesel-engine battery start systems, intrinsically safe systems and impressed-current cathodic protection systems, outside any hazardous area.



Most main electrical power systems on ships, in the range from 400V to 690V, will have an insulated neutral. It is, however, important that a ground-fault is detected and cleared as quickly as possible. This is to avoid a large short-circuit current on a second ground-fault, which can be in excess of the 3-phase fault current for which the equipment is rated, which can do damage beyond repair.
Hazardous areas will also have an insulated neutral power supply system, as the flash-over from a faulted cable in a grounded system, which may cause an explosion, is too high.
The diagram on page 21 shows the principal lay-out of this system.

8.2.2 Solid and low-impedance grounded systems

The main advantages are:

- No special attention for equipment insulation required
- Automatic detection and immediate isolation of ground faults
- Ground fault current flows for a short period of time, restricting damage
- Avoiding arcing ground over-voltages
- Maintains phase voltages at a constant value to ground.

The main disadvantages are:

- Instant disconnection and loss of the service
- Fault currents can be large and can cause extensive damage and have the risk of explosion.

Most low-power, low-voltage systems in the range from 110-230V have a solid grounded neutral. This power is mostly supplied from a phase to neutral source like a transformer and is used to supply small power consumers and lighting.
There are two basic types of distribution for solid or low impedance grounded systems:

a. 3-phase 4-wire with neutral earthed with hull return
b. 3-phase 4-wire with neutral earthed without hull return (TN-S-system) for all voltages up to and including 500 V A.C.

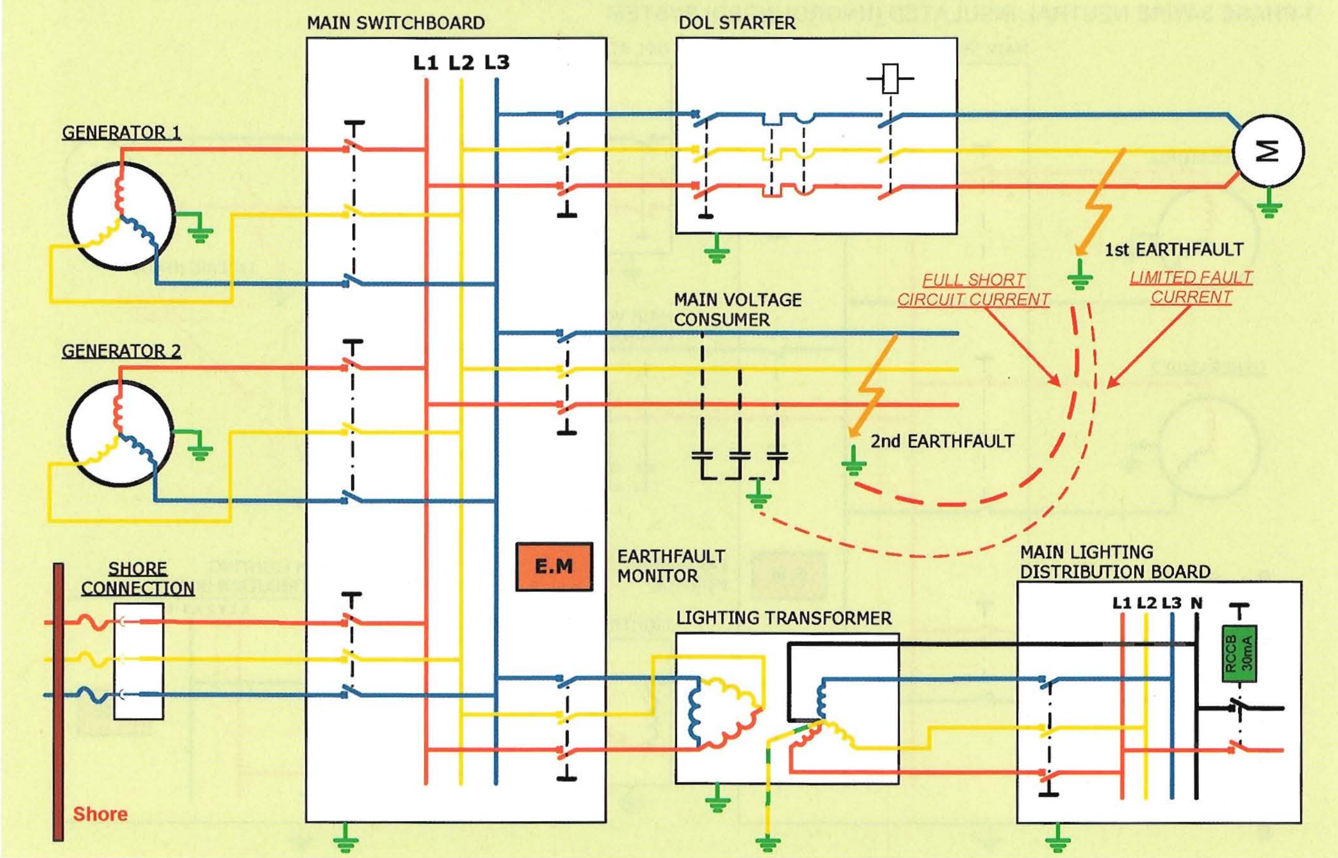
The type without hull return (b) resembles installations commonly used on shore in houses and is used primarily in the accommodations of ships.
The additional advantage of such a system is that it will require the same skills for operation and maintenance as for onshore installations. Labour legislation in various countries makes companies responsible for the safety of workers or crew on board of ships. Using this type of system would make it easier to comply as standards with respect to safety, training, operational authorisation, etc. would be the same. Special consideration should be given to low-voltage supplies to for instance steering gear or pumps for essential services as these should not trip on a ground fault. For these services it would probably be best to make a dedicated supply directly from the main power source. The diagram below shows the principle lay-out of a system with an ungrounded main power system but with a grounded low-voltage system.

8.2.3 High impedance grounded

High impedance grounding, using a resistance to ground, is used in the majority of medium voltage systems and offers several advantages:

- Low ground-fault currents, limiting damage and reducing fire risk
- Minimal ground-fault flash hazard due to system-over voltages
- Low protection equipment costs.

3-PHASE 3-WIRE NEUTRAL INSULATED (UNGROUNDED) WITH LV GROUNDED SYSTEM



The resistance is connected between the neutral point and the ship's hull. The resistance limits the ground-fault current to a low value, but one that is high enough to ensure selective operation of ground-fault protective devices.

Determining the value of the grounding resistance, to ensure the operation of the ground-current detection and protection equipment, is the work of qualified high-voltage engineers.

As with a low-voltage insulated system the operation of a high impedance grounded high-voltage system with a ground fault is in principle possible but cannot be recommended.

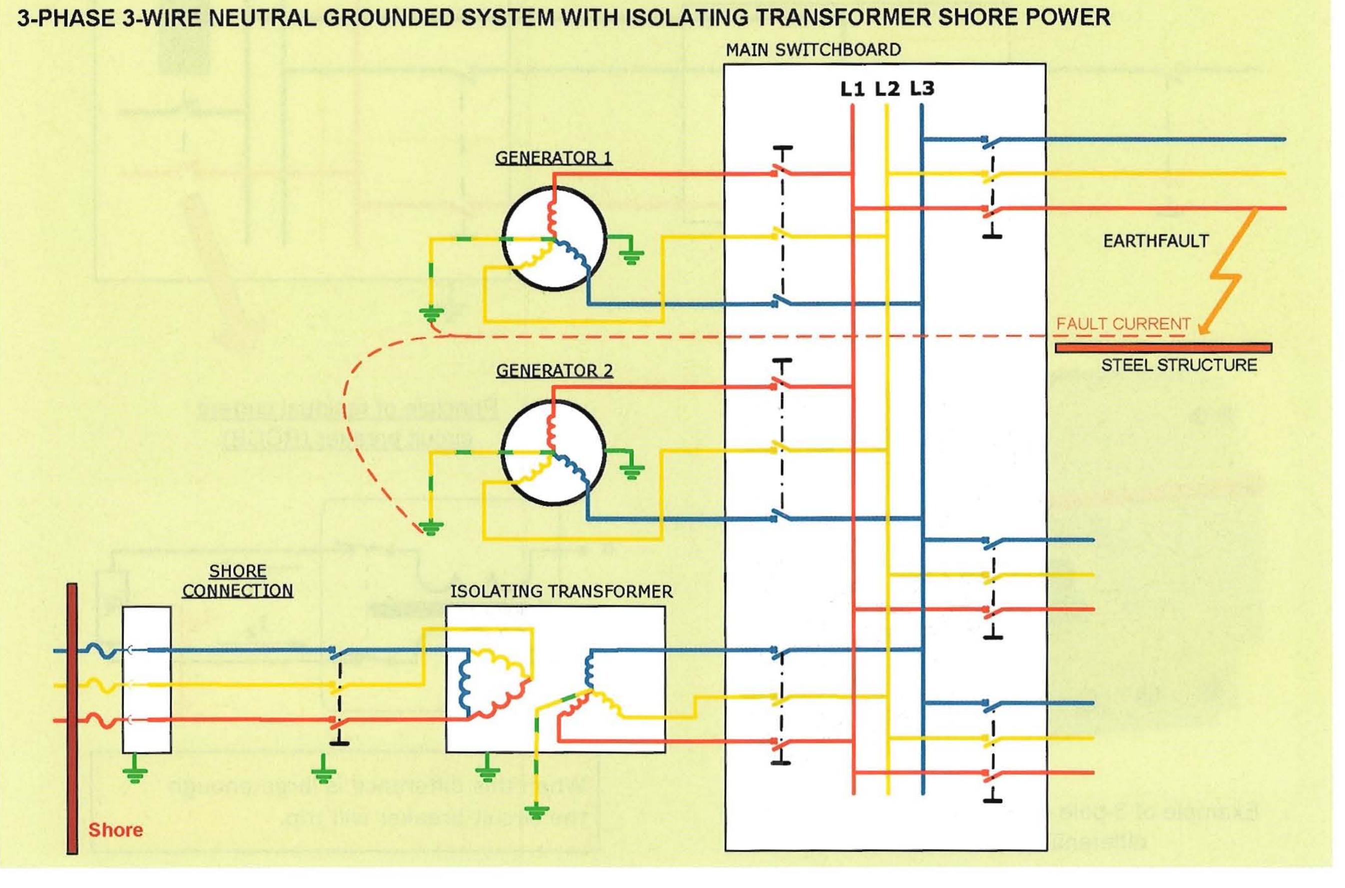
There is always a danger that the fault will escalate to a phase-to-phase fault and cause fire or extensive equipment damage. It is therefore advised to isolate the equipment and repair the ground fault as soon as possible. With can be relatively easy as a high-voltage system on board of a ship will normally be not very extensive.

8.3 Some practical advice on grounding arrangements

When different voltage levels or different types of services are involved, the treatment of the neutral should be dealt with for each part separately, regardless of the other part. Beware of equalising currents when a system neutral is connected to ground at several points and do not connect transformer neutrals and generator neutrals in the same distribution system at the same voltage level.
The connections of grounding arrangements to the hull shall be so arranged that any circulating current in the earth connections do not interfere with radio, radar, communication and control equipment circuits.
When a system neutral is grounded, manual disconnection for maintenance or insulation resistance measurement should be possible.
When a four-wire distribution system is used, the system neutral shall be connected to earth at all times without the use of contactors.
Most ground-faults occur in miscellaneous electrical equipment away from the main power production like in lighting fittings, galley equipment and deck fittings.
In an "ungrounded" distribution system it will be an advantage to supply this equipment from a separated "grounded" system so that the ground-faults will be self-clearing.
In an "ungrounded" system it is worth considering the installation of a "fault-making switch", with a series impedance when necessary, which could be used at a convenient time to temporarily connect the system neutral to ground and cause a faulty circuit to trip.

8.4 Grounding arrangements and shore connections

When the neutral of the electrical system is grounded, the hull may, in some cases, function as the grounding point for the shore supply when in port. This then would lead to galvanic corrosion of the ship's hull due to the ground currents flowing between ship and shore. To avoid this, an isolation transformer can be fitted on board in the shore supply. The secondary side of the isolation transformer can then be connected to the ship's ground to form a neutral point with no connection to the shore system. An example of a neutral grounded system with an isolating transformer in the shore power supply is given on the diagram below.



8.5 Dangers from electric shock

The way in which the neutral is handled has no significant effect on shock risk to personnel.
The human tolerance to shock currents is so low that any method of grounding the neutral has the possibility of allowing a potential lethal current to flow. Even the line to earth capacitive current in an ungrounded system could be dangerous. Reducing the risk to humans from electric shock can be done by using Residual Current Devices (RCD's), of high sensitivity being 30mA, with an operating time shorter than 30ms. RCD's can only be effective on solid grounded sub-systems, like in the accommodation, where these are fitted behind a neutral grounded transformer.
The diagram below shows the principal lay-out of a 3-phase 4-wire low-voltage neutral grounded system with RCB's. Another way of reducing the risk of electric shock in low-voltage sub-systems (<250V) is the use of isolating transformers.

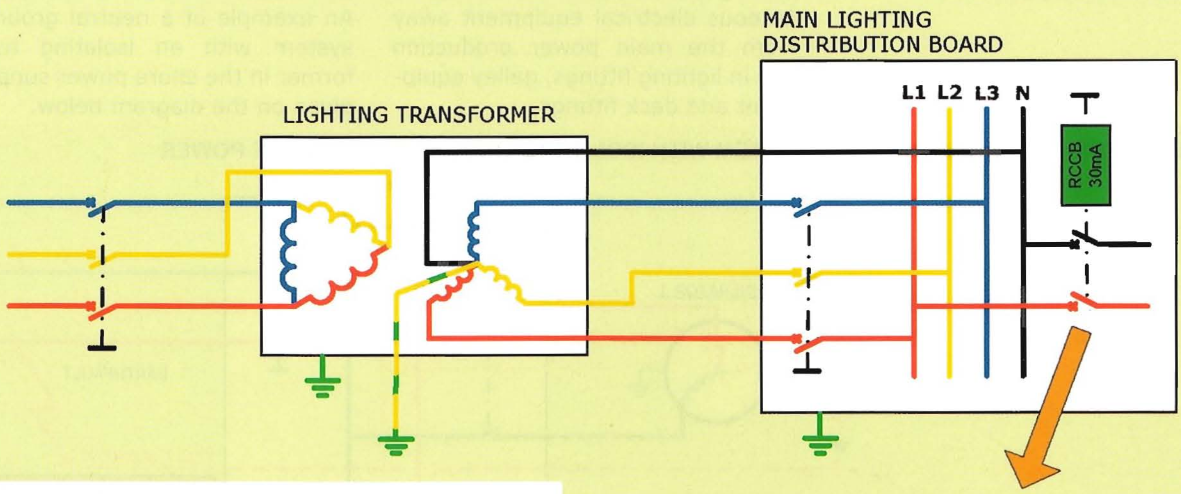
9 Redundancy criteria

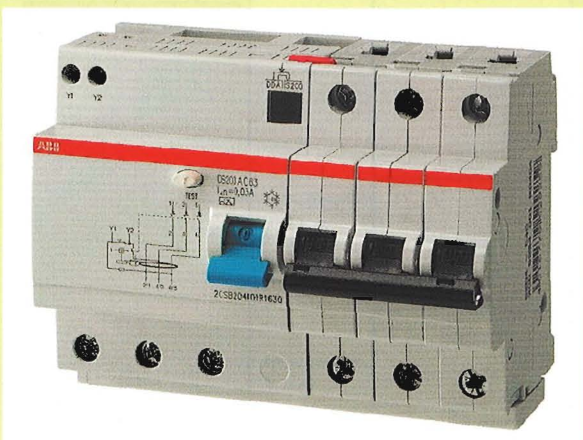
Essential services, those services required for the operation and safety of the ship, must be duplicated in such a way, that a single failure in the service or in its supply system does not cause the loss of both services.
This is done by arranging individual supply circuits to each service.
Those supply circuits have to be separated in their switchboards and throughout the cable length and as widely separated from each other as practicable, without the use of any common components.
Common components are switchboard sections, feeders, protection devices, control circuits or control gear assemblies. This is the basis for a high voltage one-line diagram, a low-voltage one-line diagram and the 24V DC one-line diagram, as well as the lay-out of the switchboards and panels.
Physical separation against propagation of fire and electrical damage to other sections supplying the duplicated service is required.

9.1 Normal services

Some examples of consumers of systems that are duplicated:
- Starting-air compressors
- Sprinkler pumps / Fire extinguishing pumps / Ultra-Fog pumps / Drencher pumps
- Bilge and Ballast pumps,
- Sea-water and fresh-water cooling pumps, HT and LT systems
- Electric propulsion equipment
- Starting batteries and battery chargers for electric starting engines
- Fire detection and alarm systems
- Fuel-oil pumps and heaters
- Controllable-pitch propeller pumps,
- Lubricating and priming-pumps for main engines, gearboxes, auxiliary engines, shafting if electric driven
- Inert-gas fans, scrubber pumps and deck-seal pumps
- Steering gear pumps

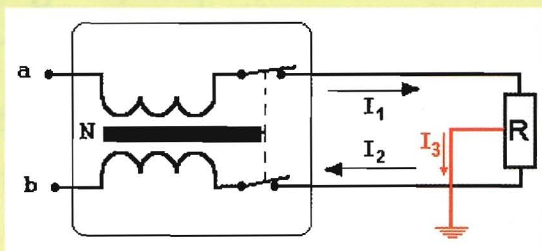
3-PHASE 4-WIRE LOW VOLTAGE NEUTRAL GROUNDED SYSTEM WITH RCCB'S





Example of 3-pole circuit breaker with built on differential trip unit (ABB)

Principle of residual current circuit breaker (RCCB)



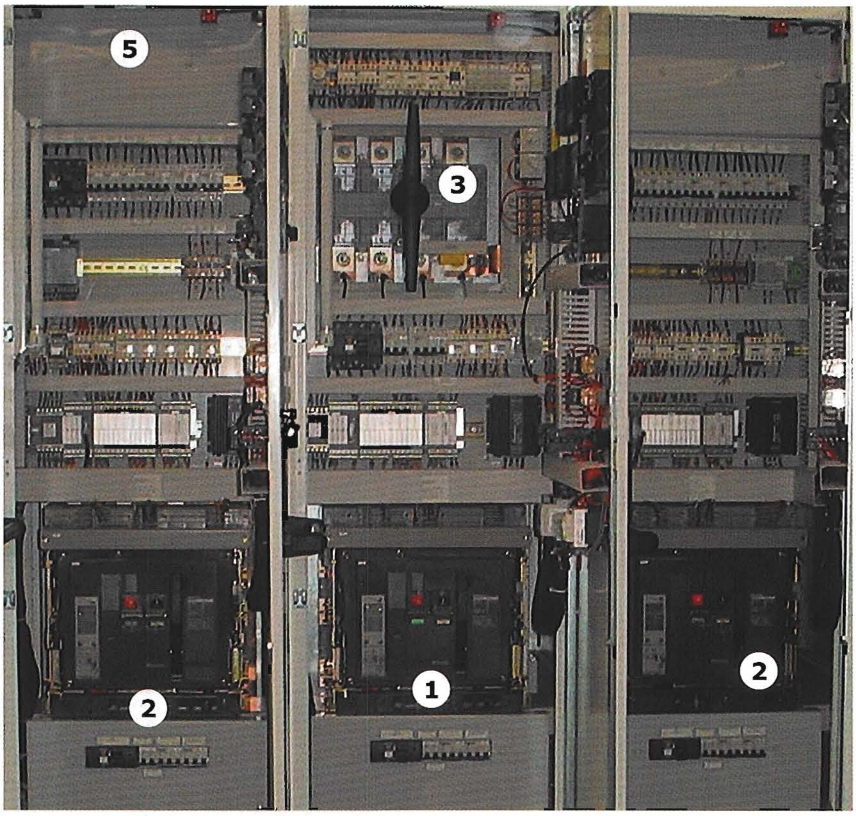
When this difference is large enough the circuit breaker will trip.

- Thrusters for dynamic positioning, where it should be noted that thrusters for manoeuvring do not have to be duplicated but could have for instance dual feeders from two different switchboard sections
- Lighting systems do not have to be duplicated as long as two final sub-circuits serve each cabin or accommodation space; one circuit may be from the emergency switchboard
- Navigational aids as required by statutory regulations connected to a distribution board with change-over feeders from main and emergency switchboards
- Navigation lights with a dedicated distribution board with dual feeders from main and emergency switchboards. Dual lights are not required by law as long as the replacement of a broken bulb is possible, in adverse weather conditions as well
- Remote operated valves
- Engine-room fans
- Watertight doors
- Windlasses
- Power sources and control systems for above services.

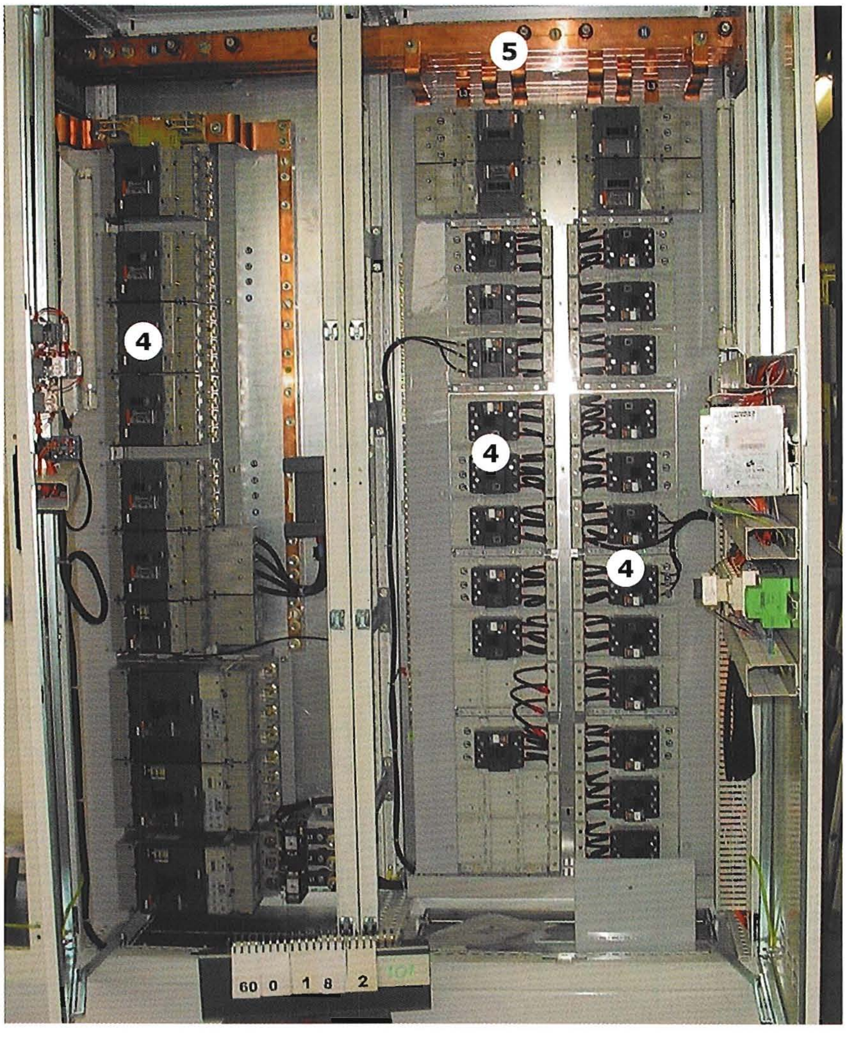
In addition, for the accommodation the following services are necessary for minimum comfort:
- cooking / heating
- domestic refrigeration
- mechanical ventilation
- sanitary and fresh-water.

Moving domestic refrigeration to the essentials list is under discussion. The following services are not considered necessary to maintain the ship in normal sea-going operations:
- cargo-handling and cargo-care equipment
- hotel services other than those for habitable conditions
- thrusters other than those for dynamic positioning.

However, in a non-essential tripping system, thrusters are not to be tripped before cooking, heating, ventilation, sanitary and any other non-sailing services. This to avoid dangerous situations during manoeuvring and mooring.



1. Shore connection circuit breaker
2. Generator circuit breaker
3. Bus section isolator
4. Essential consumers circuit breakers 1
5. Main bus bar



Examples of a switchboard lay-out, showing essential consumers section, generator panels section with bus section isolator and essential consumers section.

9.2 Emergency services

Emergency services may include for example:

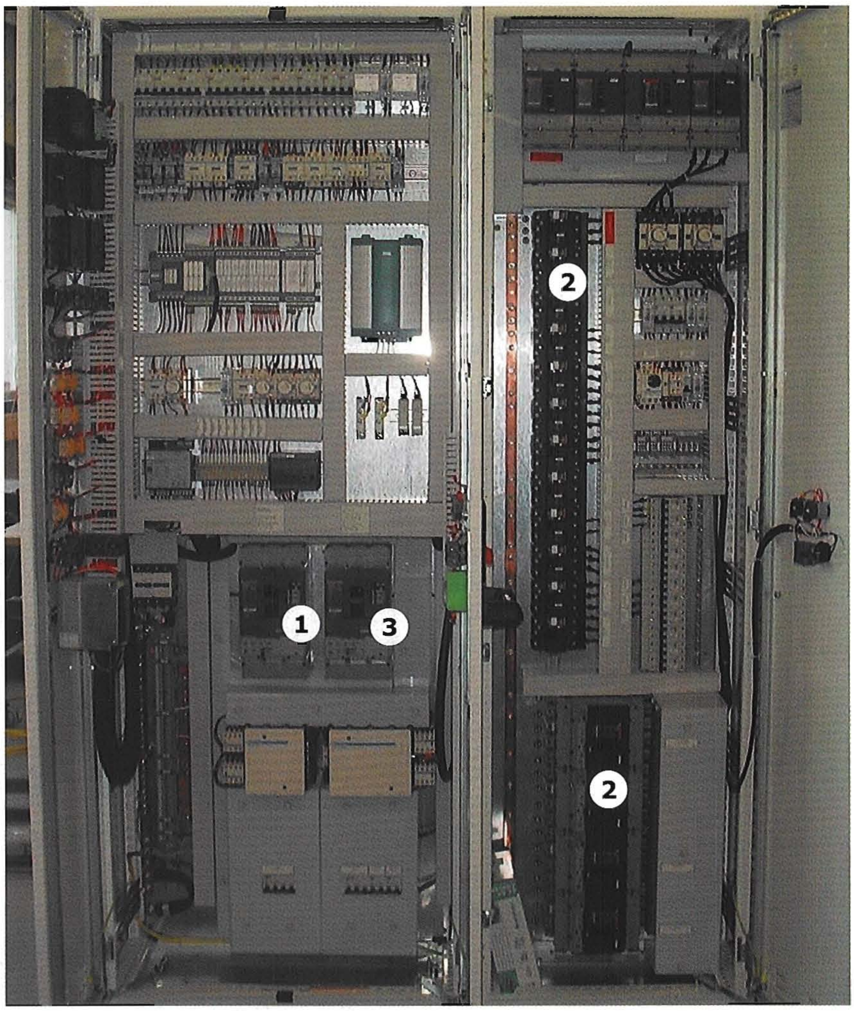
- Emergency lighting
- Navigation lights
- Internal communication
- Emergency fire-pump
- Sprinkler/ultra-fog pump
- Emergency bilge pump with bilge valves.

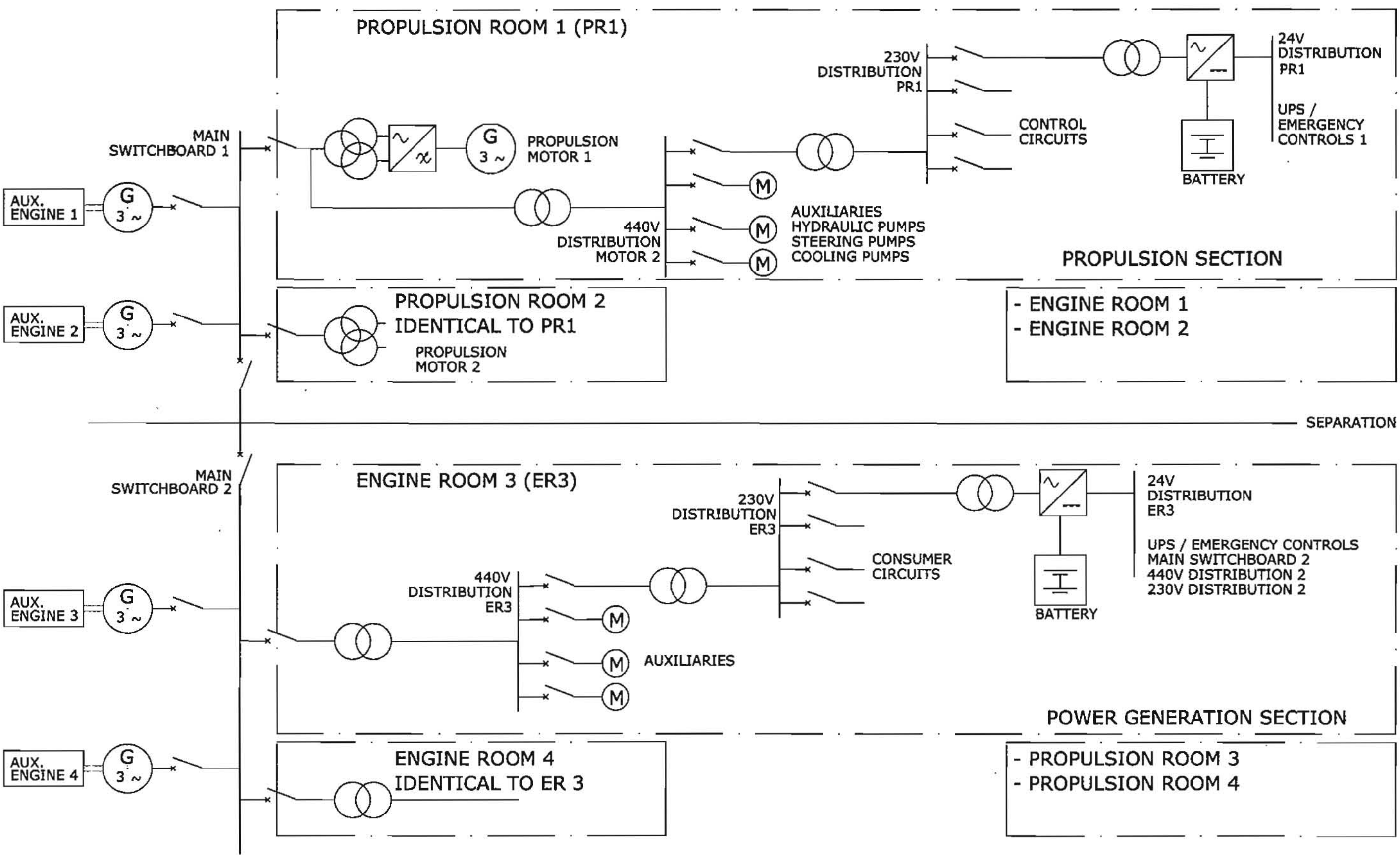
For passenger-ships emergency services must be available for 36 hours, for cargo-ships the minimum time is 18 hours.
This determines battery capacity or the contents of the fuel tank in case of an emergency diesel-generator.

The picture on the right shows an emergency switchboard with two sections:

- section for the emergency generator and the bus-tie connection to the main switchboard
- section for the emergency consumers distribution.

1. Emergency generator circuit breaker
2. Emergency outgoing circuit breakers
3. Bus tie circuit breaker to main switchboard





9.3 Diesel electric propulsion

On page 24 is a simplified one-line diagram for a diesel-electric propelled vessel with four (4) diesel-generators and four (4) thrusters for propulsion. Only half of the diesel-electric propulsion and half of the main distribution is shown.
The top of the diagram shows the distribution for the four thrusters. Each thruster has a single HV feeder, a single 440 V transformer and switchboard, a single 230 V transformer and switchboard, as well as a single 24 V DC battery supply and switchboard.
A single failure in this system would lead to failure of one thruster, equal to the result of fire or flooding of the thruster space.
The diesel-engine generator-rooms have two diesel-generator sets per engine-room with duplicated essential auxiliaries, and:

- HV switchboard with duplicated bus section circuit breakers
- 440 V transformer and switchboard
- 230 V transformer and switchboard
- 24 V DC battery charger and distribution switchboard.

With this arrangement the effect of a single failure would be less than that of fire or flooding that would cause the failure of an HV switchboard and consequently, the loss of two thrusters.
The cable routing of the thrusters supplied from one engine-room must not pass the other engine-room. Likewise, the cable routing for one thruster must not pass the adjacent thruster-room.

9.4 Engine room battery systems

Below is a simplified one-line diagram of a 24 V engine-room starting battery and engine control distribution system for a yacht with also electric starting of the main engines.
Here too, a single failure shall not cause the loss of both propulsion engines and one or more auxiliaries.
The 24 V engine-room systems consist of two identical distribution boxes with a normally open link between the boxes for emergency supply.
The Main Switchboard will have a similar lay-out with Auxiliary Generators 1(PS) and 2(CL) connected to the PS section and Aux. Generator 3 (SB) to the SB section. The Main Switchboard will have a bustie-breaker between the PS and SB sections.

The portside 24 V DC system is powered by the battery charger supplied from the main switchboard port section and the DC dynamos of auxiliary engines 1 and 2.

This system supplies the control circuits for:

- main 24V supply Auxiliary Engines 1 and 2
- main 24V supply Main Engine 1
- main 24V supply Bridge control-systems PS
- back-up 24V supply Auxiliary Engine 3
- back-up 24V supply Main Engine 2
- back-up 24V supply Bridge control-system SB

And through a normally closed link the starting motors of:

- Auxiliary Engines 1 and 2
- Main Engine 1

The starboard side 24V DC system is powered by the battery charger supplied from the main switchboard SB section and the DC dynamo of auxiliary engine 3.
This system supplies the control circuits for:

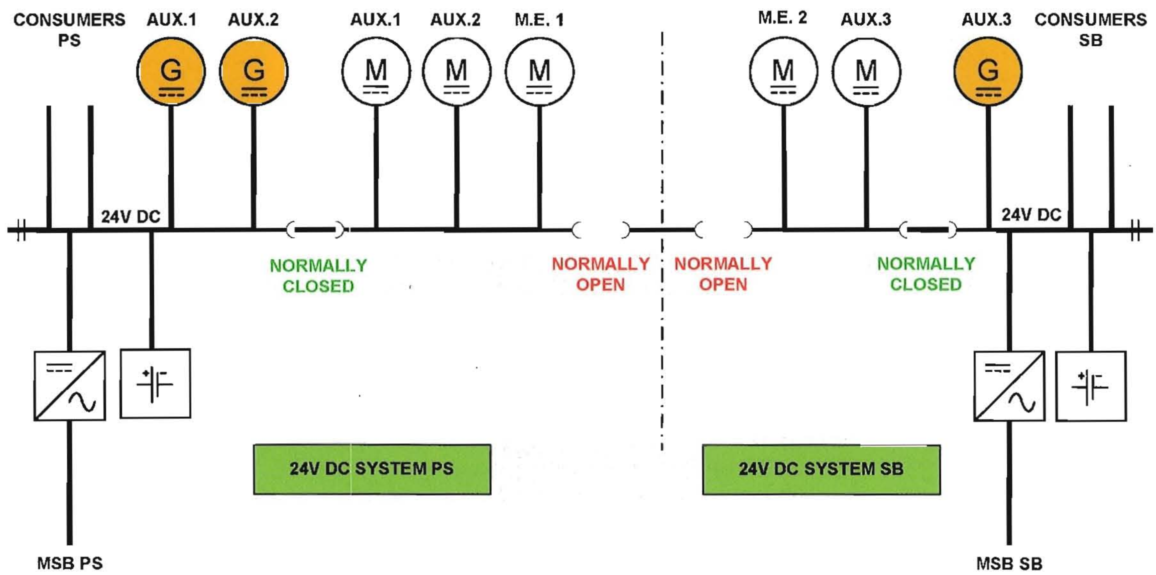
- main 24V supply Auxiliary Engine 3
- main 24V supply Main Engine 2
- main 24V supply Bridge control-systems SB
- back-up 24V supply Auxiliary Engines 1 and 2
- back-up 24V supply Main Engine 1
- back-up 24V supply Bridge control-system PS

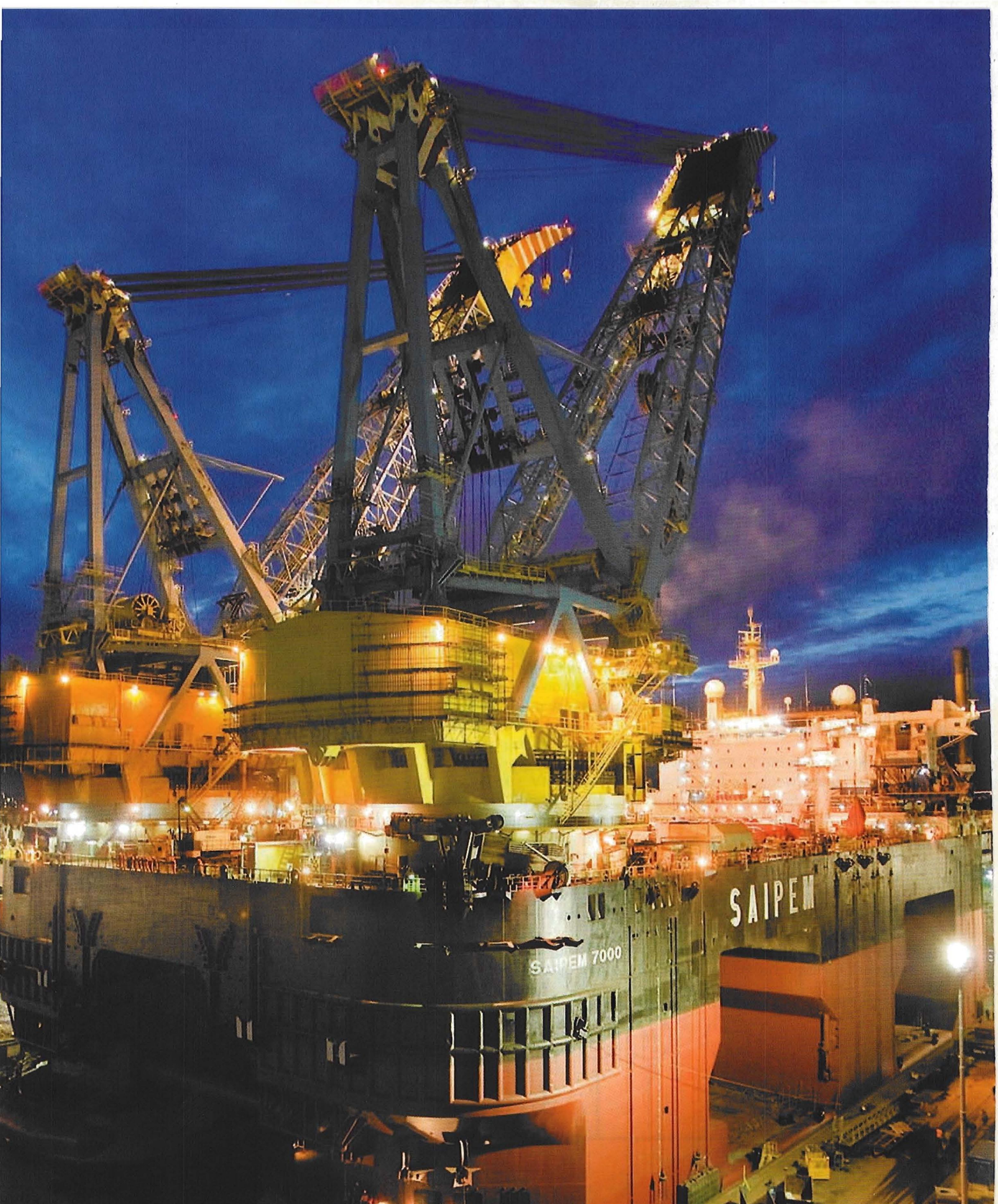
And through a normally closed link the starting motors of:

- Auxiliary Engine 3
- Main Engine 2

All control circuits have to be monitored for failure and alarmed.

Diesel electric offshore vessel





4. ONE-LINE DIAGRAM

The basic **one-line diagram** shows the principle layout of the electrical installation.
It indicates the number and rating of generators and the electrical arrangement of the main switchboard, including the main bus bars, possible separation and the division of the essential consumers over the two bus bar sections.
The diagram also includes power supply circuits to distribution boxes and panels throughout the ship and the electrical consumers connected there.
A basic one-line diagram tells more about the electrical installation than pages of specifications.

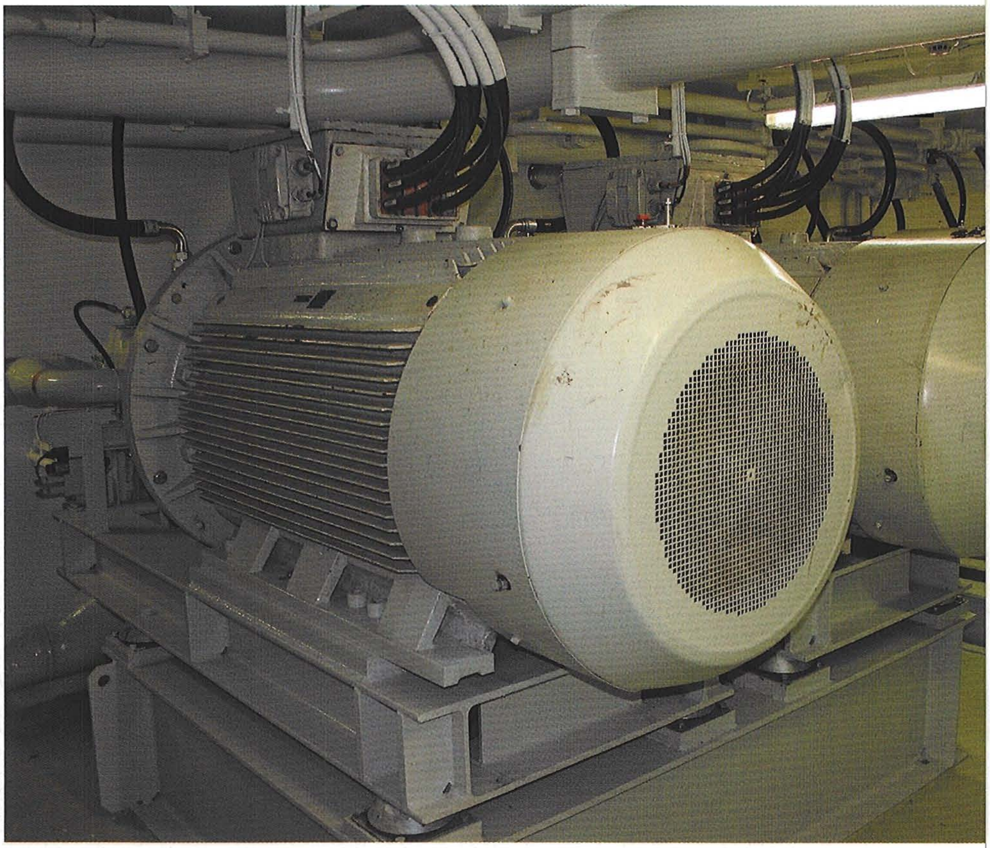
1 One-line diagram

One-line diagrams clearly show the difference in redundancy, emergency services, capacities and additional redundancy to cope with fire and flooding in an engine-room, as may be required for a DP vessel.

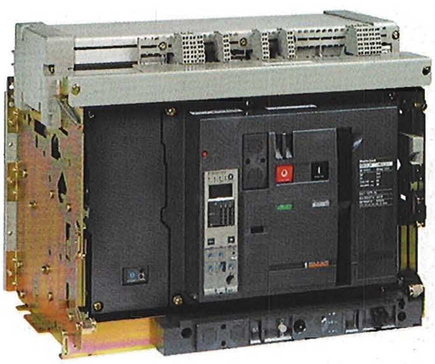
Basic one-line diagrams of the following ships are described:

1 Diesel-electric crane/pipe-laying barge
2 Chemical tanker
3 Car- and passenger-ferry
4 Sailing-yacht

Diesel generator



Electromotor

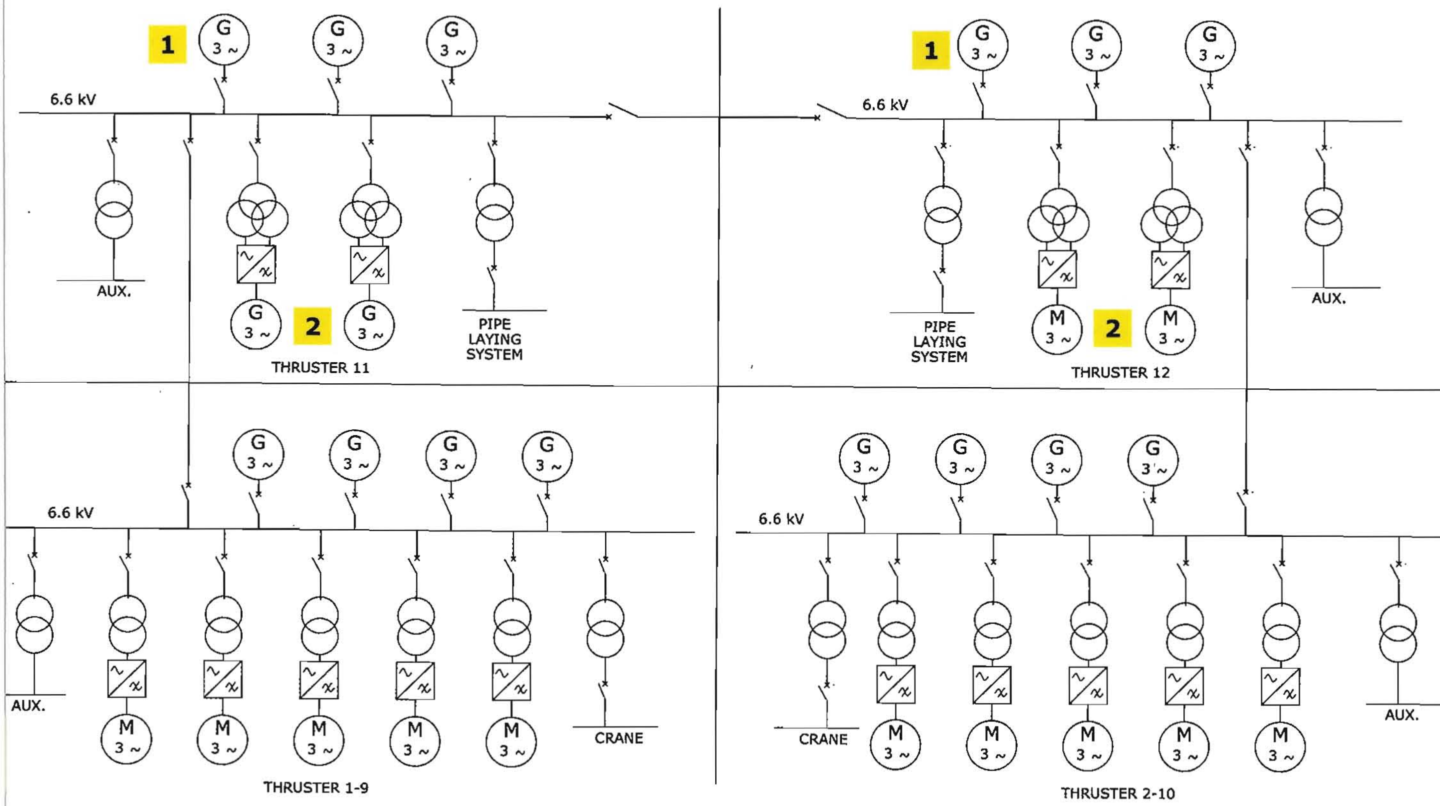


Circuit breaker

2 One-line diagram of a crane-barge

This barge (see page 26) is equipped with 12 generator sets, each 6.6kV about 6 MW divided over four engine-rooms, four switchboards in four separate spaces and 12 azimuth thrusters divided over two floaters. The thrusters are fitted in 6 thruster-rooms.

The generators marked 1 are not yet installed. The same counts for the thrusters marked 2. The locations are prepared for future installation.

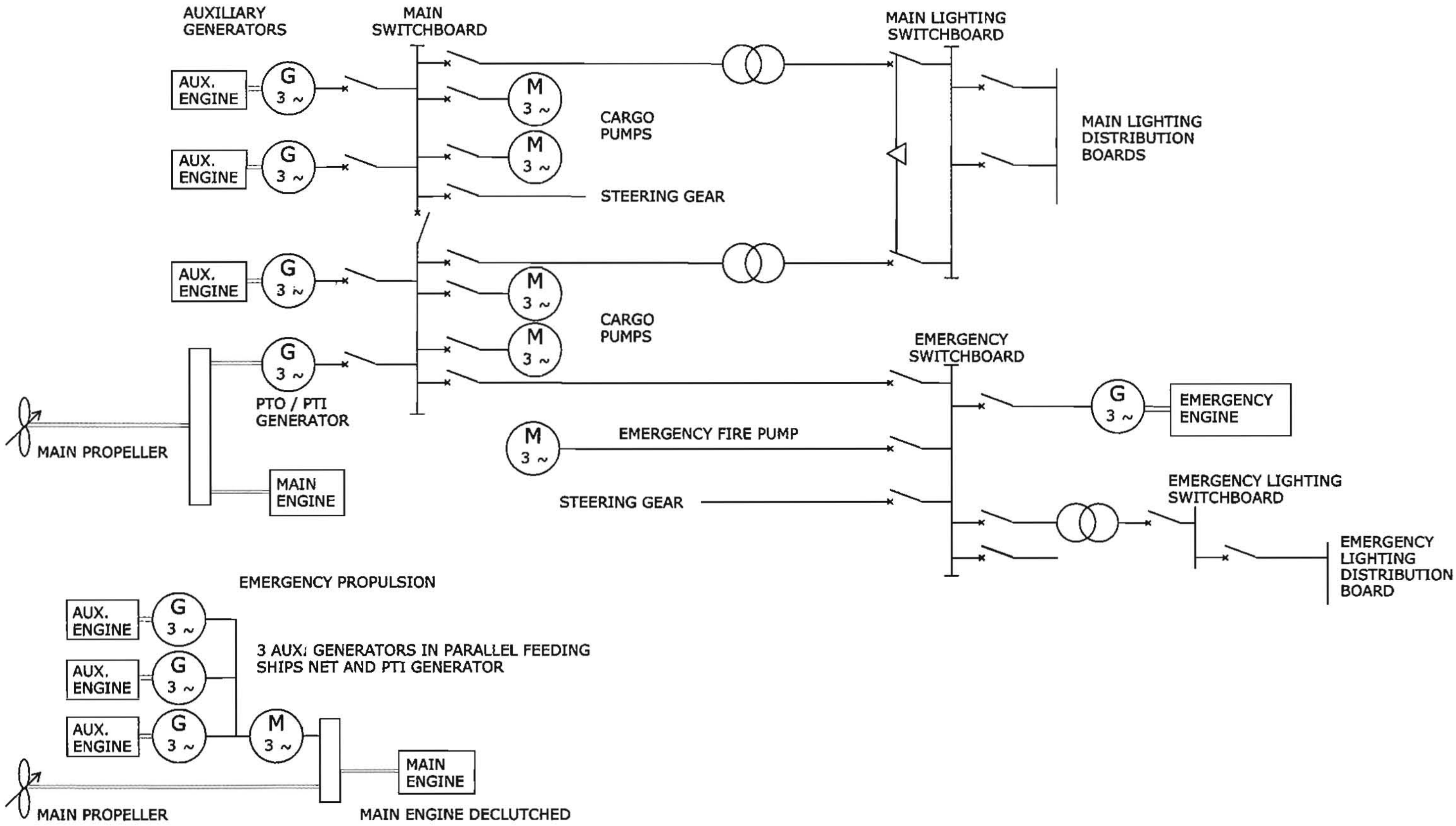


Single-line diagram diesel-electric D.P. crane-ship and pipe-laying vessel

Engine-control room

3 One-line diagram of a chemical tanker

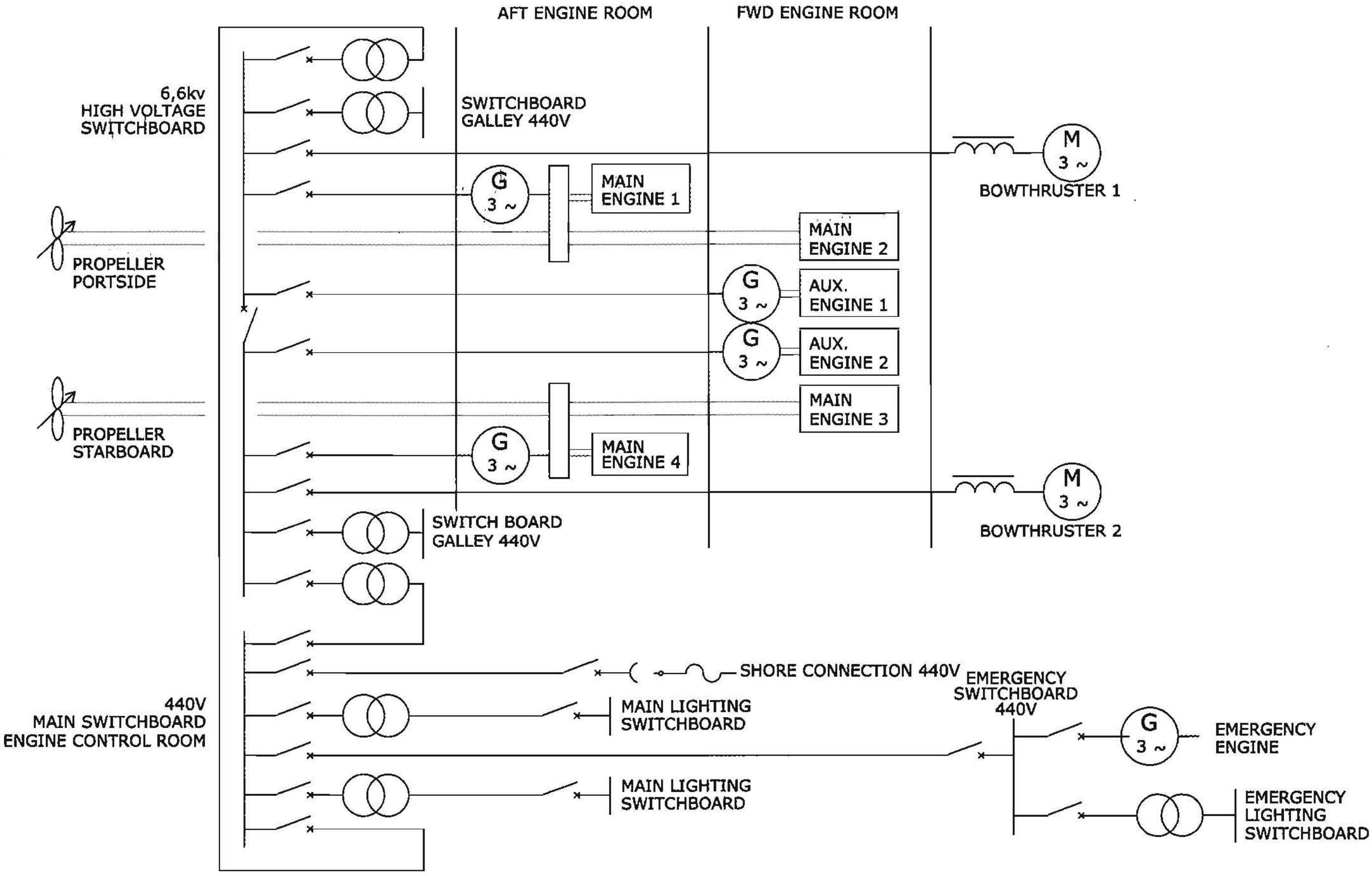
Chemical tankers usually have three or four generator sets. One generator set is capable of taking the normal sea-load.
In port, more generators are required to take the load of the cargo-pumps during discharge. The cargo-pumps are normally electric or hydraulic driven.
When hydraulic, the power pack is electric driven.
The main engine drives the propeller via a gear-box.
A generator is driven via a power-take-off on the gear box. This generator can sometimes also be used as an electric motor for emergency propulsion power.
The necessary power is then supplied by the available diesel-generators.



4 One-line diagram of a passenger-ferry

Propulsion is taken care of by two propellers, each served by two main diesel engines, each on a reduction gearbox. Electric power is provided by two main generators, 6.6 kV, and by two shaft-driven generators, through PTO's on the gear-boxes.
The generators supply the 6.6 kV switchboards.

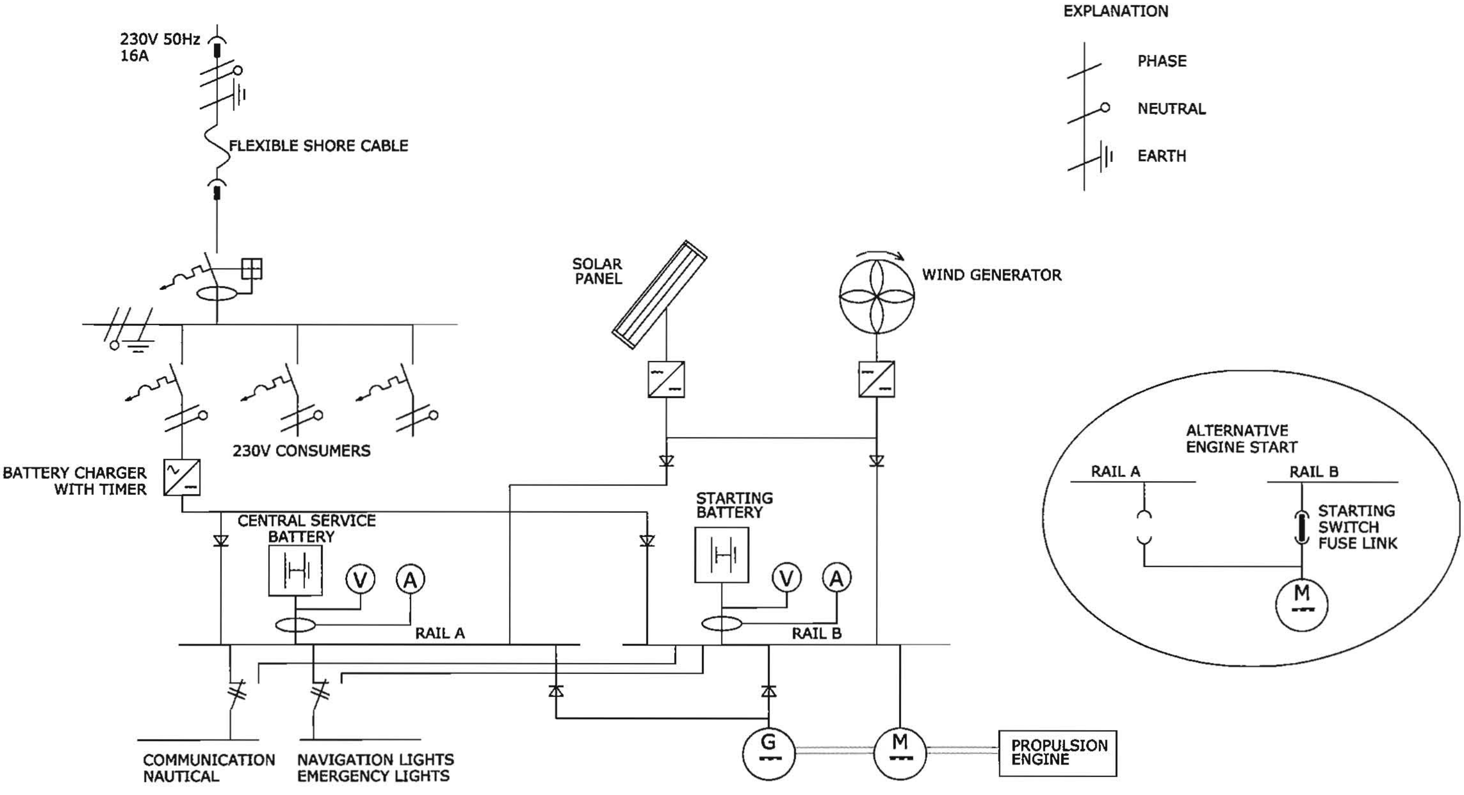
From this 6.6 kV switchboard a secondary 440 V system is fed through transformers, to supply the consumers. The bow-thruster is directly fed from the 6.6 kV switchboard. Parallel running of diesel generators and shaft generators is only possible for the time needed to switch from one generator to the other.
At sea, the diesel-generators are disconnected.

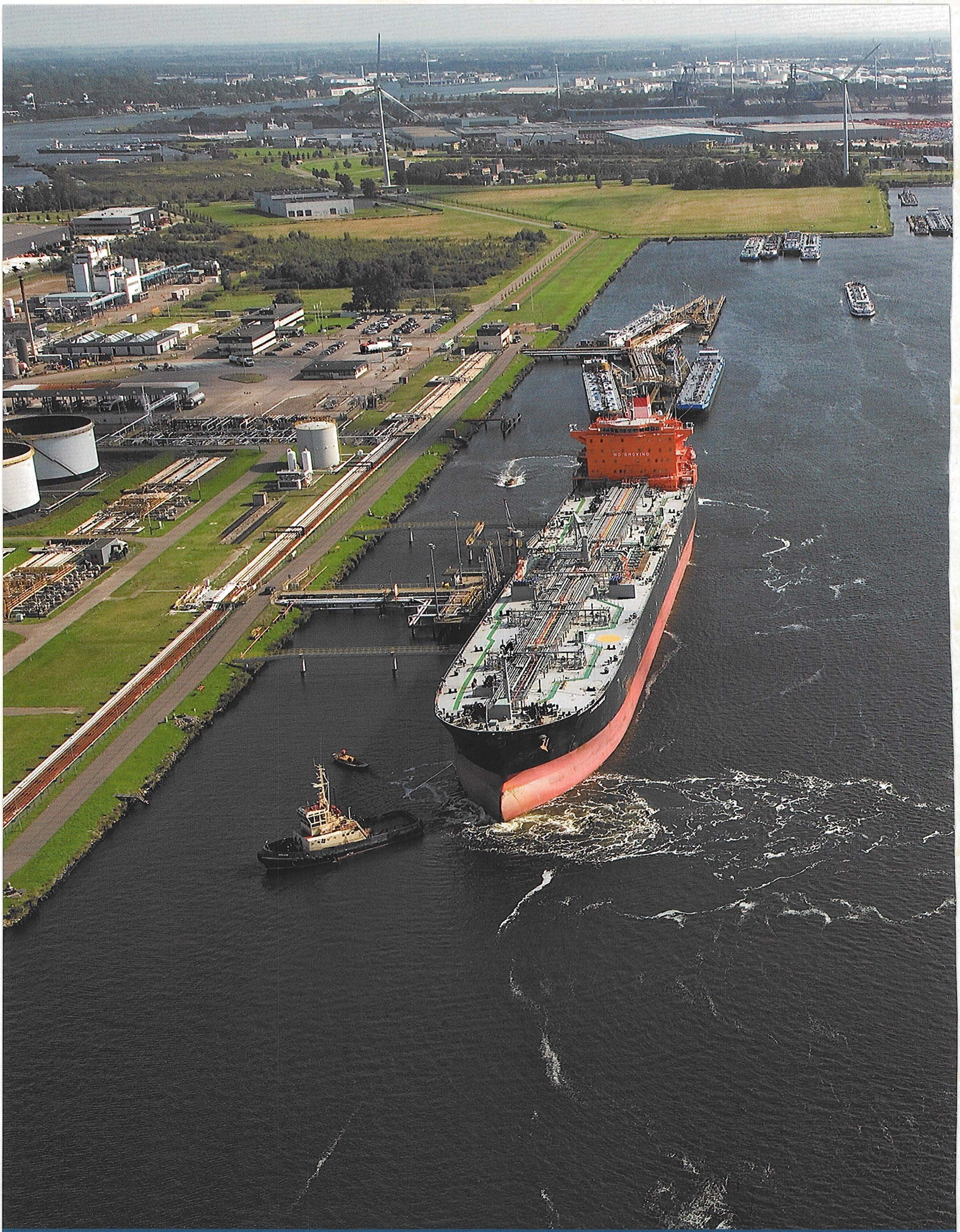


5 One-line diagram of a small sailing yacht

A 10 or 12 metre sailing yacht is normally provided with two 12 or 24 volt circuits, each fed by a battery. The systems are completely separate. One is installed to provide the power for starting the auxiliary diesel engine, the other for all consumers such as lighting, navigation lighting and equipment, radio, VHF.
The batteries are charged by the dynamo of the diesel engine.

The charging current is led through a diode-bridge, allowing only charging current and no discharging flow. This is to prevent current flowing from one battery to the other. The main reason is that the starting battery is not discharged by lights or other consumers.
Shore power is often plugged into a separate 230 volt system for heating and lighting, which also feeds a battery charger, charging both batteries via the same diode-bridge. A timer prevents over-charging.
The batteries can also be charged when underway under sail, in a very limited quantity by solar panels and/or a wind-driven dynamo.





5. LOAD BALANCE

A **load balance** is made at the start of a project to determine the required number and ratings of the diesel-generators.
As for the creation of this first load balance many assumptions may have been made.
The list will have to be maintained and updated at various stages of a project to fine-tune it with detail design of the electrical installation.

1 Basic procedures to make a load-balance

1.1 General

A load-balance lists all electrical equipment with its rating and use in various operational conditions.

A load-balance will be based on the mechanical designs of the various systems. The result will be a list with all pumps and various equipment with their individual mechanical power ratings. By applying correction factors for pump-motor efficiency the required electrical power is obtained.

Lighting loads are estimated from the ship's general arrangements and electronic aids are obtained from similar vessels or Vendors to complete the list.

When the electrical load list is completed this can be analysed to estimate the expected power demand of the electrical system under various operational conditions.

The expected power demand is calculated by multiplying each service power by a "demand" factor.

The demand factor is a combined load factor and diversity factor and is the ratio of the estimated power consumption of a service to its normal full-load power consumption.

By applying the expected power factor to the calculated real power in kW or MW the apparent power in kVA or MVA is found. Note: in the absence of precise data 0.8 may be used for the power factor. Then by comparing the expected load for the different ship operating conditions, the number and rating of the main generators can be assessed.

1.2 List of the operational conditions

In general the following operational conditions apply to all vessels:
- normal sailing/transit
- loading/discharging
- manoeuvring
- emergency

Then the type of vessel will determine any other operational modes.

A dredger for instance will require assessment of load demands for dredging and pumping ashore.

For heavy-cargo ships the load demands for (de-) ballasting will have to be assessed.

For ships with dynamic positioning systems, such as pipe-laying vessels, crane-vessels, drilling-vessels and rock-dumping vessels the load situation must be assessed with regard to redundancy criteria for thruster systems and other vital systems. This is especially vital when the installed load exceeds the available power as can be seen in the example below.

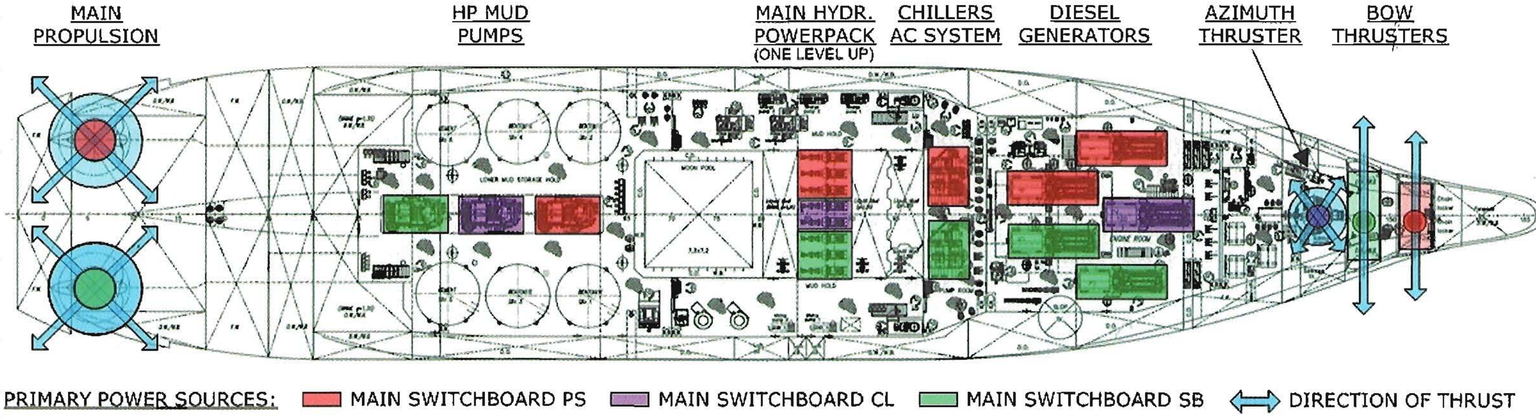
1.2 List of the electric consumers

The consumers will normally be grouped in order of their purpose as follows:
- Propulsion
  - auxiliaries
  - continuous running
  - non-cont. running
- Ship's auxiliaries
  - continuous running
  - non-cont. running
- Hotel auxiliaries
  - continuous running
  - non-cont. running
- Cargo-handling
  - auxiliaries
- Emergency auxiliaries.

1.3 Essential and non-essential consumers

Essential consumers are those related to the safe navigation and propulsion of a vessel and the welfare of crew and passengers.
When consumers may be switched off without danger they may be classified as non-essential.
Switching off non-essential consumers, which most of the time will be an automatic action, may help to reduce power in case the running diesel-generators get close to overload. It also allows a less strict selectivity requirement which can lead to a cost reduction for the installation.

Example of a DP2 Drilling Vessel with 11MW available power and 13.5MW supplies for main power consumers. When the other ship's consumers are added the total installed power is approximately 16MW which makes a good load assessment and power management with non-essential consumer-control essential.



1.4 Compiling a load balance.

When making a load balance one can use a number of standard values that are based on long-time experience or common practice. Below are some examples of these standard values that may be used when compiling a load balance.

The first part deals with common standards that may be used for ships in general
The second part gives standards for large yachts with an example of a load balance.

All figures relate to the column "%MAX" in the tables on the next page and return the proportional value of the consumer in the sum of all electrical loads.

When compiling a load balance a reservation must be made in every operational mode to start and run the largest non-continuous running consumer fully loaded.

For example when compiling the list of the emergency consumers the fire-fighting pump, if this is the largest, must be able to start and run on the base load.

When all data is in the load balance, a margin of 10% must be added to allow for distribution losses such as in the cables.

Following are some examples of loads which can be used in making a load balance.

1.4.1 Engine-room auxiliaries continuous running

The following consumers are normally continuous running in the engine-room.

Assigned load 100%
- ME Seawater pumps
- ME Freshwater pumps
- ME Lubricating-oil pumps
- ME Fuel-oil booster pumps
- ME circulating pumps
- Gear-box lubr. oil pumps
- Engine-room fans

The percentages given for consumers in the examples above represent the **load factors**.
A load factor is the average consumed power divided by the maximum rated power.

1.4.2 Engine-room auxiliaries intermittent running:

The following consumers are normally intermittent running in the engine room.

Assigned load during sailing 30% and manoeuvring 80%
- Hydraulic pumps controllable pitch propeller
- Steering-gear pumps
- Standby pumps for pumps listed under 1.4.1

Assigned load 30%-50%
- Start-and control- air compressors

Assigned load 30%
- ME Lubricating-oil priming pump, when used, during starting only

Assigned load 20%
- Bilge pumps
- Ballast pumps
- Mooring and anchor winches when self-tensioning or in harbour
- Provision cranes.

1.4.3 Hotel auxiliaries continuous switched on

Hotel auxiliaries are all systems that relate to the well-being of crew in the accommodation of a ship.

Normally the following services will be continuous switched on.

Assigned load 100%
- Main lighting system

Assigned load 50%
- Socket-outlet circuits

The accommodation HVAC system is assigned 0-50-100% depending on the outside temperatures.

For passenger-ships and mega-yachts sailing with or without passengers can make a big difference for the load. Large portions of the installation may be switched off when there are no passengers on board which will reduce the total load.

More details on this can be found later in this chapter where an example is given of the load balance of a mega-yacht.

1.4.4 Hotel auxiliaries intermittent switched on

The following consumers will normally intermittent be switched on.

Assigned load 30%
- Normal galley, laundry and pantry equipment.
- Provisional cooling system

But when a cruise-ship is involved and passengers are on board the assigned load for these services will be 100% as there will be catering day and night for the guests.

1.4.5 Cargo-handling auxiliaries

For a cargo-vessel the following specific loads are assigned when these systems are installed.
- Deck cranes 40%
- Cargo pumps 80-100%
- Dredge pumps 80-100%
- Cargo doors and valves 20%
- Refrigeration containers 30%.

It must be noted that for refrigerated containers higher figures may be required during loading as the cooling system will have to make up for the down-time during transfer of the containers from shore to ship.

1.4.6 Emergency consumers

The total load on the emergency generator must be carefully planned as this will be the last power source in an emergency situation and an overload situation must be avoided at all times.

The following are some consumers that always will be required.
- Emergency lighting 100%
- Emergency fire-pump 20%
- Steering-gear pump 30-80%
- Battery chargers 30%.

For a small ship an emergency battery will be sufficient to supply the emergency consumers.
Larger ships will need an emergency diesel-generator for these consumers.

The minimum discharge time for the emergency battery or the capacity of the fuel tank for an emergency diesel are defined by the Class Rules and Regulations and the SOLAS regulations.

For cargo-ships this is in general 18 hours, for passenger-ships 36 hours.

For passenger-ships there is an additional requirement to install a transitional emergency source of electrical power. This is an emergency battery system that will supply power to emergency lighting and other vital systems such as the public address system for at least one half hour or until the emergency generator is operative and connected.

A separate load balance must be made for this system when installed.
The radio installation will normally have its own dedicated battery with a minimum discharge time of 1 hour. This battery will be directly charged by the emergency generator. The charging system for the radio battery must be able to charge this in less than 10 hours.

Normally navigation and nautical equipment will be all or partly supplied by the emergency source of supply and can be assigned 30% load.

1.5 Verification of values

The estimated figures in the load balance can be verified at the relevant stages of a project.

During the design period electrical data sheets from equipment can be used to update basic values, like power ratings and efficiency, in the list.

During testing and commissioning the actual measured values or the values from the equipment nameplate can be obtained and used to update the list.

During the harbour test and sea trials all figures for the various operational modes can be verified and the load balance can be finalized for delivery with the "As Built" drawings and documents.

1.6 Example load balance mega-yachts

The load balance for a mega yacht under various operational conditions is given as an example.

The following operational conditions are defined:
1. Harbour without guests
2. Harbour with guests
3. Manoeuvring without guests
4. Manoeuvring and dynamic positioning with guests
5. Sailing without guests
6. Sailing with guests.

Dynamic positioning, which is sometimes available on a yacht, is used for instance when the ship cannot drop anchor but must be kept on position anyhow.

1.6.1 Harbour without guests

When a yacht is in port without guests the number of electric consumers is limited. Only the engine-room auxiliaries required to keep the yacht in a ready-for-sailing-condition will be running.

Ship's service auxiliaries such as hydraulic power packs for doors, hatches, cranes and mooring winches will be in limited use just like equipment in the galley, pantries and laundry.

Other systems like thrusters, helicopter auxiliaries will not be used. Furthermore some nautical and communication equipment on the bridge required in port and crew call and entertainment systems will be used.

Most of the lighting and the HVAC system will be mostly switched off and only be used in engine-rooms and part of the accommodation used by the crew.
The resulting expected electrical loads are shown in the example of the load balance in the column harbour and crew.

In this operational condition the power management system will limit the generated power to one generator. This will be an environmentally friendly profile where the load of one generator is limited to maximum 95%.

In the event that this generator limit is reached, the power management system can temporarily reduce some loads to avoid overload and tripping of the running generator. Most of the time this reduction is done by adjusting the capacity of the HVAC system or by switching off non-essential consumers.

It is then to the engineer on watch to select a different operational mode with more generator capacity.

When enough shore power is available for this operational condition this can be used instead of using the generator.

1.6.2 Harbour with guests

Logically this condition is the up scaled version of the previous with more power demand due to intensive use and the addition of demand from guest quarters.

Some additional systems to the previous condition are those for:
- Swimming pools with Jacuzzi's.
- Guest-entertainment systems

The resulting expected electrical loads are shown in the example of the load balance in the column harbour and crew and guests.

Again the power management system will control the total generated power. Depending on the outside temperature and the electrical load normally there will be two generators running with this condition.

1.6.3 Manoeuvring without guests

When the ship is entering or leaving port it requires electrical power for manoeuvring which will include one or more relatively large thrusters.

As there are no guests with this specified operational condition the basic power requirements are as mentioned before under 1.6.1 Harbour without guests.

Normally this condition can be selected on the power management system which will start, synchronise and connect 3 generators to the main switchboard.

With enough electrical power there will be no limitation to the connection of consumers so all required services can be connected.
The only restriction will be that the thruster(s) will have first priority and the power management system will reduce power to selected services like HVAC when required.
The resulting expected electrical loads are shown in the example of the load balance in the column "manoeuvring with crew".

	MEGA YACHT						HARBOUR			
	EXAMPLE LOAD LIST (LOADS IN KW)		RATED	LOAD	USED	MAX	CREW		CREW AND GUESTS	
	DESCRIPTION	QTY	LOAD	FACTOR	LOAD	LOAD	% MAX	LOAD	% MAX	LOAD
	PROPULSION AUXILIARIES									
E310	Steering gear pump (1- MSB; 2- ESB)	4	4,90	0,80	3,92	15,68	0%	0,00	0%	0,00
E610	Main engine Lub oil priming system	2	2,40	0,80	1,92	3,84	0%	0,00	0%	0,00
E610	Main engine Coolant pre-heating unit	2	20,00	0,80	16,00	32,00	25%	8,00	25%	8,00
E650	Aux eng SW pumps exhaust	3	1,00	0,80	0,80	2,40	0%	0,00	0%	0,00
	Generatorroom fan PS	1	1,10	0,80	0,88	0,88	100%	0,88	100%	0,88
	Generator coolers PS	2	1,50	0,80	1,20	2,40	50%	1,20	50%	1,20
E710	Starting air compressor	2	5,50	0,80	4,40	8,80	25%	2,20	25%	2,20
E714	Air Dryer	1	0,33	0,80	0,26	0,26	25%	0,07	25%	0,07
E720	Fuel oil transfer pump	1	4,00	0,80	3,20	3,20	0%	0,00	0%	0,00
E730	Lub oil transfer pump	1	3,00	0,80	2,40	2,40	0%	0,00	0%	0,00
E810	Fire fighting / bilge pump	2	17,50	0,80	14,00	28,00	0%	0,00	0%	0,00
E810	Emergency fire fighting pump	1	17,50	0,80	14,00	14,00	0%	0,00	0%	0,00
	Engine room fans	2	15,00	0,80	12,00	24,00	25%	6,00	25%	6,00
	TOTAL PROPULSION AUXILIARIES					**137,86**		**18,35**		**18,35**
	SHIPS SERVICE AUXILIARIES									
E320	Anchor/ mooring winches Fwd	2	15,00	0,80	12,00	24,00	0%	0,00	0%	0,00
E875	Hot water circulation pumps	3	0,22	0,80	0,18	0,53	100%	0,53	100%	0,53
E881	Sewage plant	1	12,00	0,80	9,60	9,60	20%	1,92	40%	3,84
	Provision cooling system	1	20,00	0,80	16,00	16,00	20%	3,20	20%	3,20
	TOTAL SHIPS SERVICE AUXILIARIES					**50,13**		**5,65**		**7,57**
	HELICOPTER AUXILIARIES									
E802	Heli fuel pump skid	1	1,50	0,80	1,20	1,20	0%	0,00	0%	0,00
E346	Heli foam water pump	1	30,00	0,80	24,00	24,00	0%	0,00	0%	0,00
	TOTAL HELICOPTER AUXILIARIES					**25,20**		**0,00**		**0,00**
	THRUSTERS									
	Bow thruster	1	300,00	0,80	240,00	240,00	0%	0,00	0%	0,00
	Stern thruster	1	250,00	0,80	200,00	200,00	0%	0,00	0%	0,00
	TOTAL THRUSTERS					**440,00**		**0,00**		**0,00**
	GALLEY/PANTRY									
	Main Galley Crewdeck									
452	Ceramic cooking plate, supply 1+ 2	1	8,00	0,80	6,40	6,40	10%	0,64	40%	2,56
452	Induction cooking plate, supply 1+ 2	1	5,00	0,80	4,00	4,00	10%	0,40	40%	1,60
452	Ice cube maker	1	0,67	0,80	0,54	0,54	5%	0,03	10%	0,05
452	Refrigerator	2	0,23	0,80	0,18	0,37	5%	0,02	5%	0,02
452	Dlshwasher	2	5,00	0,80	4,00	8,00	5%	0,40	5%	0,40
	TOTAL GALLEY AND PANTRY					**19,30**		**1,49**		**4,63**
	LAUNDRY									
E453	Washing machine	6	5,50	0,80	4,40	26,40	20%	5,28	60%	15,84
E453	Dryer	6	6,44	0,80	5,15	30,91	20%	6,18	60%	18,55
E453	Steam iron	1	0,85	0,80	0,68	0,68	20%	0,14	60%	0,41
	TOTAL LAUNDRY EQUIPMENT					**57,99**		**11,60**		**34,80**
	NAUTICAL ELECTRICAL/NAUTICAL									
E513	Battery charger General service	1	1,20	0,80	0,96	0,96	10%	0,10	10%	0,10
E516	Normal lighting (interior)	300	0,01	0,80	0,01	2,40	50%	1,20	50%	1,20
	Emergency lighting guests (interior)	400	0,01	0,80	0,01	3,20	10%	0,32	50%	1,60
E518	Exterior lighting	770	0,01	0,80	0,01	6,16	50%	3,08	50%	3,08
E561	Alarm and monitoring installation	1	2,00	0,80	1,60	1,60	10%	0,16	10%	0,16
	TOTAL ELECTRICAL EQUIPMENT					**14,32**		**4,86**		**6,14**
	HVAC OUTSIDE TEMPERATURE +20									
	Preheaters AC1-AC5	1	52,00	1,00	52,00	52,00	0%	0,00	0%	0,00
	Fans AC1-AC5 (frequency controlled)	1	27,50	1,00	27,50	27,50	35%	9,63	75%	20,63
	Waterchillers 1-4 (frequency controlled)	4	63,00	1,00	63,00	252,00	25%	63,00	63%	158,76
	Supply fans accommodation	1	7,00	1,00	7,00	7,00	100%	7,00	100%	7,00
E761	Auxiliary seawater circulating pump	2	15,00	1,00	15,00	30,00	50%	15,00	50%	15,00
E762	Auxiliary Freshwater circulating pump	2	30,00	1,00	30,00	60,00	50%	30,00	50%	30,00
	Fresh air unit crew fan	1	1,10	1,00	1,10	1,10	100%	1,10	100%	1,10
	TOTAL HVAC EQUIPMENT					**429,60**	**0%**	**125,73**	**0%**	**232,49**
						1.174		**168**		**304**
	TOTAL LOAD						**HARBOUR**			**472**

The above list with consumers and their maximal electric consumption, under the various standard circumstances, is called the load balance.

This is a shortened example of such a list. A realistic list with 'all' consumers would take a considerable number of pages.

MANOEUVRING				SAILING				EMERGENCY	
CREW		CREW AND GUESTS		CREW		CREW AND GUESTS			
% MAX	LOAD	% MAX	LOAD	% MAX	LOAD	% MAX	LOAD	%MAX	LOAD
50%	7,84	50%	7,84	50%	7,84	50%	7,84	50%	7,84
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
100%	0,88	100%	0,88	100%	0,88	100%	0,88		0,00
50%	1,20	50%	1,20	50%	1,20	50%	1,20		0,00
25%	2,20	25%	2,20	25%	2,20	25%	2,20		0,00
25%	0,07	25%	0,07	25%	0,07	25%	0,07		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00	100%	14,00
50%	12,00	50%	12,00	50%	12,00	50%	12,00	50%	12,00
	24,19		24,19		24,19		24,19		33,84
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	100%	0,53	0%	0,00	100%	0,53		0,00
20%	1,92	40%	3,84	0%	0,00	0%	0,00		0,00
20%	3,20	20%	3,20	0%	0,00	0%	0,00		0,00
	5,12		7,57		0,00		0,53		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
	0,00		0,00		0,00		0,00		0,00
80%	192,00	80%	192,00	0%	0,00	0%	0,00		0,00
80%	160,00	80%	160,00	0%	0,00	0%	0,00		0,00
	352,00		352,00		0,00		0,00		0,00
5%	0,32	20%	1,28	5%	0,32	20%	1,28		0,00
5%	0,20	20%	0,80	5%	0,20	20%	0,80		0,00
5%	0,03	10%	0,05	5%	0,03	10%	0,05		0,00
5%	0,02	5%	0,02	5%	0,02	5%	0,02		0,00
5%	0,40	5%	0,40	5%	0,40	5%	0,40		0,00
	0,97		2,55		0,97		2,55		0,00
20%	5,28	60%	15,84	20%	5,28	60%	15,84		0,00
20%	6,18	60%	18,55	20%	6,18	60%	18,55		0,00
20%	0,14	60%	0,41	20%	0,14	60%	0,41		0,00
	11,60		34,80		11,60		34,80		0,00
10%	0,10	10%	0,10	10%	0,10	10%	0,10	30%	0,29
50%	1,20	50%	1,20	50%	1,20	50%	1,20		0,00
10%	0,32	50%	1,60	10%	0,32	50%	1,60	100%	3,20
50%	3,08	50%	3,08	50%	3,08	50%	3,08		0,00
10%	0,16	10%	0,16	10%	0,16	10%	0,16	50%	0,80
	4,86		6,14		4,86		6,14		4,29
0%	0,00	0%	0,00	0%	0,00	0%	0,00		0,00
35%	9,63	75%	20,63	35%	9,63	75%	20,63		0,00
25%	63,00	50%	126,00	25%	63,00	50%	126,00		0,00
100%	7,00	100%	7,00	100%	7,00	100%	7,00		0,00
50%	15,00	50%	15,00	50%	15,00	50%	15,00		0,00
50%	30,00	50%	30,00	50%	30,00	50%	30,00		0,00
100%	1,10	100%	1,10	100%	1,10	100%	1,10		0,00
0%	125,73	0%	199,73	0%	125,73	0%	199,73		0,00
	524		627		167		268		
MANOEUVRING			1.151	SAILING			435	EMGY	38

1.6.4 Manoeuvring with guests

Again this is the up-scaled version of the previous condition. The effect will be a higher connected load. As there will be enough electrical power all consumers can be connected with the same restrictions as mentioned before

The resulting expected electrical loads are shown in the example of the load balance in the column "manoeuvring with crew and guests"

1.6.5 Sailing without guests

In this condition the power management system will limit the total generated power to one generator. This will be an environmentally friendly profile where the load of one generator is limited to an optimum 95%.

When required the power management system will temporarily reduce the load of some consumers like the HVAC system or switch off the non essential consumers.

The resulting expected electrical loads are shown in the example of the load balance in the column Sailing with crew.

1.6.6 Sailing with guests

This is the extended version of the previous condition with the HVAC systems for crew and guests at full capacity. The actual power consumption will depend on the outside temperature.

The power management system will control the total generated power and will normally connect one or two generators.

The resulting expected electrical loads are shown in the example of the load balance in the column Sailing with crew and guests.

1.6.7 Emergency mode

In an emergency the consumers as listed will have to be supplied.

Sufficient spare capacity should be part of the design to allow starting of the largest emergency pump and distribution losses.

The resulting expected electrical loads are shown in the example of the load balance in the column "Emergency"

TYPE CONSUMER	OPERATIONAL	HARBOUR		MANOEUVRING/DP		SAILING		EMERGENCY
	PROFILES	CREW	CREW AND GUESTS	CREW	CREW AND GUESTS	CREW	CREW AND GUESTS	
PROPULSION AUXILIARIES		33,40	33,40	62,52	62,52	62,52	62,52	0,00
SHIPS SERVICE AUXILIARIES		27,58	74,90	5,12	50,54	0,00	43,50	0,00
HELICOPTER AUXILIARIES		0,00	0,00	0,00	0,00	0,00	0,00	0,00
THRUSTERS		2,00	2,00	360,40	360,40	0,00	0,00	0,00
GALLEY/PANTRIES		3,30	16,95	3,35	13,41	3,35	13,59	0,00
LAUNDRIES		10,79	32,38	10,79	32,38	10,79	32,38	0,00
NAUTICAL		18,36	27,44	18,56	27,64	18,56	27,64	0,00
SUBTOTAAL		**95,43**	**187,06**	**460,74**	**546,88**	**95,22**	**179,62**	**0,00**
EMERGENCY								
HEATING/VENT/AIRCO	MINUS 5	299,02	436,01	299,02	436,01	299,02	436,01	0,00
	ZERO	275,74	365,64	275,74	365,64	275,74	365,64	0,00
	PLUS5	235,10	302,03	235,10	302,03	235,10	302,03	0,00
	PLUS10	220,14	282,36	220,14	282,36	220,14	282,36	0,00
	PLUS15	171,80	260,12	260,12	260,12	171,80	260,12	0,00
	PLUS20	136,73	243,49	136,73	210,73	136,73	210,73	0,00
	PLUS25	162,87	239,39	162,87	239,39	162,87	239,39	0,00
	PLUS30	229,97	242,11	229,97	242,11	229,97	242,11	0,00
	PLUS35	262,73	272,35	262,73	272,35	262,73	272,35	0,00
AVAILABLE GEN CAPACITY		295,00	587,00	880,00	880,00	309,00	588,00	207,00
GENERATORS RUNNING		1,00	2,00	3,00	3,00	1,00	2,00	1,00
GENERATOR CAPACITY		309,00	309,00	309,00	309,00	309,00	309,00	180,00
GEN TOT. CAP.		**309,00**	**618,00**	**927,00**	**927,00**	**309,00**	**618,00**	**180,00**
%GENERATORCAPACITY		0,95	0,95	0,95	0,95	0,95	0,95	0,95
GEN TOT. CAP. AFTER CORR.		**293,55**	**587,10**	**880,65**	**880,65**	**293,55**	**587,10**	**171,00**
AVAILABLE FOR HVAC		**198,12**	**400,04**	**419,91**	**333,77**	**198,33**	**407,48**	**171,00**

Summary sheet of a load balance. Green marked cells are within capability of generators.

1.7 Load balance small sailing-yacht

Although not obvious, a small sailing boat will also require a load balance of some sort.
A single line for a yacht like this is shown in chapter 33. This yacht has a shore supply, a dynamo on the main engine and a solar-cell and/or a wind-generator.

In port the primary supply will be the shore supply, taking care of heating, cooking, ventilation and battery charging.

When sailing there are two modes:
- running on the engine and charging the batteries with the dynamo.
- sailing on wind power and charging the batteries with the wind generator in combination with the solar cells.

The capacity of the solar cells and the wind generator is very limited when compared to the dynamo on the engine and heating and/or cooking with the engine off may very well be impossible.

Only some lighting and some communication may be possible for a longer period when on sails only.

Therefore cooking on sailing boats is seldom done using electrical power. Normally gas (butane or propane) or kerosene is used.

When the battery power gets low the engine must be started to charge this again. Failing to do so will cause communication systems to fail after some time which could jeopardise safety of the crew in an emergency.
For that reason often battery condition meters are installed.


VOLVO OPEN 70
USA 7706
WALT DISNEY PICTURES
PIRATES of the CARIBBEAN
USA 7706
www.VolvoOceanRace.org
PIRATES of the CARIBBEAN

6. MAINS VOLTAGE SELECTION

In general, the price of electrical equipment rises with the voltage. Consequently the cheapest electrical installation is fitted in an automobile: 12V DC, with hull return. This kind of installation is limited to small craft. Trucks, which have a higher power demand, use 24V DC.
For ships, the normal electrical installations use either 400/230V 50Hz or 440V 60 Hz. The latter voltage is somewhat impracticable, as no standard light bulbs are available and transformers are needed to overcome this problem. Nevertheless, this voltage is widely used.

1 Switch-gear low voltage

Switch-gear has two design criteria: thermal capability and physical strength.
The thermal short-circuit capability of standard low-voltage switchgear is based on a nominal voltage of maximum 500V both 50Hz and 60Hz.
The short-circuit strength of busbar systems for the same (low) voltage as above is maximal 220kA (peak), in line with the load limit of the largest breaker on the market. This breaker has a breaking capability of 100kA RMS (root mean square).

RMS is the effective value of AC voltage and current compared with DC voltage and current.
For example the effective voltage of 142V peak AC is about 100V and measuring instruments are calibrated in RMS voltage and currents.

The 100 kA current during short-circuit conditions is equal to a nominal load of 7500 A. (based on a ratio: nominal current / short-circuit current of 1/13. See short-circuit calculations in part 7), which equals 5MVA at 400V / 50 Hz to 6 MVA at 450V / 60 Hz.

At 450V this could be an installation with three generators, each 2000 A, suitable for continuous parallel operation.

Also cable-wise this is close to the installation limits, as the power cables from the generator to the switchboard could be:
10 cables each 3x95 mm^2, filling a 500 mm wide cable tray. The next step up in switchgear is: 6600V, followed by 12,000V and 24,000V. The maximum practicable value for ships is 15,000V.

In Europe, land based industrial installations normally operate on an electrical distribution system of 3-phase, four-wire 400/230V 50Hz.
The advantage is that the switchgear components are easy to obtain and relatively cheap.
In the USA, however,, a distribution system of 3-phase 3-wire 450V / 60Hz is used in combination with 110V / 60Hz for the lighting. Lighting transformers are therefore required, as the delta voltage from a 450V network is about 280V, which has to be converted to 110V by transformers.

A 400V / 50Hz generator at 1500 RPM, when rotating at 1800 RPM, produces about 480V and consequently 60 Hz.
A standard 400V / 50Hz 1500 RPM electric motor produces 20% more power when fed with 480V / 60Hz and rotates at 1800 RPM.

The link between voltages and 50-60 Hz is almost linear.

If America changed to the European 400V / 50 Hz generators and motors, the 60 Hz voltage would go up to 480V.
As already mentioned, the capability of low-voltage switchgear is limited to about 100 kA RMS or 220 kA (peak), which limits the total generator capacity to about 5 to 6 MVA depending on the short-circuit figures.

To accommodate the increase in electrical power demand on for instance large offshore platforms or wind-turbine installation vessels more often a primary voltage of 690V-60Hz is selected.
The down-side of this selection is that most switch-gear has a proportional decrease in short-circuit making and breaking capacity when the voltage increases above 500V.
But as Owners are reluctant to introduce high-voltage systems, as these would require specially trained staff and special tools and spares, the 690V systems are more and more favoured.

Ship, without cranes, has 3 generators of 500 KW each, one running in port, one at sea and two during manoeuvring.

Quantity and rating of generators depends on the load balance with the load requirements in various conditions.

Harbour load 500 kW / Sea load 1000 kW is a usual value for a non-complicated ship like a bulk-carrier without cargo- handling equipment.
Harbour load 2000 kW / Sea load 1000 kW is normal for a similar ship, but with heavy cargo-gear (cranes), which requires different generator capacities.
An electrically propelled ship could need a harbour load at 1000 kW, manoeuvring, 3000 kW and when underway at maximum speed, 7000 kW.
This can be supplied by two sets of 1000 kW and two sets of 2500 kW, with the short-circuit characteristics still 450 V / 60 Hz.

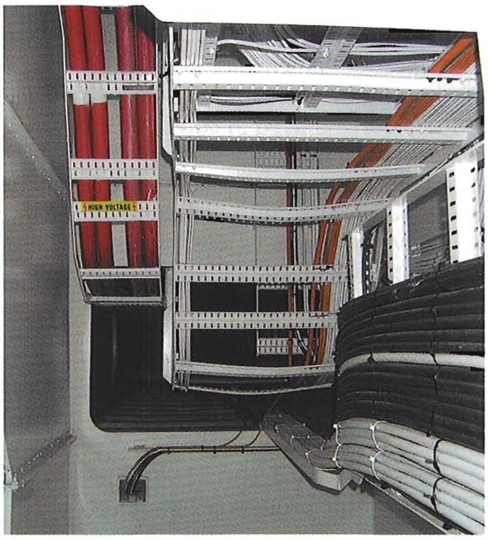
This is close to the limit, as the maximum rating of a low- voltage circuit breaker is 6300 A, sufficient to cope with the 2500 kW generator.

In summary, up to 5000 to 7000 kW: 400 V / 50 Hz or 450 V / 60 Hz is possible.
The next commercially feasible step with respect to availability of switch-gear, generators, motors and cables is 6600 V / 50 or 60 Hz.
Most rotating equipment and transformers for these loads have to be produced specifically, anyway.

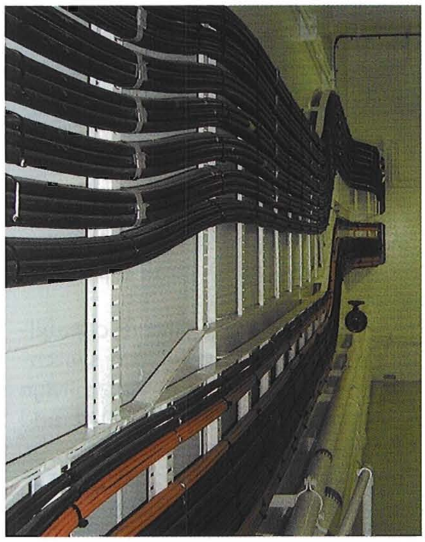
IEC 61892-2, the International Electro technical Commission's standard for Mobile and fixed offshore units Electrical installations, recommends the voltage levels as shown in the table.

Another possibility is to limit the total connected generator capacity to a bus-bar by disconnecting sections by bus-section circuit breakers so that the short-circuit-level is limited to the switchgear capacity.

Cruise-ships are mostly diesel-electric and have 6.6 kV / 60 Hz electrical systems which require 8-9 MVA.



Two 3000kW high-voltage cable runs (2 x 2 red cables on the left)



3000kW low-voltage cable run

Alternating current (AC) distribution systems IEC 61892-2

Voltage	Type	Application
11kV - 3-phase	Generation and distribution voltage	Installed generator capacity exceeds 20MW Motors from 400kW and above for DOL starting
6,6kV - 3-phase	Generation and distribution voltage	Installed generator capacity is between 4MW to 20MW Motors from 400 kW and above for DOL starting
3,3kV - 3-phase	Distribution voltage	Second high-voltage distribution level for large consumers.
690V - 3-phase	Generation and distribution voltage	Installed generator capacity is below 4MW Motors below 400 kW for DOL starting primary voltage for converters for drilling motors.
400V - 3-phase	Distribution voltage	Living Quartres, Kitchen and Laundry larger equipment
400/230V TN-S	Distribution voltage	Lighting and small power single-phase heaters below 3kW incl. heat tracing
UPS 230V IT	Distribution voltage	Instrumentation, control, telecommunication and safety systems
230V IT ESB	Distribution voltage	Emergency power supply systems
230V TN-S ESB	Distribution voltage	Emergency lighting and small power

2 Switch-gear high voltage

The lowest rating for switch-gear and cables commercially available is 7200V. This leads to the nearest standard voltage of 6600 V / 50 Hz or 60 Hz. The next steps are 12.000 V and 24,000 V, 50 Hz or 60 Hz.
So far, the maximum installed voltage system is 15,000 V, which is the highest commercial voltage of a ship generator without the requirement for a step-up transformer. Most diesel-electric ships have a high-voltage distribution system. Some have separate generator sets for low voltage power and lighting, but most have transformers to create the low voltage. The dimensions of switch-gear, cable sizes and weights also influence the use of a high-voltage distribution system.

Container ships with refrigeration, in general, have a 6.6 kV / 60 Hz installation with a PTO generator (main-engine driven generator) with a capacity of 3-4 MVA and auxiliary generators with a capacity of 2 or 3 times 2 MVA. The required power when loading or discharging cargo in port would be 3-4 MVA.

3 Cables

Cables are the transport medium for current and power.
Apart from the limitations of switch-gear, selection of high voltage reduces the quantity of cables required to deliver a certain amount of power. For example 3000kW thruster supplied from a 690V - 60Hz power supply, requires 15 parallel cables 3x95 mm² or 18 single cores 240mm².
The same thruster supplied by a 6.6kV distribution system would consume less than 300A and can be supplied by a single 3x185mm² high-voltage cable.
By using high-voltage the space required and weight for cabling is substantially reduced.
In addition to saving weight the use of a high-voltage system will also reduce the cost for installation, steel-work and penetrations as there are less cables involved.
Commissioning of high-voltage cables does also require a high-voltage test when the cables are fixed.

4 Generators and motors

Standard generators and motors in high-voltage execution are not very different in appearance and cost from low-voltage standard motors.
Azipod propulsion systems are only available in high-voltage execution.

DP crane-vessel and J-lay Pipe-layer equipment.

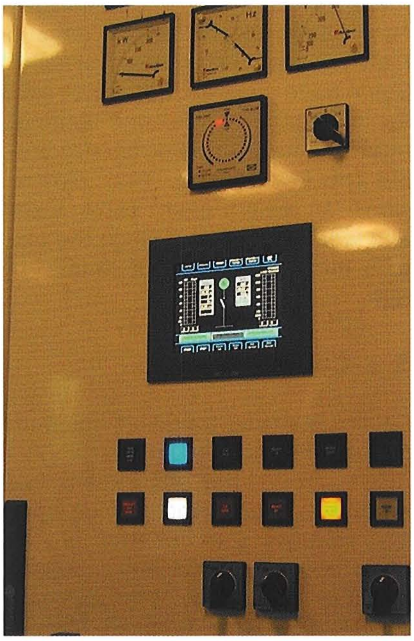
5 New developments DC systems

Semi-conductor converters are under rapid development, with prices going down and quality improving with lower harmonics. Semi-conductor converters make it possible to control stepless the speed of a fan to produce just the required air-flow, a pump to produce the required liquid flow or a compressor to produce the required amount of compressed gas.
For example the cooling-water pump for an airconditioning system can have its speed adjusted to the cooling demand. This saves energy as the air does not have to be heated first and cooled afterwards to achieve and maintain the desired temperature in the space to be cooled. Similarly, the cooling-water pumps for an engine, when regulated by this type of converters, produce sufficient flow to keep the engine at the correct temperature, using as parameters the water temperature, the air temperature and the engine load.
Water chillers which produce the right amount of chilled water as demanded by the various systems are also more environmentally friendly and energy-saving. Excess cold used to be dumped, wasting energy.
Generator sets will produce the required power first at AC, with a constant frequency.
When converted via DC into AC with variable voltage and frequency, they can supply an AC motor with power at the most efficient speed.
Also electric heaters can be stepless controlled by semi-conductor devices.
Of course, there are also items of the electrical system that require a fixed voltage and a fixed frequency, but these are limited.

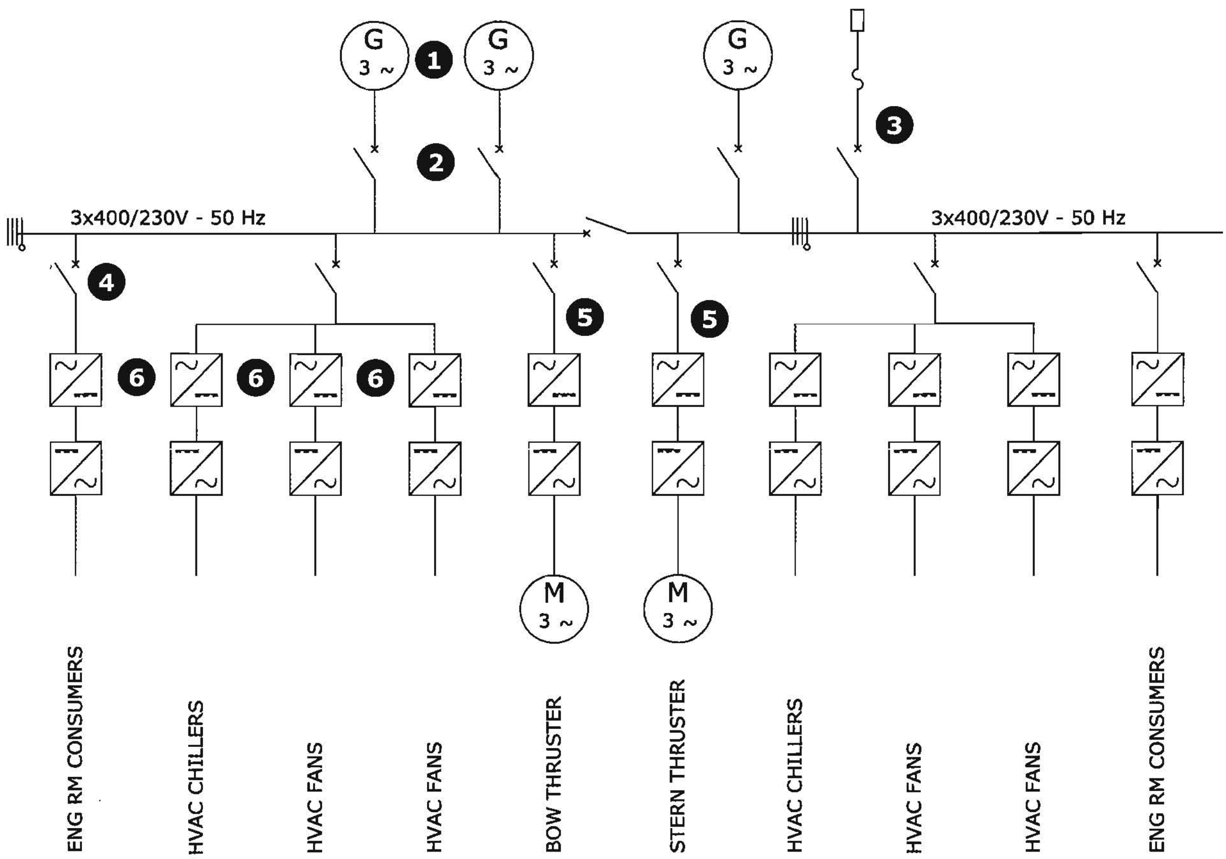
Having a look at the above one-line diagram, with equipment based on the load-balance, the 'normal' today's solution requires many components/parts:

1. Two or more diesel-generators producing constant voltage, constant frequency and sinusoidal rotating voltage,
2. A generator control panel with an AC circuit breaker and synchronising and loadsharing equipment,
3. Complicated shore connections with converters to adapt to the shore voltage and frequency, converting this power to the required power for the ship,
4. Out-going groups with AC circuit breakers supplying AC throughout the ship,
5. Large frequency converters for bow and stern thrusters to limit starting currents, and preventing voltage drops,
6. Many small frequency converters for single consumers or groups of consumers requiring the same frequency.

Note: sometimes filters are added to eliminate distortions and create a "clean" distribution system



Generator control panel



Stepping back to look at the real requirements for this installation gives a different approach with the following list (above diagram):

1. Diesel-generators producing electric energy.
2. Shore connections converting shore power into the ship's energy system.
3. Converters converting this electric energy into suitable voltage and frequency for the single consumers and groups of consumers.
4. Two relatively small converters converting the ship's energy into a clean constant voltage and constant frequency system for dedicated consumers.

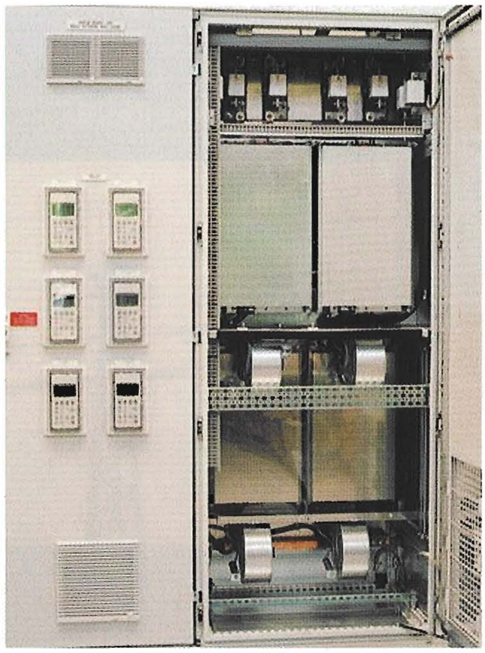
The ship's energy system could also be designed and installed using DC as main power. When designed in accordance with the still existing, but outdated classification rules, with the consequence of complicated DC switch-gear, this would reduce the feasibility due to complexity, cost and maintenance.

Reducing the DC distribution rules to their basics: safe to operate, reliable, self-monitoring and self-protecting, there could be a more feasible design and installation in accordance with today's state-of-the-art solution.

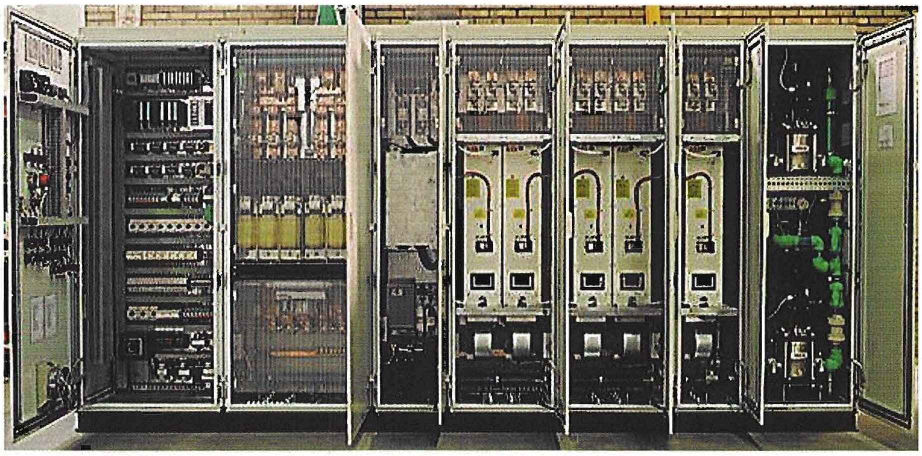
Using today's semi-conductor switching devices, to connect and disconnect under normal operating conditions up to their switching capabilities, protected by high speed DC fuses against short-circuits, could result in a more simple system.

The bus-bar separation, same as required in an AC system and division of essential duplicated consumers over these two sections would lead to a redundant system.

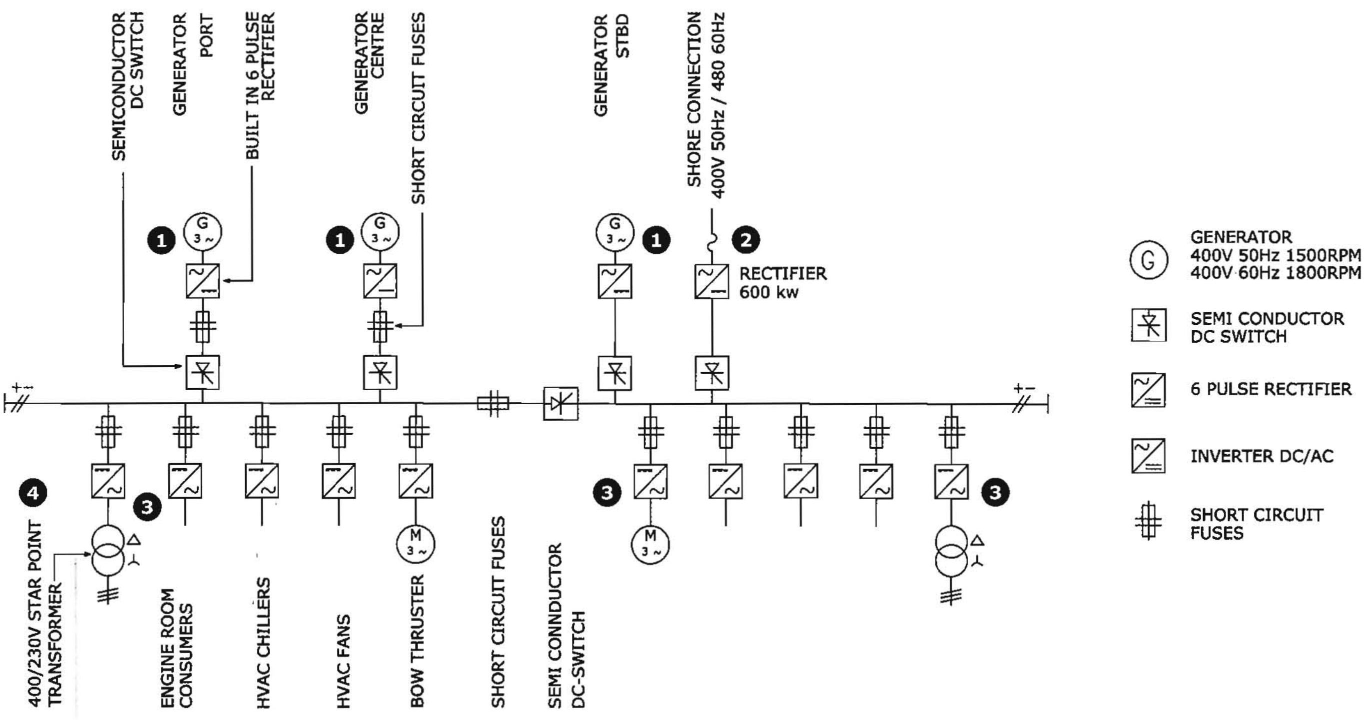
A Failure Mode and Effect Analysis (FMEA) for the first new designs could help to get the rules adapted and the design approved.



DC-DC converter



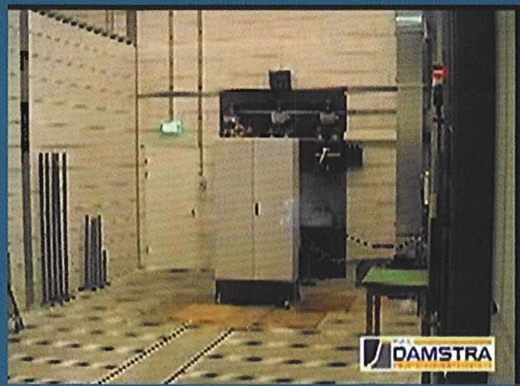
AC-AC converter

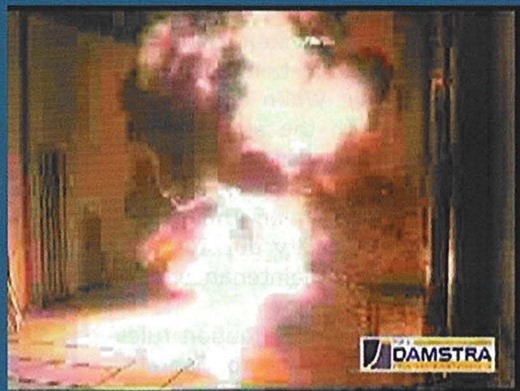


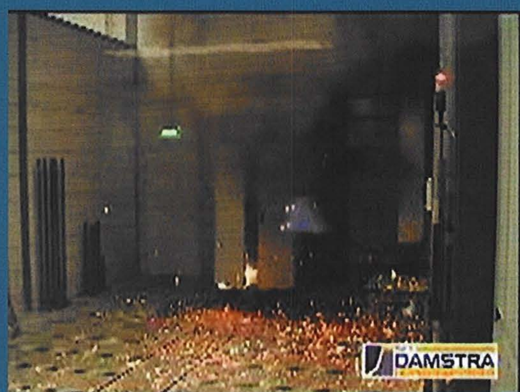
DC one line with short-circuit fuses and semiconductor DC switches

Accident

Test







7. SHORT-CIRCUIT CALCULATION

Short-circuit calculations are needed to determine the required switching capabilities of the circuit breakers, the breaking capabilities of fuses and the dynamical strength of bus-bars and other current carriers.

Type-approved and type-tested bus-bar systems and switchboard assemblies are sufficiently available so that custom design of these components is not necessary.

1 Short-circuit behaviour of generators

A high short-circuit capacity is commercially undesirable as it increases the cost of the switchgear., however,, a fixed relation exists between the nominal capacity of a generator and the ability to produce larger currents. For instance when an electric motor is started within the limitations of the voltage dips.

On the left page a set of photos is shown of an accident and a test-initiated arc in a low voltage 400 V 50 Hz distribution panel with a short-circuit level of only 15kA RMS.

1. Short-circuit accident.
A large mobile crane, outside, came too close with its jib to an overhead high-voltage distribution lane. An arc develops, as the crane has earth via retractable supports, being set down at the time of the accident.
When the fault has been cleared by an upstream circuit breaker, both the crane and the asphalt road are still on fire.

2. Short-circuit test in a laboratory
In a standard electrical cabinet, two bus-bars are installed vertically.
Between the bus-bars a thin conductor is fitted horizontally.
When the bus-bars are connected to a high voltage supply, the short-circuit is arranged via the thin conductor, resulting in an arc.
The thin conductor melts instantly, but the arc is maintained.
After 3 seconds the power supply to the bus-bars is disconnected.

Instantaneous behaviour of a generator is generally the result of the dimensions of that generator and is not influenced by a control system such as an automatic voltage regulator.

In short, a generator with a low reactance is capable of supplying large starting currents without excessive voltage dips, when starting a large motor.
A low-reactance generator will also produce large currents when short-circuited. This requires more expensive switch-gear.
A high-rectance generator is not capable of producing the starting currents of large motors. This type of motors will then require star delta starters, auto-transformer starters or even soft electronic starters to keep the voltage within the limits of the generator.

A generator needs to be able to produce a short-circuit current which is large enough to trip a circuit breaker or interrupt a fuse anywhere in the system. When the generator is not able to produce this current the circuit breaker or fuse will not disconnect a short-circuit.
When this short-circuit is not interrupted in time this may lead to a fire. Short-circuit capability is therefore an essential feature of a ship's generator.

Voltage dips caused by starting and stopping of large consumers have to be limited to the minimum figure that causes failure of the other consumers. Contactors open at coil voltages lower than 65% of nominal. Incandescent lights flicker at voltages below 80% of nominal.
Fluorescent lights show a change below 90% and the halogen lights used on yachts already react when the voltage drops to 95% of the nominal voltage.

2 Short-circuit current of AC systems

In the absence of precise data the prospective fault current for alternating-current systems on the main switchboard may be estimated to be the sum of: 10 times the full load rated current for each generator that may be connected.
The value obtained above is approximately the symmetrical RMS current and a value for the breaking capacity of the circuit breakers and fuses.
At a power factor of 0.1 the associated peak value of the short-circuit current is approximately 2.5 times the above value.
This peak value should be taken into account when determining the making capacity of circuit breakers and the required mechanical strength of the bus-bar system.
The peak value determines the forces between the bus-bars.
Example of calculation in chapter 4.

3 Short-circuit current of DC systems

The short-circuit current of batteries at their terminals can be calculated as follows:

- 15 times the ampere hour rating of the battery, for battery systems intended for a low rate of discharge, such as a battery duration exceeding 3 hours.
- 30 times the ampere hour rating of the battery, consisting of sealed lead acid cells or alkaline cells having a capacity of 100 Ah or more, intended to discharge at high rates, corresponding to a battery duration of less than 3 hours.
- to get the total short-circuit current in a DC system, 6 times the full-load current of all DC motors in service should be added to the values as found for the batteries.

When the prospective short-circuit values obtained, with the quick check as described above, exceed the maximum allowed values, more detailed calculations must be made.
When making detailed short-circuit calculations for AC systems in ships these should be based on 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. systems.

Particular to ships are the short cables in combination with the sometimes high prospective short-circuit currents.
It must be noted that the majority of design offices use special computer programs, like Etap and EDSA, to model the electrical system and calculate short-circuits.

4 More advanced short-circuit calculations AC systems

The calculations start with a simple estimate, without any figures from the generator and is based on general experience, followed by a simple improvement involving some data from the generator.
A third still relatively easy improvement, giving, however, a less significant reduction, is a calculation incorporating cable data. In all cases also the contribution of the electric motors in service has to be added.

4.1 First estimate without generator data.

When no detailed generator is available a first estimate of the short-circuit currents can be made. The values for the nominal power and voltage of the generator are selected arbitrarily as an example.

Nominal power S_n (kVA) Example 1000kVA

Nominal voltage U_n (V) Example 400V

Nominal Current I_n (A) Can be calculated from $I_n = \frac{S_n}{U_n\sqrt{3}}$ in this example $\frac{1000}{400\sqrt{3}}$ approximately 1400A.

When no further data is available most classification societies use the following calculation to determine the short-circuit current: I_k RMS $= 10 \cdot I_n$
In this example this would be 14000A (RMS) for one generator. For each additional generator of the same size this value is added so when you have for example three of these generators feeding a switch-board in parallel the Ik RMS will be 42000A or 42kA. This is the current that the circuit breakers and fuses shall be able to interrupt, called the breaking capacity.
Another essential figure is the maximum current that the circuit breaker has to interrupt if closed on a short-circuit. This is indicated as the asymmetrical peak value, in formula $I_{peak} = 2.5\ I_k$ RMS
If no data are available the rule of thumb gives 2.5 times the RMS value so in the example 35000A peak for one generator and 105kA peak for three generators.
This is the current the circuit breaker shall be able to make, called the making capacity.

The capability figures for circuit breakers, like making and breaking capacities, are given in de maker's documentation. When this documentation indicates that a circuit breaker can handle the breaking of a short-circuit only once, one or more spare circuit breakers of the relevant type must be carried on board.
This peak value determines also the maximum forces between the conductors and bus-bars. For bus-bars this value must be used to determine the mechanical strength which the bus-bar system must be able to withstand. With the design of the bus-bar system the outcome of this will be used to select bus-bar supports and their spacing.

4.2 Improved calculation with data from the generator.

When more information is available from the generator the short-circuit calculation can be improved. The example shows the result when the sub-transient reactance of the generator, which is the impedance of the generator directly after a short-circuit in the first 0-6 cycles, would be available which is set here for 12%

Sub-transient reactance X"d (%), in this example 12%

The short-circuit current I_k RMS equals to $I_k\ rms = \frac{I_n}{X''d}$ In this example $\frac{1400}{12\%}$ 12000*A* rms = 12kA

Stator resistance Ra (mΩ) In this example 2mΩ

Stator reactance can be calculated from $Xa = x''d \cdot \frac{U_n^2}{S_n} = 12 \cdot \frac{400^2}{1000} = 19.2$ U_n = the nominal voltage, S_n = the nominal rated power.

From the ratio $\frac{Ra}{Xa}$ which in this example is $\frac{2}{19.2} = 0.1$, the cos φ and the surge factor (See graph on page 52, top)

The result is a cos φ = 0.1 and a surge factor χ = 1.65 The peak short-circuit can then be calculated as :
$I_{peak} = I_k\ rms \cdot \chi \cdot \sqrt{2}$

The outcome is 12000 · 1.65 · √2 equals 28kA peak a substantial lower figure than the earlier result.

4.3 Improved calculation with data from cables

A further but smaller improvement in the accuracy of the short-circuit calculation is to take into account the resistances and impedances of cables connecting the generator to the switch-board.

Rl cable resistance is $Rl = \frac{rl \cdot l}{n}$ Xl = cable reactance. = $Xl = \frac{xl \cdot l}{n}$

rl, xl and l are the specific resistance, specific reactance and length of a cable and n the number of parallel cables.

Example figures per metre cable are as follows:

Cable type	rl (Ω 0.204 per km or mΩ per metre)	xl mΩ per metre 50Hz	and x mΩ 60Hz
3 × 120 mm²	0.164	0.072	0.086
3 × 95 mm²	(200A) 0.204	0.075	0.090
3 × 70 mm²	0.280	0.075	0.092

The generator in this example, with a nominal current of 1400A (see 4.1), can be connected to the Main Switchboard with 7 parallel cables 3 × 95 mm2. When the length of these cables is set to 20 metres the cable resistance can be calculated as follows:

$Rl = \frac{rl \cdot l}{n}$ equal to $\frac{20 \cdot 0.204}{7} = 0.6$ mΩ.

The cable reactance is $Xl = \frac{xl \cdot l}{n} = \frac{20 \cdot 0.075}{7} = 0.22$ mΩ.

The total resistance R = Ra + Rl = 2 + 0.6 = 2.6 mΩ.
The total reactance is X = Xa + Xl = 19.2 + 0.22= 19.4 mΩ.

The impedance $Z = \sqrt{R^2 + X^2} = \sqrt{2.6^2 + 19.4^2} = 20.2$ mΩ.

The short-circuit current I_k RMS = $\frac{U_n}{\sqrt{3} \cdot Z} = \frac{400}{\sqrt{3} \cdot 20.2}$ = 11.8 kA RMS. This is not a big change compared to the previously found result of 12 kA

With the more accurate $\frac{R}{X}$ = 0.14 the surge factor is χ = 1.55 and thus the asymmetrical peak value 1.55√2.11.8 kA or 24.9 kA peak.

The following are the conclusions from the example calculations above for the contribution of a generator to the short-circuit currents.

	4.1 first estimate	*4.2 with gen data*	*4.3 with cable data*
I_k	14kA RMS	12kA RMS	11.8kA RMS
Surge factor χ	2.5	1.65 √2	1.55 √2
I_{peak}	35kA peak	28kA peak	24.9kA peak

4.4 Adding motor data

To complete short-circuit calculations the contribution of running motors must be added. To make this part of the calculation some values have been assumed as an example.
Nominal power S_n (kVA) Example 700kVA
Nominal voltage U_n (V) Example 400V

Nominal Current I_n (A) Can be calculated from $I_n = \frac{S_n}{U_n\sqrt{3}}$ in this example $\frac{700}{400\sqrt{3}}$ approximately 1000A.

When there is no further data available most classification societies use the following calculation to determine the short-circuit current I_k RMS = 3.5 I_n In this example this would be 3500A (RMS)
The surge factor χ can be taken from the generator figures.
The resulting figures for the motor contribution to the short-circuit values are for each type of calculation:

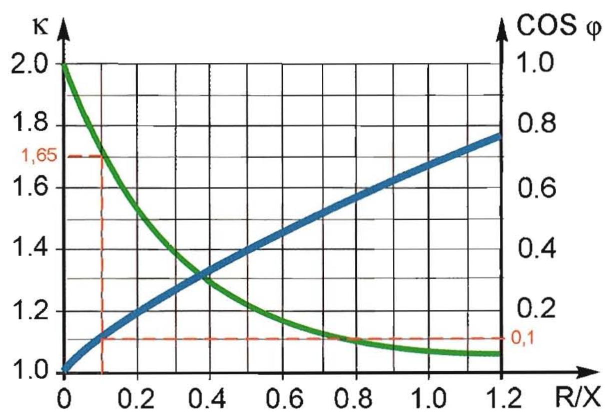
	4.1 first estimate	*4.2 with gen data*	*4.3 with cable data*
I_k	3.5kA RMS	3.5kA RMS	3.5kA RMS
Surge factor χ	2.5	1.65 √2	1.55 √2
I_{peak}	8.75kA peak	8.2 kA peak	7.6 kA peak

4.5 Conclusions

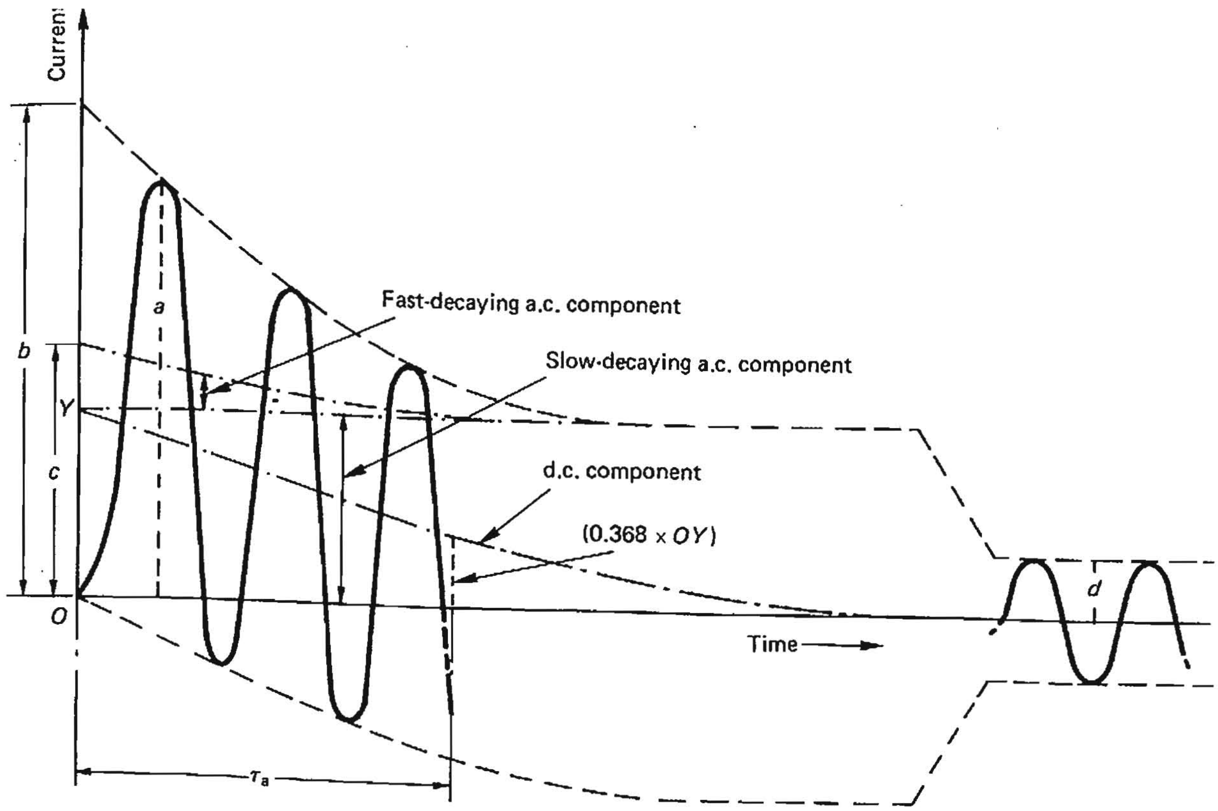
The conclusion from the example calculations above is that when more data is available and there is sufficient time to process this the results will be more accurate.

Generator plus Motor contribution

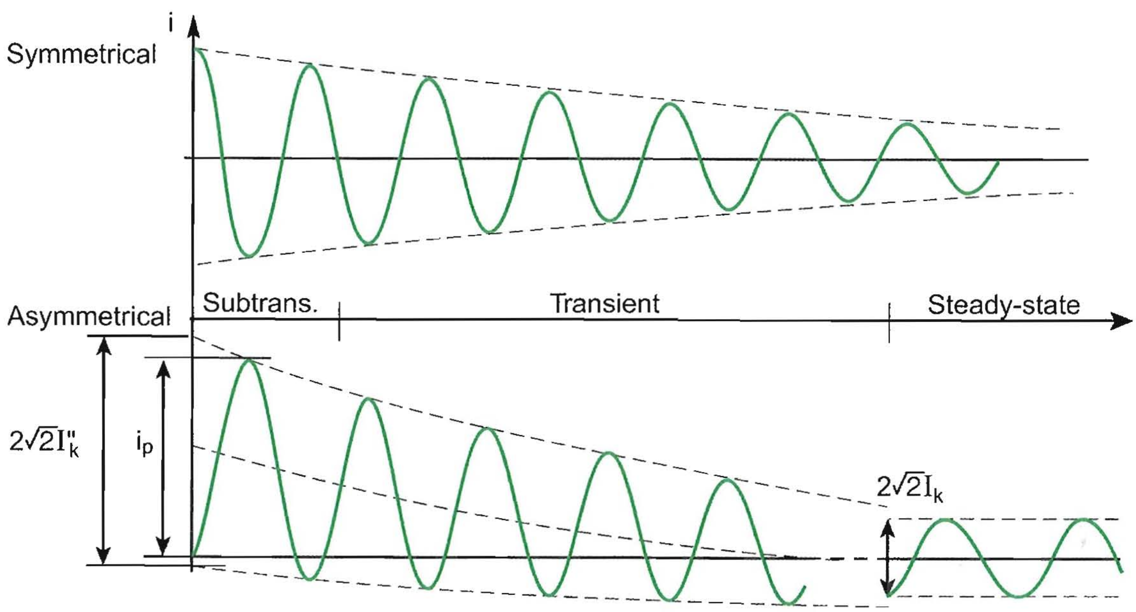
	4.1 First estimate	*4.2 with gen data*	*4.3 with cable data*
I_k total RMS	17.5 kA RMS	15.5 kA RMS	14.9 kA RMS
I_k total peak	43.75kA peak	36.2kA peak	32.5 kA peak



Value of surge factor X in relation to R/X value of net



short-circuit currents close to a generator with details of components



short-circuit currents near a generator (schematic diagram).

5 Mechanical strength of bus-bars

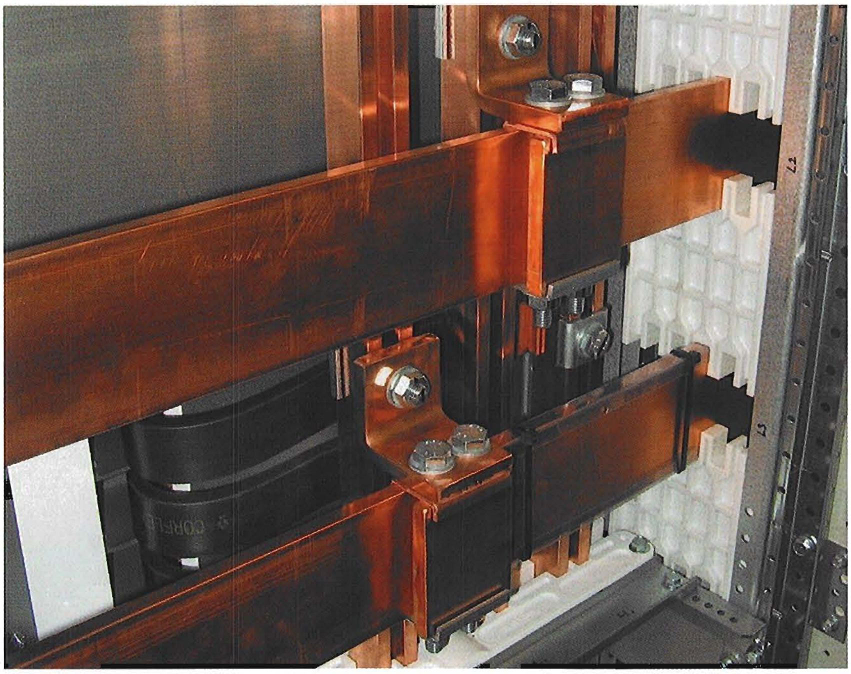
MAX CONTINUOUS CURRENT (AMP)				
	TEMP RISE 50K		TEMP RISE 30K	
BUS BAR CROSS SECTION	1 RAIL	2 RAIL	1 RAIL	2 RAIL
25X5	433	776	327	586
30X5	502	890	379	672
40X5	639	1108	482	836
50X5	772	1317	583	994
60X5	912	1524	688	1150
80X5	1173	1921	885	1450
30X10	756	1300	573	986
40X10	944	1624	715	1230
50X10	1129	2001	852	1510
80X10	1643	2796	1240	2110
100X10	1974	3286	1490	2480

Maximum current ratings of bus-bar systems

Circuit breaker

MAX SUPPORT DISTANCE RELATED TO PEAK CURRENT AND BUS BAR SIZE						
	Ipeak (kA)	11	24	48	63	82
	Irms (kA)	6	12	23	30	39
	BUS BAR					
SINGLE Bus-bar	25x5	1000	527	261	200	154
	30x5	1000	578	286	219	169
	40x5	1000	667	331	253	195
	50x5	1000	746	370	284	218
	60x5	1000	837	416	318	245
	80x5	1000	944	468	359	276
DOUBLE Bus-bar	25X5	1000	746	370	284	218
	30X5	1000	817	406	311	239
	40X5	1000	944	468	359	276
	50X5	1000	1000	524	401	309
	60X5	1000	1000	588	451	342
	80X5	1000	1000	663	508	342

Maximum support distances for bus-bar systems



Main switchboard bus bar supports

6 Thermal rating of bus-bars

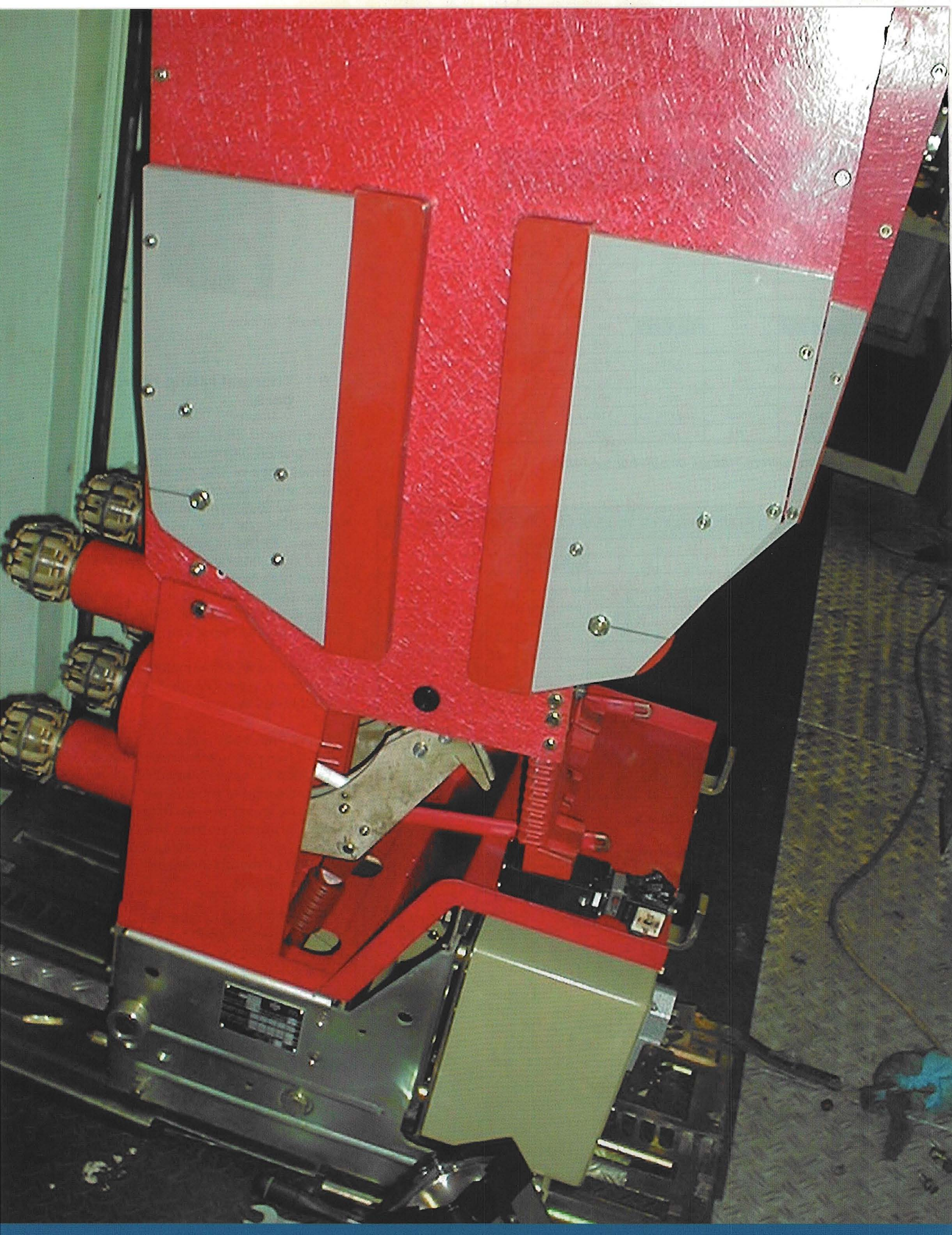
The figures from the short-circuit calculation determine the required capabilities of the circuit breakers and the required strength of the bus-bar system in the switchboard. Switchboards are usually type-tested so the capabilities are verified in a laboratory or assembled from type-tested parts.
Also the bus-bar system is usually manufactured out of type-tested parts as bus-bars and their supports.
The tables give the maximum continuous current (A) for single- and double-rail systems.

Using the basic data and results from the example short-circuit calculation on pages 50 and 51 allows the selection of the bus-bar system for one generator as follows. The results are taken from the calculations with cable data and contribution of motors being Ik" 14.9kA and Is 32,5kA

The 1000kVA generator has a nominal current of 1400A which allows the selection of a double bus-bar system of 60x5mm with a temperature rise of 50C which can carry 1524A

Using this selection the support distance in relation to the peak current can be selected. Selecting the column with Ipeak 48kA and Ik" (RMS) 23kA will be correct in relation to the outcome of the calculations (32.5kA/14.9kA). A maximum support distance of 588mm would be allowed. A practical choice for this would be 500mm.

See the tables on this page for details on which the values related to this example are coloured.



8. CIRCUIT BREAKERS, CONTACTORS AND SELECTIVITY

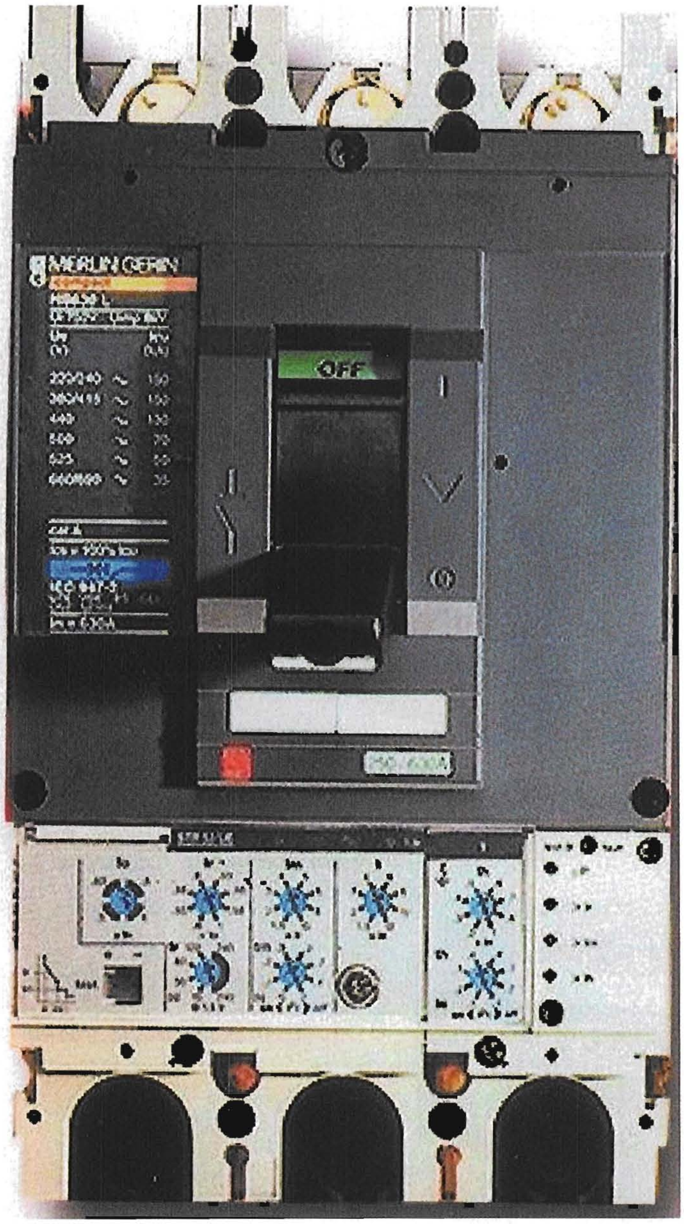
This section explains the differences between a circuit breaker and a contactor, which both make and break a circuit.

The main difference between a circuit breaker and a contactor is that a circuit breaker is designed to detect and switch a short-circuit current and overload current when applicable, whereas a contactor is an automated switch.

1 Circuit breakers and contactors

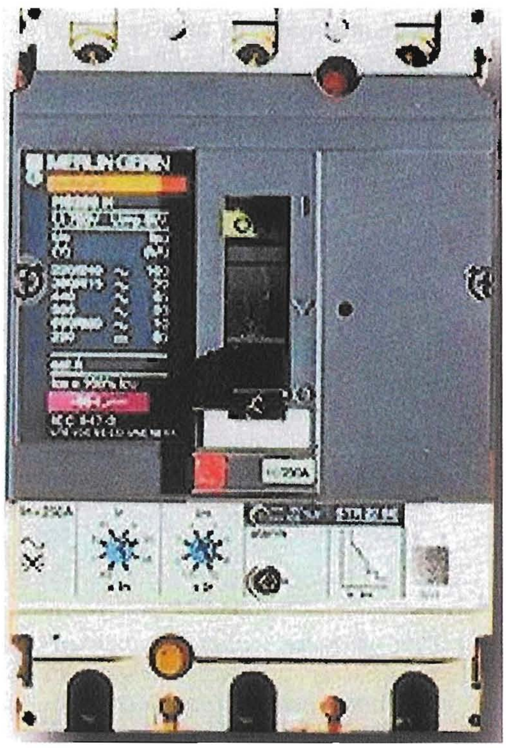
A contactor has far better electrical properties than a circuit breaker, but it is all related to the nominal current.
A small, miniature, circuit breaker with a nominal rating of 16A can interrupt a short-circuit current of 6000 A, which is nearly 400 times the nominal current, however, this can be done only a few times.

A contactor of 16 A can switch on the starting current up to 160 A of a 16 A nominal motor thousands of times.
It also can interrupt the full-load current of 16 A thousands of times.
A contactor will weld or destroy its contacts at 6000 A short-circuit current.



250 Ampere circuit breaker (width 30 cm)

16 Ampere circuit breaker (width 3 cm)



90 Ampere circuit breaker (10 cm)

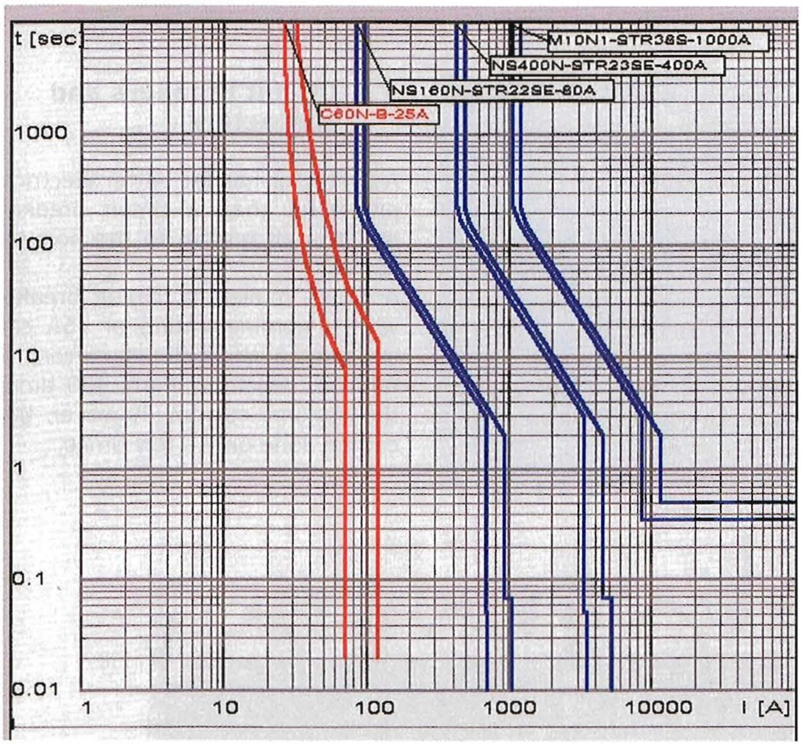
When a contactor is used to interrupt a fault current of more than 10 times the nominal current for which it has been designed for, its contacts will melt together or the contactor explodes.
Contactors have to be protected against fault currents by circuit breakers or fuses.

A circuit breaker is therefore not very suitable for starting a large motor and a contactor is not suitable for interrupting a large current.
The switching capabilities of circuit breakers are given for different conditions.
Some circuit breakers are capable of interrupting a fault current one time only and have to be replaced like a fuse.
Consequently for this type of circuit breakers having spares on board is mandatory.
Moulded-case circuit breakers, especially the current limiting types, can only be replaced as a whole. Replacement of contacts is not possible without special tools available.

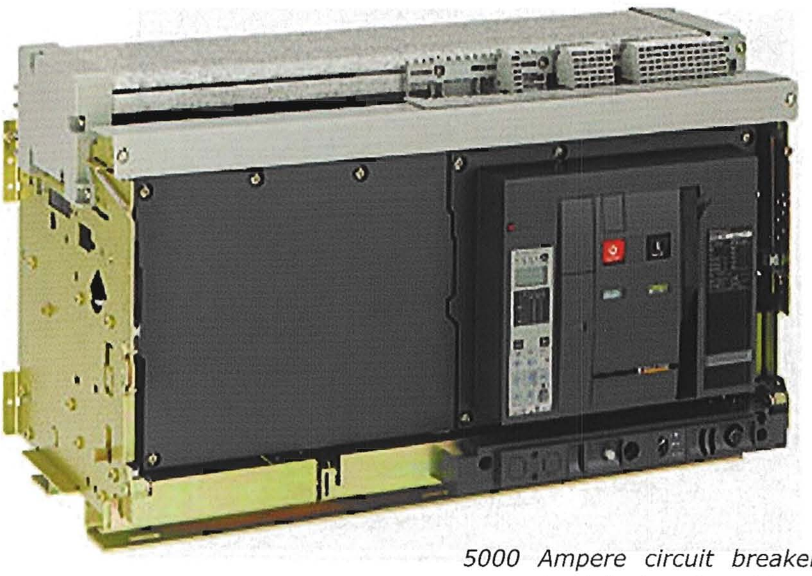
For the purpose of starting a large motor, a contactor is needed, especially if the starting is direct-on-line. Direct-on-line starting will cause a starting current of about 8 to 10 times the nominal current, for which contactors are designed.

A circuit breaker is able to switch on a current about 25 times nominal and break a current about 10 times nominal, but fewer times than a contactor.
The performance figures (data sheet) of circuit breakers and contactors have to be used to determine what is the best solution for a particular system.

Circuit breakers, rated 630A-6300A nominal, have a closing capacity of 220 kA and a breaking capacity of 100 kA for a limited number of operations.



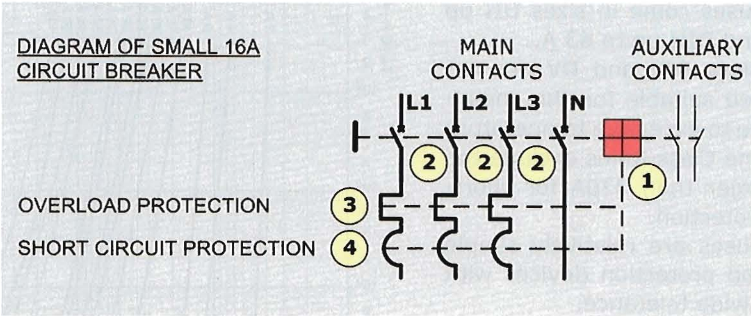
Current versus time characteristic of 4 circuit breakers in series



5000 Ampere circuit breaker, approximately 1 metre wide

1000 Ampere circuit breaker

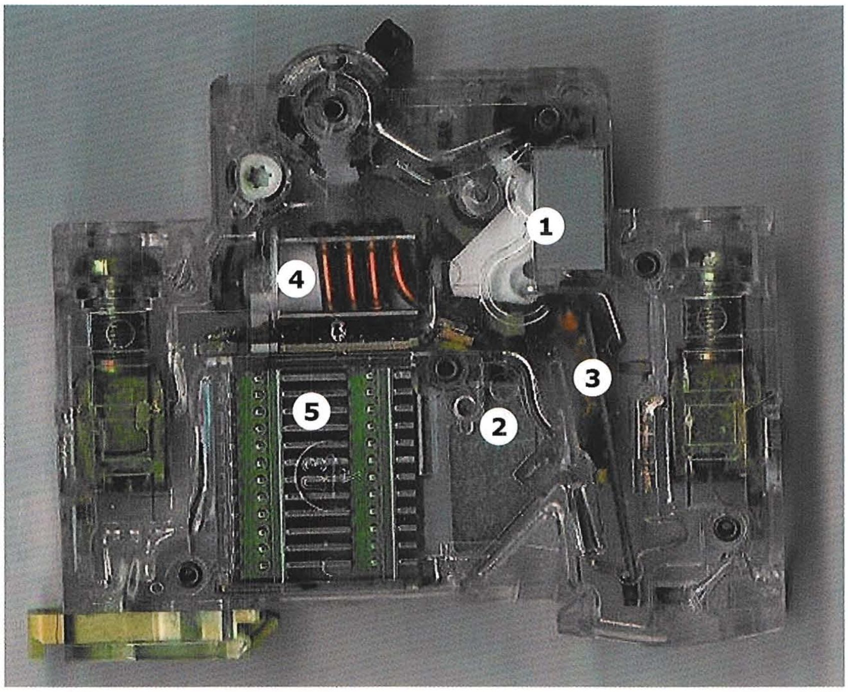
1000 Ampere circuit breaker approximately 0.5 metre wide with different types of protection devices i.e.: generator protection, motor protection or distribution protection relays



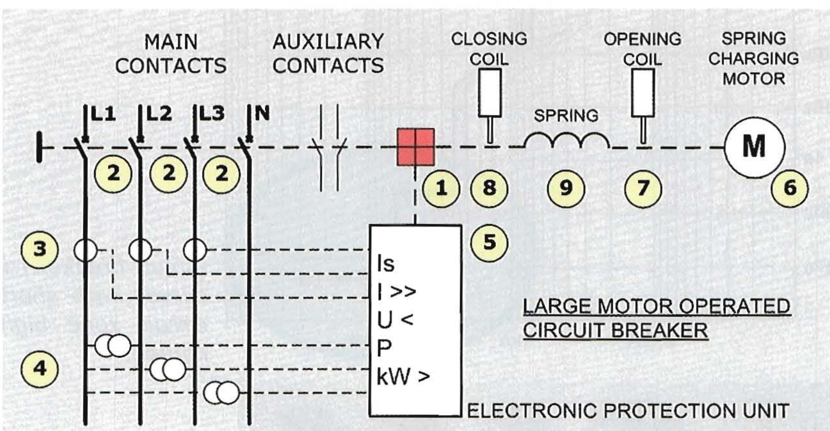
Scheme of a small mechanical circuit breaker 16A.

The picture below shows the components.

1. lock
2. main contacts
3. overload protection
4. short-circuit protection
5. arcing chamber



The 16 Ampere circuit breaker, showing its components needed to interrupt the short-circuit current



Simplified diagram of a large motor operated 1000A circuit breaker.

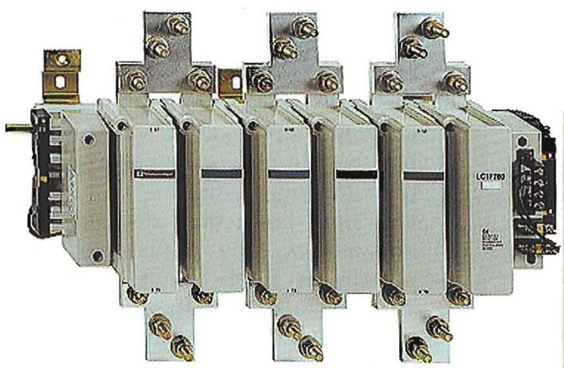
1. lock
2. main contacts
3. current transformers
4. voltage transformers
5. electronic protection unit
6. spring charge motor
7. opening coil
8. closing coil
9. spring

2 Contactors (magnet switches)

The closing mechanism of a contactor is operated by a coil pulling an iron core and thus closing the contacts. Opening is by de-energising the coil and small springs open the contacts. The force of the coil depends on the voltage.

When a large motor is started direct on-line, creating a large voltage drop at the starter and thus at the coil, the contacts may open during the starting current.
AC coils drop out below 80% voltage.
Replacing the AC coil by a DC coil with a saving resistance in series as soon as the contacts are closed allows voltage drops up to 50%.
Also other contactors supplied from the same power source may drop out during load steps.
The voltage dips caused by steploads are to be tested during commissioning of the installation.

Small contactor with a rating of 12A which is about 8cm wide.



Large contactor with two main contacts per phase to obtain a 1000A rating. This contactor is almost 1m wide.

The aim of **selectivity** is to isolate a fault, due to short-circuit or overload, as fast and close as possible to the fault. This is to leave as many systems alive and healthy as possible

3 Selectivity

Selectivity, or discrimination, is the technique to ensure that there is coordination between the operating characteristics of circuit breakers connected in series. The aim of this is to make sure that only the circuit breaker upstream of a fault trips and that other parts of the installation are not affected.

A design should ensure at least minimum selectivity as per classification requirements. Manufacturers of protective devices, such as circuit breakers and fuses, provide selectivity tables for their products which can be used with the design. Also special modelling software can be used to assist with determining time-current coordination.

Most circuit breakers have two specific tripping zones. One is the overload zone and the other the short-circuit zone

The overload zone is the area between the rated current of the circuit breaker itself and 8-10 times this value. In this zone the thermal protection of the circuit breaker is active. On the graph with circuit breaker trip curves on this page marked "overload" this zone is marked.

The short-circuit zone is the area above the overload zone i.e. with currents above the 8-10 times rated range as indicated above. In this zone the magnetic protection will be active, specifically when a short-circuit occurs. On the graph with circuit breaker trip curves on this page marked "short-circuit" this zone is also marked.

Overload settings protect the cable and the consumer against sustained overcurrents.

Overload protection devices are not always fully adjustable, especially in small circuit breakers. Those smaller circuit breakers are available with different curves like for instance for motor protection or cable protection.

Diazed is the European standard for screw-cap fuses

Diazed fuses come in sizes DII up to 25A and DIII up to 63 A.

Larger sizes DIV and DV are not considered suitable for ship installation due to excessive temperature rise. Some Class Rules exclude the types larger then 320A for short-circuit protection.

Diazed fuses are relatively simple and cheap protection devices with a rather wide tolerance.

The 4 A fuse melts slower than a 2 A fuse and faster than a 6 A fuse.

To obtain selectivity with fuses, it is generally sufficient to leave one size in between.

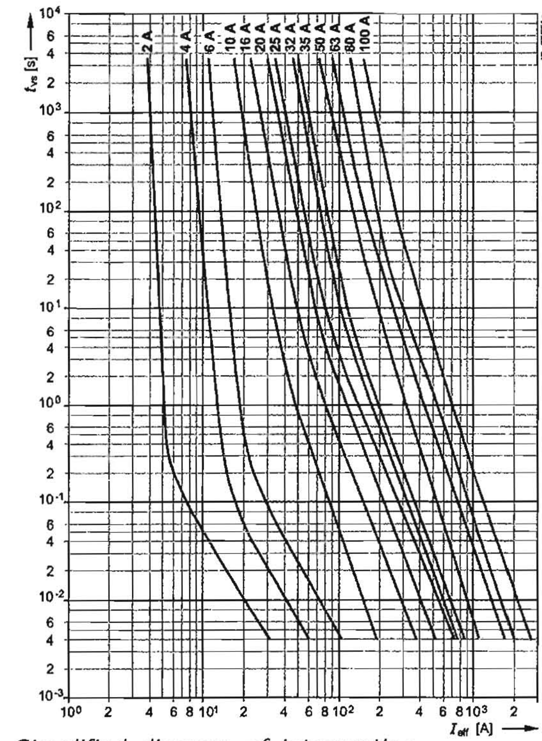
Fuses are also available with different melting curves.

These vary from "normal" for standard final sub-circuits for lighting and "slow" for motor circuits acting slightly slower.

Special very fast interrupting fuses are available to protect semi-conductor circuits.

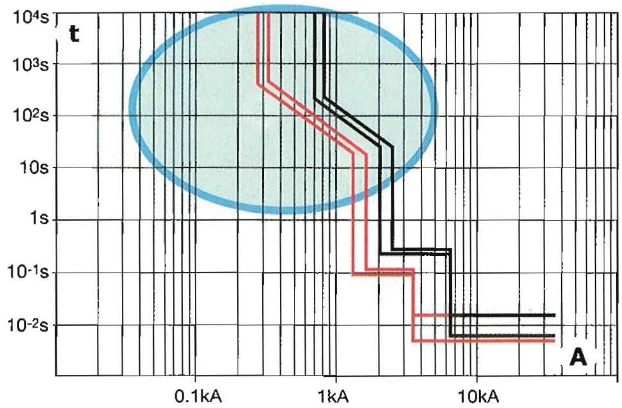
Size:	DII, DIII, DIV
Operational class:	gG
Rated voltage:	500 V AC/500 V DC
Rated current:	2 ... 100 A

Time/current characteristic curves diagram

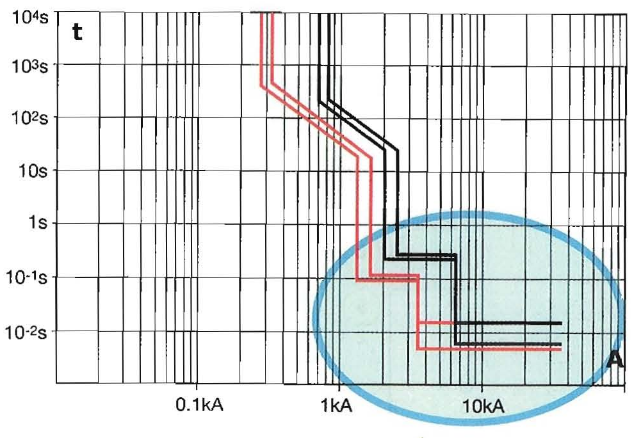


Simplified diagram of interrupting currents / time of diazed fuses.

OVERLOAD Short-circuit

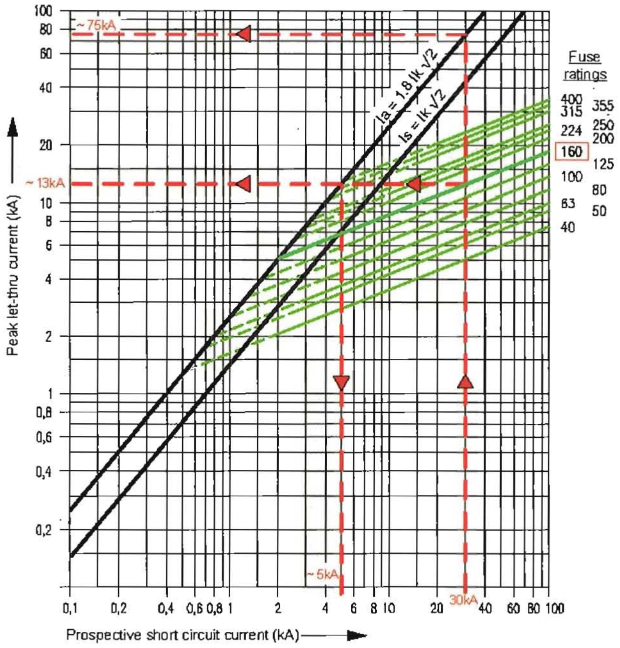


Circuit breaker trip curves with overload zone highlighted.

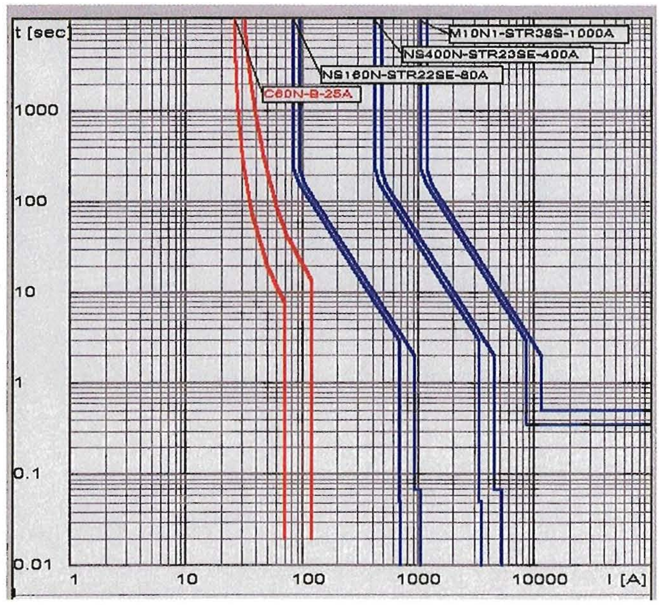


Circuit breaker trip curves with short-circuit zone highlighted.

Series of diazed fuses



Current limitation diagram for fuses 40A - 400A



Time-current curves of a generator circuit breaker with time delayed short-circuit protection and two circuit breakers with direct operating short-circuit protection.

4. Current limitation with fuses

One of the most important features of fuses is their current limiting ability. Current limiting is the effect that a faulted circuit is isolated before the fault current has sufficient time to reach its maximum value. A fuse will melt very fast and thereby limiting the total energy delivered to the fault. This fast fault isolation also limits thermal and mechanical stresses on the system and avoids damage and down time.

Fuses are sometimes used as primary protection for one or more circuit breakers where high short-circuit levels are expected and the short-circuit rating of the circuit breaker(s) is not sufficient for these levels.

To determine the current limitation of a fuse a calculation can be made but an easier method is to use the current limitation diagram provided by the manufacturer of a fuse.

The current limiting diagram on this page shows an example of the determination of the let-thru current of a typical 160A fuse. It must be noted that manufacturers produce their own current limitation diagrams and those should be used with any particular design.

In the example a prospective short-circuit of 30kA has been calculated. The black diagonal lines in the diagram represent the peak values for the short-circuit. The top line is the peak value with the DC component ($I_a = 1.8\ I_k \sqrt{2}$). The lower line is the peak value without the DC component ($I_s = I_k \sqrt{2}$)

When no fuses would be installed the peak value would be at its maximum. In the example a red line is drawn to the top line and then followed horizontally to the left to find a value of approximately 75kA.

When fuses are installed one of the green limiting curves for the particular rating can be used to find the peak value. In the example this will be approximately 13kA by following the red line again in the same way as above but using the green fuse current limit line for the 160A fuse of the example instead.

The effective RMS short-circuit value after the fuse can be found by drawing a red line down from the diagonal peak value line to the line with the prospective short-circuit current. In the example this results in a short-circuit current of approximately 5kA.

5 Selectivity diagrams

Selectivity diagrams are used to visualize the relation between the overload and short-circuit trip curves of series-connected protection devices such as fuses and circuit breakers. The selectivity diagram on this page shows the time-current trip curves of a generator circuit breaker and two circuit breakers supplied by this breaker.

The curve in red represents a typical motor supply circuit with a thermal curve for overload protection and an instantaneous short-circuit relay. The generator circuit breaker has to be able to switch off any current, that the generator (or the total capability of the other generators) can produce further downstream.

This does not impair the redundancy of the basic design.

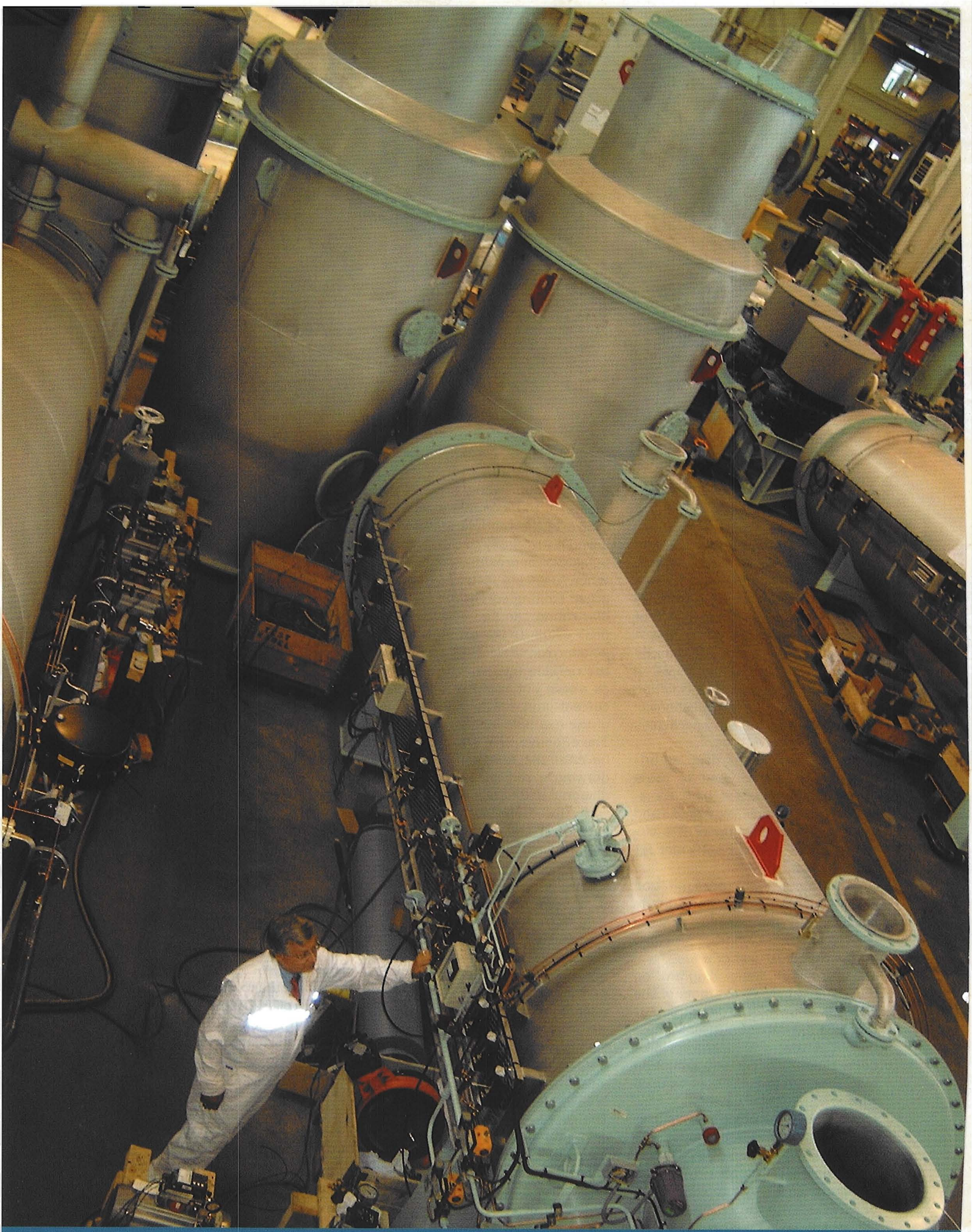
To have a totally selective installation would be very difficult and could mean the installation of expensive selective circuit breakers in the main switchboard. That is why partial selectivity is often selected in the design but this could mean that on a short-circuit more than the faulty circuit will be disconnected. This could endanger redundancy in the installation which is especially critical for DP-vessels.

This leads to an expensive installation.

However, redundancy of the basic design can also be met by dividing the duplicated essentials over more downstream distribution boxes, powering these boxes through current limiting devices.

This enables the use of less sophisticated switchgear downstream as the fault current is limited by the upstream circuit breaker. The redundancy of the essential consumer is guaranteed because its twin is supplied from a different upstream circuit. This limits the cost of all downstream switchgear with respect to circuit breakers, fuses, bus-bar systems, etc.

Redundancy is again based upon the single-failure principle. If a second fault happens to the second identical downstream distribution box, the other duplicated essential could be lost and propulsion stops. Further redundancy requirements are found in paragraph 2.



9. TYPE-APPROVED EQUIPMENT

'Type Approval' is an independent certification service, providing certificates stating that a product is in conformity with a specific standard or specification and verification of the production quality system. It is based on design review, initial type testing and verification of the production process.

1 Introduction

Type Approval consists of a review of the design against the classification rules as well as against internationally accepted standards, witnessing of initial type testing and verification of the production process.
An ISO 9000 quality assurance certification of another notified body is also acceptable.
The location onboard where the equipment will be used determines part of the required testing.
Type approved equipment has also been tested and deemed suitable for the marine environment as defined in the classification rules.
European Marine Equipment Directive (MED) is intended to ease free movement of goods within the European market. Equipment certified by a notified body as per MED directive may be used on all European ships, independent of the classification.
All Classification Bureaus accept the MED certificates of other Classification Bureaus as well as MED certificates of other notified bodies.

Using type approved equipment eases class approval but does not away with the normal certification requirements as further detailed in Chapter 27 Testing and Commissioning.

TEST		ENVIRONMENTAL CATEGORY				
		ENV 1	ENV 2	ENV 3	ENV 4	ENV 5
1	Visual inspection	X	X	X	X	X
2	Performance test	X	X	X	X	X
3	Pressure test	X	X	X	X	X
4	Insulation resistance	X	X	X	X	X
5	Power supply variation	X	X	X	X	X
6	Power supply failure	X	X	X	X	X
7	Inclination	X	X	X	X	X
8	Vibration test 1	X	X	X		X
	Vibration test 2				X	
9	Humidity test 1		X	X	X	X
	Humidity test 2	X				
10	Saltmist test					X
11	Dry heat test			X		X
	Solar test			X		X
12	Low temp. test					X
13	High voltage test	X	X	X	X	X
14	Enclosure test					X
15	EMC test	X	X	X	X	X

Basic environmental tests

ENVIRONMENTAL CATEGORIES			
CATEGORY	DESCRIPTION	AMBIENT TEMP. RANGE	
ENV 1	Controlled environment	To producers spec.	
ENV 2	Enclosed spaces subject to temperature, humidity and vibration	Min 5 °C	Max + 55 °C.
ENV 3	Enclosed spaces subject to general heat from other equipment	Min 5 °C	Max + 55 °C.
ENV 4	Mounted on reciprocating machines	Min 5 °C	Max + 55 °C.
ENV 5	Open decks	Min - 25 °C	Max + 70 °C.

2 Environmental conditions

Before type approval testing can commence the environmental conditions must be defined. The general environmental conditions for air and seawater are:

- Temperature air 45° centigrade (figures can differ for restricted services)
- Temperature seawater 32° centigrade (temperatures can differ for restricted services)
- Maximum humidity 95% not condensing,

The maximum ship movements are defined as:

- Trim: +/- 5°,
- Pitching: +/- 5°
- List: +/- 22.5°
- Roll: +/- 22.5°.

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TYPE APPROVED

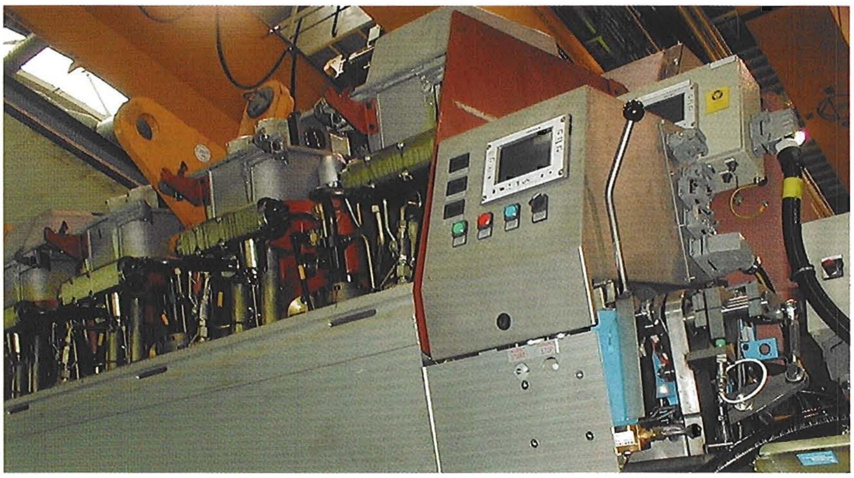
3 Type approval tests

3.1 Vibration

The object to be tested is placed on a support which is fixed to the core of an electromagnet.

The current and frequency in the coil of the electromagnet can be adjusted in order to create any desired vibration. The desired vibration is chosen in relation to the expected environment where the unit has to operate.

Vibration test



A modern diesel engine with standard control and monitoring system fitted on the engine. This unit has also been tested for severe vibration levels as can be expected on a diesel engine. The touch screen control box, mounted in the above control unit is tested separately.

Radiated and conducted interference (EMC Susceptibility) is tested in a special created environment.

Salt mist test

VIBRATION TESTS			
ENV 1	Displacement	1.5 mm	2 - 13 Hz
General	Accelleration	10 m/sec²	13 - 100 Hz
ENV 2	Displacement	1.5 mm	2 - 28 Hz
On engines	Accelleration	10 m/sec²	28 - 200 Hz

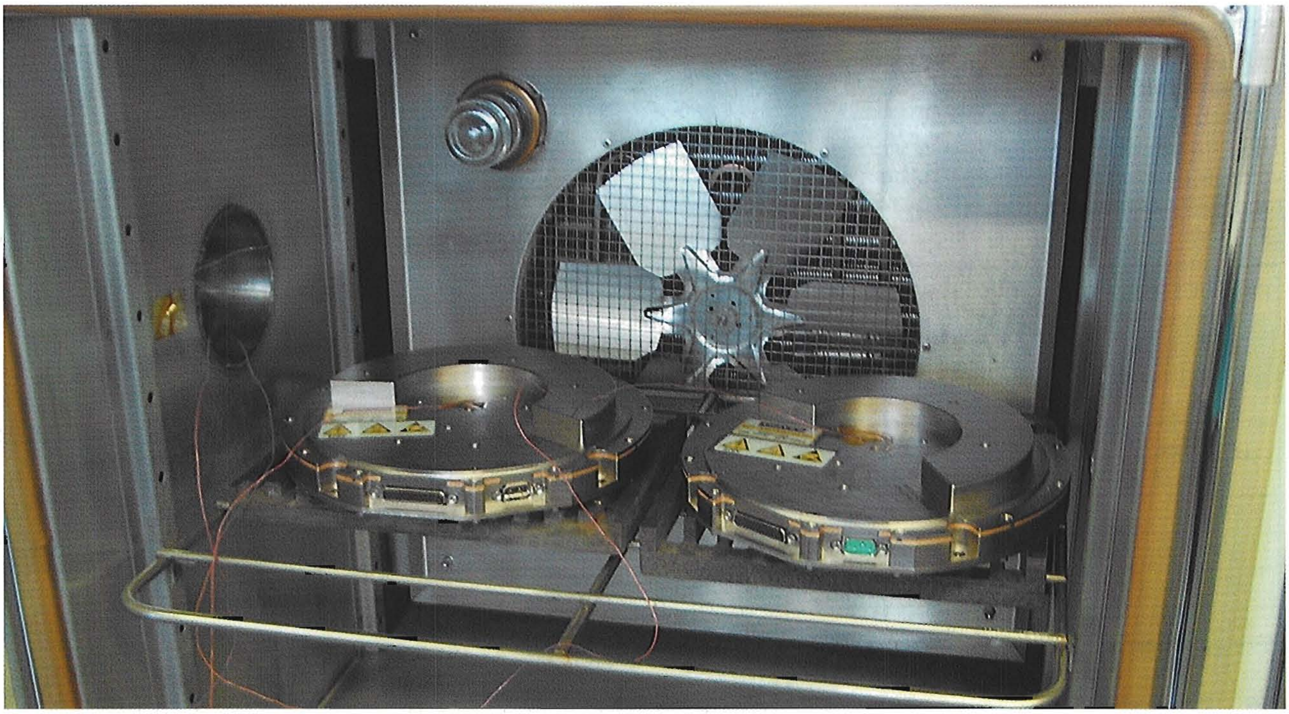
3.2 Salt environment

Equipment which has to be installed outside, and is exposed to the salty atmosphere, needs to be subjected to a salt-mist test.

Therefore it is placed for a certain time in a closed box where this environment is simulated.

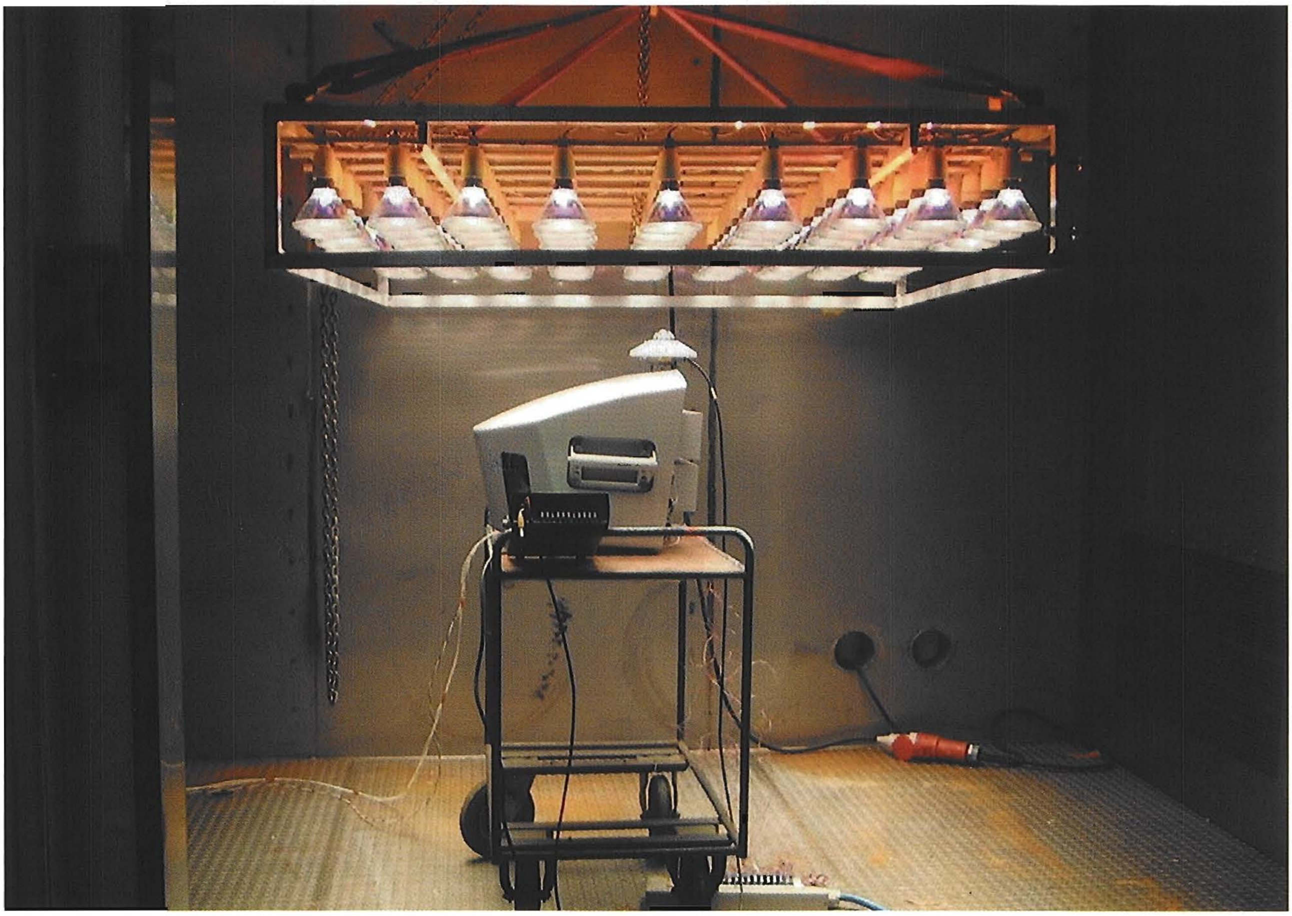
3.3 Dry heat and solar radiation

A dry heat test is required for equipment which has to be installed in spaces subject to generated heat, such as engine rooms and boiler rooms.
A solar radiation test is required for equipment which has to be installed on open deck and is directly subjected to the sun.
The dry heat test creates an environment where the complete apparatus is evenly heated up to the required temperature.



Dry heat test

The solar radiation test (below) heats the equipment up from one direction only.
This creates also mechanical stresses.



3.4 Low temperature

When a piece of equipment is intended to be installed on an open deck this needs to be subjected to a low temperature test.

3.5 High voltage

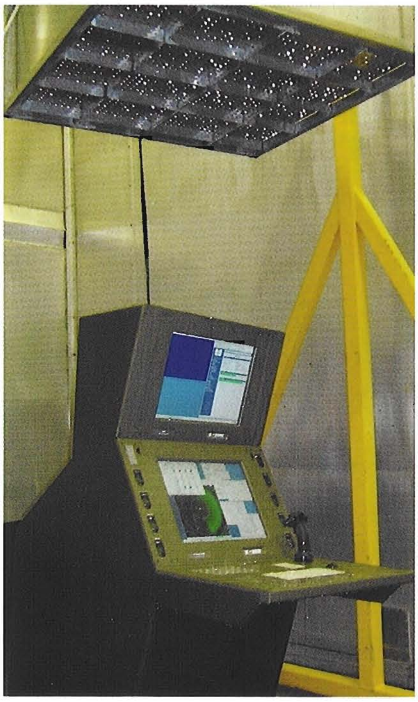
All electrical equipment needs to be subjected to a high voltage test. The relation between nominal voltage and high test voltage to be taken as per following table.

HIGH VOLTAGE TEST	
Rated Voltage U_n	Test Voltage a.c.(r.m.s.), V
$U_n \leq 60$	500
$60 < U_n \leq 1000$	$2 \times U_n + 1000$
$1000 < U_n \leq 2500$	6500
$2500 < U_n \leq 3500$	10000
$3500 < U_n \leq 7200$	20000
$7200 < U_n \leq 12000$	28000
$12000 < U_n \leq 15000$	38000

3.6 Enclosure

Equipment that needs to be used under water or on the forecastle (green water) has to be subjected to a pressure test.

If the equipment is subject to spray or dripping water a drip test is sufficient.

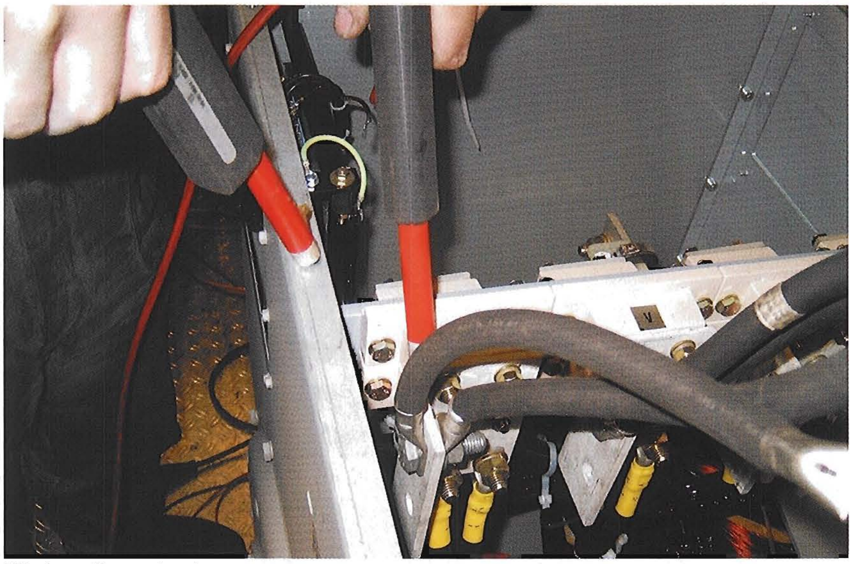


Enclosure dripping test

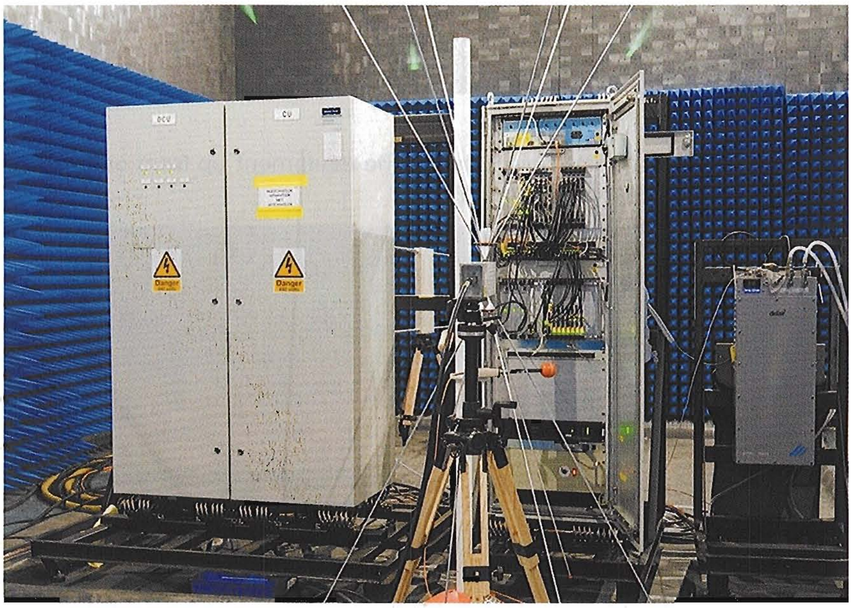
3.7 EMC

Is required for equipment incorporating active electronic components.

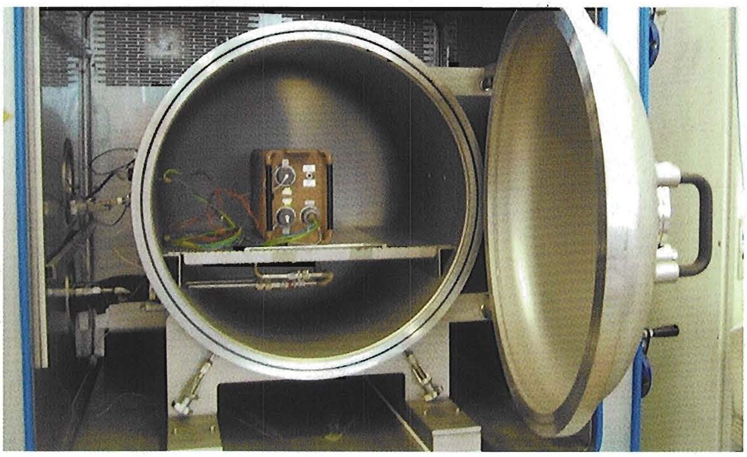
All essential equipment must be selected from the lists of type-tested equipment.
If the chosen equipment is not listed it must fulfill the requirements for type testing at least.



High voltage test



EMC test



Pressure test

Certificate of Conformity (Module G)

mca

Maritime and Coastguard Agency

An Executive Agency of the Department for Transport

Lloyd's Register Verification (LRV), having been appointed by the UK MCA as a "notified body" under the terms of The Merchant Shipping (Marine Equipment) Regulations S.I. 1999 No. 1957 and Article 9 of Council Directive 96/98/EC as amended by Commission Directives 98/85/EC, 2001/53/EC, 2002/75/EC and 2002/84/EC for Marine Equipment, certifies that:

LRV did undertake the relevant quality assessment procedures for the equipment of the manufacturer identified below which was found to be in compliance with the **Fire protection** requirements of Council Directive 96/98/EC on marine equipment as amended above and in accordance with Annex B, Unit Verification Module G, subject to the conditions below and in the attached Schedule which will also form part of this Certificate.

Manufacturer:	Place of production:
Aalborg Industries Inert Gas System B.V.	**same**
Address:	Address:
St. Hubertsstraat 10 **6531 LB Nijmegen** **The Netherlands**	**same**

Annex A.1 item no **A.1 / 3.42**

Item designation:

INERT GAS SYSTEMS COMPONENTS

Manufacturer's code no.	Product description:
062.10.1.9530	**Inert Gas system type: Gin 2500-0.15 FU**

Product identity number:

Serial number 06830

Approval is subject to continued maintenance of the requirements of the above Directives and to all products continuing to comply with the standards and conditions of EC Type Examination Certificates issued by Lloyd's Register Verification.

Date of Issue **16 January 2008**

Issued by: **Lloyd's Register Verification**

EC Distinguishing No. 0038

Certificate no. **MED 08G0009 – (Control no: GRO0805012)**

Signed: For

Name: A.W. van der Velden

For and on behalf of Lloyd's Register Verification

Note: A technical file shall be maintained to record the above product for a period of at least 10 years from date of issue of this Certificate.

Subject to the Manufacturer's compliance with the foregoing, and those conditions of Articles 10.1(1) and 11 of the Directive, the Manufacturer or his authorised representative is allowed to affix the 'Mark of Conformity' to the products above.

This certificate is issued under the authority of the MCA.

0038 / 08

The above certificate is a Type Approval Certificate with a MED logo for an inert gas system.

The steering wheel on the certificate, shows that it fulfills the Marine Equipment Directive (MED) requirements for type approval.

The MED certificate can be issued after design appraisal, and testing.

An inert gas system produces an inflammable gas, mostly N2 mixed with CO2, used in tankers as a blanket above a dangerous cargo. It serves two purposes: one to avoid an explosive cargo-air mixture above the cargo, and secondly, for certain cargoes, the prevention of mixing of cargo with the oxygen in the air.

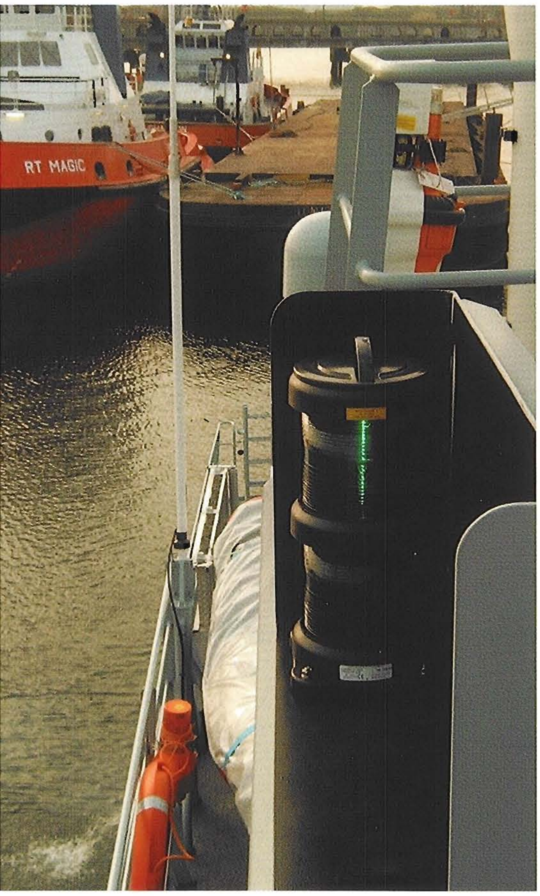
The main purpose of Marine Equipment Directive approval is to ease trade within the European community.

The equipment must be approved as per accepted international standard and the approval system shall be as per EC publication.

Furthermore, the system also consists of a design review and an initial test witnessed by the authorised body as well as a verification of the production quality system.

Currently, MED certification is limited to safety, fire fighting, navigation, nautical and communication equipment.

The 2007 European Community represents a vast amount of customers.



Type approved starboard double sidelight

Lloyd's Register

ABS TYPE APPROVED PRODUCT

USCG-EU MRA

DNV

BUREAU VERITAS 1828

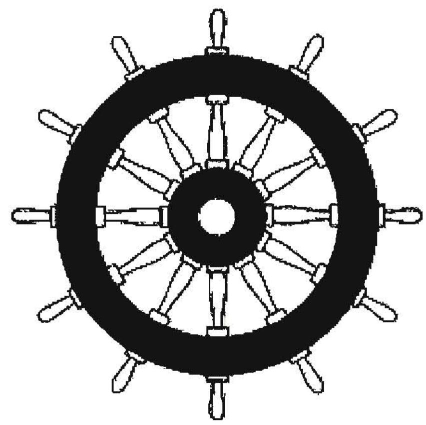
BUREAU VERITAS

Germanischer Lloyd

RINA - Registro Italiano Navale Group

Marks of the Regulatory Bodies

European market



MED certified equipment carries the wheel mark.

Bundesrepublik Deutschland

Federal Republic of Germany

Bundesamt für Seeschifffahrt und Hydrographie

Federal Maritime and Hydrographic Agency

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

EC TYPE EXAMINATION (MODULE B) CERTIFICATE

This is to certify that:

Bundesamt für Seeschifffahrt und Hydrographie, specified as a "notified body" under the terms of „Schiffssicherheitsgesetz" of 9. September 1998 (BGBl. I, p. 2860) modified last 08. April 2008 (BGBl. I, p. 706), did undertake the relevant type approval procedures for the equipment identified below which was found to be in compliance with the Navigation requirements of Marine Equipment Directive (MED) 96/98/EC last modified by Directive 2008/67/EC.

Manufacturer	**aqua signal Aktiengesellschaft**
Address	**Von-Thünen-Straße 12, 28307 Bremen, GERMANY**
Applicant	**aqua signal Aktiengesellschaft**
Address	**Von-Thünen-Straße 12, 28307 Bremen, GERMANY**
Annex A.1 Item (No & item designation)	**6.1 Navigation lights**
Product Name	**LED-Serie 65**
Trade Name(s)	**LED-Serie 65**

Specified Standard(s)

Regulation COLREG 72, Annex I/14	EN 14744, 2005
IMO Resolution A.694(17)	IEC 60945 Ed.4.0, 2002

This certificate remains valid unless cancelled, expired or revoked.

Date of issue: **2008-09-01**

Expiry date: **2013-08-31**

Issued by: **Bundesamt für Seeschifffahrt und Hydrographie**
Bernhard-Nocht-Str. 78, 20359 Hamburg, Germany
Notified body 0735

Certificate No.: **BSH/4612/6010945/08**

This certificate consists of 2 pages.

by order

Schulz-Reifer

BUNDESAMT FÜR SEESCHIFFFAHRT UND BODY HYDROGRAPHIE

This certificate is issued under the authority of the „Bundesministerium für Verkehr, Bau und Stadtentwicklung".
V2008-07-23

10. HAZARDOUS AREAS - IP RATINGS

Hazardous areas are those areas where, due to continuous or part-time presence of gases, flammable liquids or even explosive dusts, the danger of explosion exists.
Hazardous areas are for instance the tanks of a tanker with the deck above, the cargo-handling area, cargo-pump room, the car decks of a ferry where cars are stowed with fuel in their tanks, a paint store or the hold of a dry-cargo ship certified for the carriage of dangerous cargo.
The most cost-effective solution is not to install any electrical equipment in dangerous areas.

The **IP rating** (International Protection rating) as defined in IEC 60529 classifies the degrees of protection provided against the intrusion of solid objects including body parts like hands and fingers, dust, accidental contact and water.

1 Hazardous areas

Hazardous areas not only depend on the type of cargo, but also the location of the area in relation to the location of the cargo.
Inland waterway tankers sometimes sail over sea and seagoing tankers may sail a long distance upriver. At sea or inland each have specific requirements but with the same intention.

Hazardous cargoes are defined and divided into the following groups:
1. Flammable liquefied gases
2. Flammable liquids with a flash point below 60 °C and liquids heated to a temperature within 15 °C of their flash point
3. Flammable liquids with a flash point above 60 °C
4. Hazardous goods and materials, hazardous only when stored in bulk

2 Division of dangerous areas

2.1 Zone 0

Areas where an explosive gas atmosphere is continuously present, such as inside a cargo tank of crude oil, oil products, or a chemical products tanker carrying flam-

Cargo tank zone 0 with level sensors

mable liquids (other than liquefied gases) having a flash point not exceeding 60 °C.
In the case of liquefied gases, the cargo tank itself and the surrounding secondary barrier spaces are classified as zone 0.

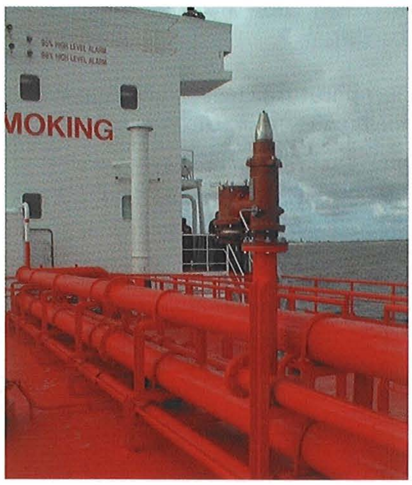
2.2 Zone 1

Areas where during normal operation an explosive gas atmosphere can be present periodically. Spaces as adjacent to and below the top of cargo tanks carrying crude oil, oil products or chemicals etc. with a flash point up to 60 degr. C. Also spaces separated by a single deck or bulkhead from zone 0, cargo pumprooms, and spaces where pipes for above cargoes are leading through.

Testing cargo tank alarms

Additionally, the areas on open deck within 3 metres of any cargo tank outlet, cargo valve, cargo pipe flange, cargo pump room outlets, and within a 6 metre radius from a high velocity discharge vent, up to 2.4 metres above deck.
A high velocity vent, often combined with the pressure / vacuum valve, is a device which allows gases to pass through at overpressure or underpressure (vacuum) of the tank with which it is connected, thus preventing damage to the tank structure. At overpressure, during loading of cargo, or as a result of heating up by sun radiation, the gases are blown out at high speed. This is to prevent those gases from forming a hazardous layer at deck level. During loading, gases in cargo tanks which are driven out by pumping in new cargo, are normally collected in the vapour return system and are recondensed in the refinery in order not to pollute the atmosphere, and to gain back cargo

Zone 1 Areas for IWW tankers range from the outside of the cofferdam fore and aft of the cargo tank area, at less than a 45º angle inwards up to 3 metres above the tank deck. The height is thus, higher than for seagoing tankers.
The areas considered dangerous for the outlet of a high pressure discharge valve have a radius of only 2 metres.
The height above deck for high velocity vents outflow only has to be one metre above deck, also much lower than as per IMO, and has to do with keeping the ship as low as possible for under-bridge passage.



Tanker deck, zone 1, with pressure vacuum valve with a high velocity vent.

2.3 Zone 2

Areas where an explosive gas atmosphere is not present during normal operation and if present, for a short period of time only, such as tankers carrying products with a flash point above 60 °C, dry-cargo ships and Ro/Ro spaces of ferries if sufficiently ventilated.

> Liquefied natural gases (LNG) and vapours from petrol are heavier than air and any opening to a deck or space below is subject to further study with respect to zoning.

3 Selection of certified equipment

Selection of certified equipment for hazardous areas has to be based upon the cargo.

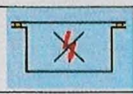
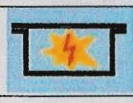
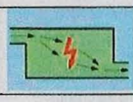
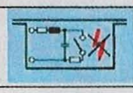
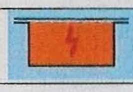
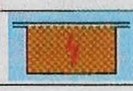
Gases are divided into the following groups:

- I: Methane, such as in coal mines
- II: General industrial gases and gases from combustible liquids and combustible solid materials
- IIA: Propane
- IIB: Ethylene
- IIC: Hydrogen

Apart from the relevant gas group, certified safe equipment shall also be selected on the basis of the maximum surface temperature during operation. This surface temperature must be below the ignition temperature of the gas from the cargo and is stated in the cargo lists (the certified booklet on board a vessel with the allowed types of cargo).

Temperature classes and maximum surface temperatures are:

T1: < 450°C	T4: 135°C
T2: 300°C	T5: 100°C
T3: 200°C	T6: 85°C

EXPLOSION PROOF TYPES					
TYPE OF PROTECTION	CODE	ZONE	DIAGRAM	APPLICATION	STANDARD
INCREASED SAFETY	e	1		TERMINAL AND CONTROL BOXES	IEC
				SQUIRREL CAGE MOTORS	60079-7
				LIGHTING FITTINGS	
FLAMEPROOF ENCLOSURE	d	1		OTHER MOTORS	IEC
				SWITCHGEAR AND CONTROLGEAR	60079-1
				INDICATING EQUIPMENT	
PRESSURIZED	p	1		SWITCHGEAR AND CONTROLGEAR	IEC
				ANALISERS	60097-2
				LARGE MOTORS	
INTINSIC SAFETY	ia	0		INSTRUMENTATION	IEC
				COMMUNICATION	60079-11
				SENSORS	
OIL IMMERSION	o	1		TRANSFORMERS	IEC
				STARTING RESISTORS	60079-6
POWDER FILLING	q	1		TRANSFORMERS	IEC
				CAPACITORS	60079-5
				TERMINALS	
ENCAPSULATION	m	1		SWITCHGEAR AND CONTROLGEAR	IEC
				INDICATION LIGHTS	60079-18
				DISPLAY UNITS	
LIMITTED GASTIGHT IP55	n	2		LIGHTING FITTINGS ON CARDECKS	IEC 60529
				SOCKET OUTLETS ON CARDECKS	
				VENTILATED AND ABOVE 45cm	

4 Summary of certified means of protection

- Certified intrinsically safe
- certified intrinsically safe category 1b
- Flame proof equipment type "d"
- Pressurised equipment type "p"
- Non sparking equipment type "N"
- equipment for cable trays and cables
- Cables with metallic shielding and non-metallic impervous outer shielding

Example of extract from cargo list

SUMMARY OF MINIMUM REQUIREMENTS						
PRODUCT NAME	HAZARDS	REQTS VENTILATION	EXAMPLES OF ENV. CONTROL	TEMP CLASS	APP GROUP	FLASH POINT
	SAFETY	CONTROLLED	INERTING	T1 - T6	IIA, IIB or IIC	NON FL.
	POLUTION	OPEN	DRYING			YES >60°
	S/P BOTH		VENTILATION			NO <60°
ACRYLIC ACID	S/P	CONTROLLED	NO REQ.	T2	IIA	NO <60°
CYCLOHEXYLAMINE	S/P	CONTROLLED	NO REQ.	T3	IIA	NO <60°
ISOPROPYL ETHER	S/P	CONTROLLED	INERTING			
MANGO KERNAL OIL	POLUTION	OPEN	NO REQ.			YES >60°
NITRO BENZENE	S/P	CONTROLLED	NO REQ.	T1	IIA	YES >60°

4.1 Intrinsically safe equipment

Intrinsically safe equipment is equipment isolated by a barrier unit; the barrier limits the energy in the hazardous area to the extent that it cannot cause a spark which could start an explosion. The cable from the barrier unit to the intrinsically safe unit in the dangerous area must be routed separately from other, not intrinsically safe cables to prevent the cable picking up additional power through induction that would exceed the IS safe limit.

4.2 Equipment in zone 0

In Zone 0, no other electrical equipment than that which is certified intrinsically safe, category "1a", can be used.

There are lists of dangerous cargoes, in the form of gases, liquids and solid materials, stating the requirements for electrical equipment in zones 1 and 2.

4.3 Separation by gastight boundaries

A space separated by a gas tight bulkhead or deck from another space can be classified as a less hazardous zone, taking into account sources of release and the ventilation conditions.
Sources of release are venting and other openings to cargo tanks, slop tanks, cargo piping, piping systems and equipment containing liquid or gas having flanged joints or glands.

From the table is seen that preventing any potential leak in a space and ventilation system can ease the requirements for a space. Details and more instructions can be found in IEC standards 60092-502 for tankers and IEC 60092-506 for ships carrying hazardous goods. When the area classification depends on ventilation, failure of this ventilation must be monitored and alarmed and all equipment not suitable for the area without ventilation, must be switched off.
Doors must not be fitted between a hazardous and non-hazardous area unless required operationally and never in a zone 0 area.

An enclosed space with access to zone 1 may be considered zone 2 and an enclosed space with access to zone 1 may be considered non-hazardous, provided the space is ventilated by overpressure and the door is self-closing.

4.4 Equipment in hazardous zones

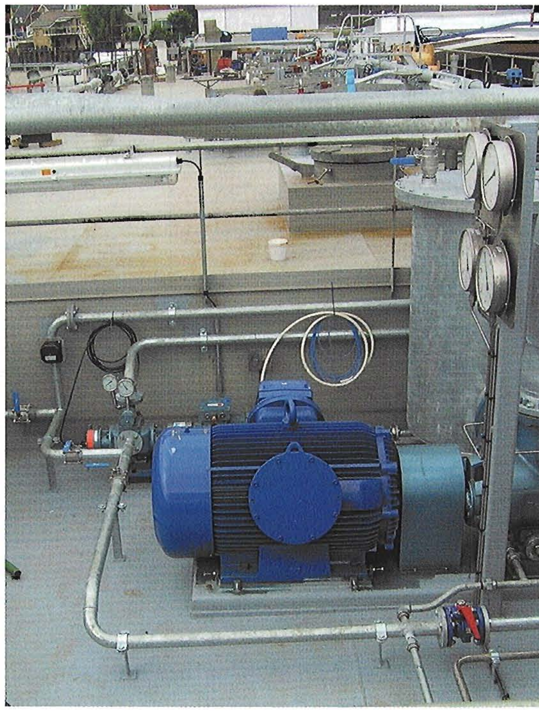
Equipment in zones 1 and 2 also has to be selected and to fulfill requirements according to stringent rules. In zone 1, in general intrinsically safe, flameproof or pressurized. In zone 2 some relaxation. Cables need to be provided with metallic shielding, covered by a non-metallic outer layer. Cable joints are permitted, contrary to zone 0.

	SPACES SEPARATED BY ONE GASTIGHT BULKHEAD OR DECK	
ZONE	WITH SOURCE OF RELEASE OF GAS	
	WITH VENTILATION	WITHOUT VENTILATION
ZONE 0	ZONE 1	ZONE 0
	CARGO PUMPROOM	COFFERDAM + CARGO FLANGES
ZONE 1	ZONE 2	ZONE 1
	SPACES WITH CARGOPIPE FLANGES	SPACES + CARGOPIPE FLANGES
ZONE 2	ZONE 2	ZONE 1
	SPACES WITH CARGOPIPE FLANGES	SPACES + CARGOPIPE FLANGES
ZONE	WITHOUT SOURCE OF RELEASE OF GAS	WITHOUT SOURCE OF RELEASE OF GAS
	WITH VENTILATION	WITHOUT VENTILATION
ZONE 0	ZONE 2	ZONE 1
	BALLASTPUMPROOMS	COFFERDAM VOID
ZONE 1	NON HAZARDOUS SPACE	NON HAZARDOUS SPACE
ZONE 2	NON HAZARDOUS SPACE	NON HAZARDOUS SPACE

4.5 Codes and standards for hazardous areas.

With the design of electrical installations in hazardous areas typical codes and standards should be used. These may include Rules and Regulations from Class, the American Petroleum Institute (API), European ATEX, IEC and others.

It should be noted that codes and standards for equipment in hazardous areas are changing to more international standards like ATEX and IEC Equipment Protection Levels (EPL) and these should be checked on a regular basis or at least at the start of a project.



Zone 1. Tanker deck with flameproof motor

Zone 2. Car deck of ferry with IP55 equipment

ENVIRONMENTAL CONDITION	LOCATION	MINIMAL LEVEL PROTECTION	PERMITTED EQUIPMENT			
EXPLOSION DANGER			SWITCH GEAR	MACHINES	OTHER EQUIPMENT	
ZONE 0	TANKS AND HOLDS DANGEROUS GOODS	INTRINSICALLY SAFE TYPE 1A	NO	NOT APPL.	MEASURING EQUIPMENT	
ZONE 1	TANKER DECK	EXPLOSION PROOF	YES	YES		
ZONE 1	PAINT STORE	EXPLOSION PROOF	NO	NO	LIGHT ONLY	
ZONE 1	BATTERY ROOMS	EXPLOSION PROOF	NO	NO	LIGHT ONLY	
ZONE 2	CARDECKS	IP 55	YES	YES	ABOVE 45 CM	1
ZONE 2	BOATSTORES ON YACHTS	IP 55	YES	YES	ABOVE 45 CM	2
DANGER TO PEOPLE	DRY SPACES	IP 20	YES	YES		
NO MECHANICAL DAMAGE	CABINS	IP 20				
	CORRIDORS	IP 20				
	BATHROOMS	IP 34	NO	NO	LIGHT ONLY	
DRIPPING WATER	ENGINE CONTROL ROOM	IP 23		YES		
LIGHT MECH.DAMAGE	NAVIGATION BRIDGE	IP 23				
	ENG RM ABOVE TWEENDECK	IP 23				
	SWITCHBOARD ROOM	IP 23				
SPLASH WATER	Engine roomS	IP 44		YES		
MODERATE MECH. DAMAGE	BATHROOMS	IP 44			SAFE SOCKETS	
	GALLEY	IP 34				
	LAUNDRY	IP 34				
SPRAYWATER OR DUST	ENG RM BELOW FLOORPLATES	IP 55	NO	YES		
SOLID WATER	FORESHIP AND OPEN DECK	IP 67	NO	YES		
SUBMERGED	SUBMERSIBLE	IP 68	NO	YES		3
NOTES	1-10 AIRCHANGES	2- ALSO GAS DETECTION	3- DEPTH TO BE SPECIFIED			

5. IP Ratings

Protection classes are categorized in the IP Rating, indicating the protection against dust and water and in the EX Rating, indicating the protection against flammable gases. Between the two there is a considerable overlap.

The ratings are mainly standardized by IMO, IEC and NEC 500 (USA).

IMO is for worldwide maritime use, IEC is the International Electrical Committee, worldwide in use for land and sea.

NEC, the National Electrical Committee, is the USA Standard, with emphasis on gas, dust and fibres. In the USA is mining an important topic.

The type of protection depends on the environmental conditions as per table on this page.

Engine room with IP 44 and higher motors

IP RATINGS	ELECTRICAL EQUIPMENT
FIRST DIGIT PROTECTION AGAINST DUST	SECOND DIGIT PROTECTION AGAINST WATER
O NO PROTECTION	0 NO PROTECTION
1 OBJECTS < 50mm	1 Vertical Dripping water
2 OBJECTS < 12mm	2 Angled dripping water 75-90°
3 OBJECTS < 2.5mm	3 Sprayed water 45-90°
4 OBJECTS < 1.0mm	4 Splashed water
5 Dust Protected	5 Water jets
6 Dust tight	6 Heavy seas
	7 Immersion under 1m water column
EXAMPLE: IP 68	8 Infinite immersion under "X"metre water column
	"X"to be stated on certificate/nameplates

IP 23 is the rating of the most cost-effective motor available, to be used in dry spaces, without the danger of gases or dust. There is a minimal protection against dripping water.

IP 44 is the next grade up. It ensures protection against splashed water and dust particles larger than 1 mm.

IP 55 Gives protection against a water jet (firehose) limited gases and dust.

IP 66 suitable for use on open decks with splashed solid water, heavy seas.

IP 67 is dust tight and can be immersed in up to 1 metre of water. It should be noted that equipment with this IP rating is not suitable to be used on open deck where 'green' water could be present. This should be checked with drawings / design.

IP 68 equipment can be used infinitely immersed under a defined water column. The certificate of approval must indicate the maximum allowed water pressure.

The table on this page gives an explanation of the digits in an IP rating.

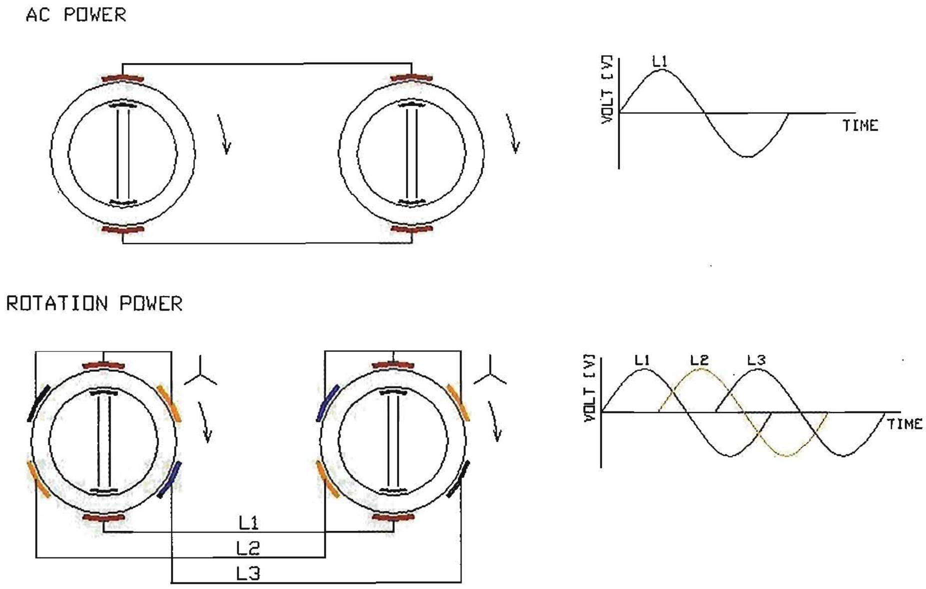
Galley with IP 34 or higher equipment

11. AC SOURCES

AC sources on a ship are normally the generators and when in port possibly the power delivered via the shore connection.

1 Generators

An electric generator is a device that converts mechanical rotating energy into electrical energy.
When a generator produces an alternating current it is called an alternator.
The two main components of an alternator are:
- the stator, which is the static part
- the rotor which is the rotating part inside the stator.



Alternating current and rotating current"

The stator consists of a large number of coils that are interconnected in a fixed pattern and of which the ends are terminated in connection boxes.
The rotor will have magnetic poles that when rotated inside the stator will induce a voltage in the stator coils.
When three sets of stator windings are installed, with an offset of one third, the result will be a three-phase AC current.
The magnetic field of the rotor can be produced in a number of ways:
- by induction (in a "brushless" alternator)
- by permanent magnets (in very small machines)
- by a rotor winding energized with direct current through slip rings and brushes.

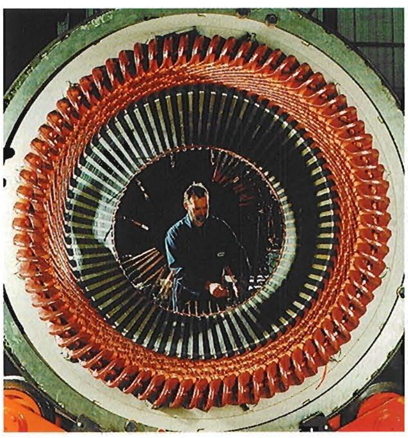
Alternators on ships usually will be of the brushless type.
The frequency that is produced by an alternator depends on the number of poles and the rotational speed.
The speed corresponding to a particular frequency is called the synchronous speed for that frequency.
The frequency on ships normally is 50Hz or 60Hz and, to give an impression, below are some combinations of the number of rotor poles and the required speed to obtain these frequencies from an alternator.

FREQUENCY		POLES	
50hZ	60hZ	POLES	POLE PAIRS
RPM	RPM		
3600	3000	2	1
1800	1500	4	2
1200	1000	6	3
900	750	8	4
720	600	10	5
600	500	12	6
100		72	36

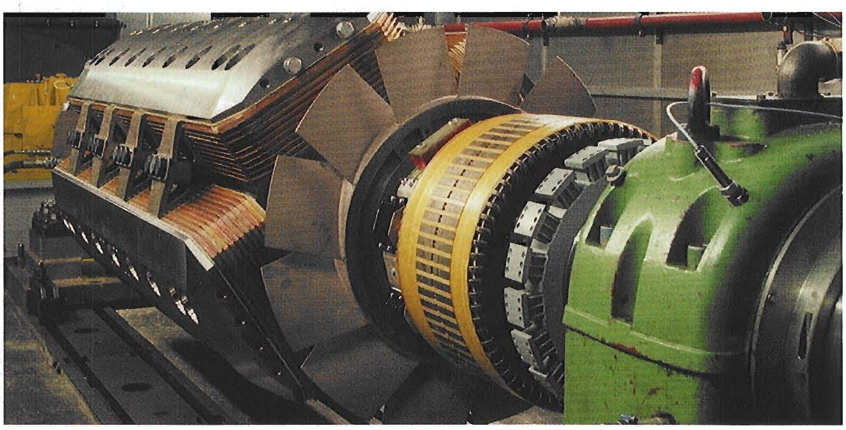
Alternators for use on ships are basically modified standard industrial types which are de-rated to perform under the environmental conditions as defined in the applicable Rules and Regulations and IEC Standard relating to the environment on ships.

2 Characteristics of ships' generators

Generators for ships have, in addition to the industrial generators, a permanent magnet for self-exciting when starting up.
They also have an adapted AVR (Automatic Voltage Regulator) to generate a sustained short-circuit current of 350% of the nominal current.
This short-circuit current is required to allow the circuit breakers to trip in a selective way.



A large generator stator during production. The separately manufactured windings are fitted into the stator and connected together.



The rotor for the same machine in a balancing machine.

The ability of ships' generators to produce a short-circuit current high enough for selectivity or discrimination is essential and above industrial (shore) standards.
Furthermore, they have to be able to run in parallel, sharing the current load without the assistance of automation devices. See IEC 600922-302 Equipment, Generators and Motors for further details.

3 Testing of generators

Generators have to be tested under various load conditions as per Classification Requirements during the Factory Acceptance Test (FAT) at the manufacturer and later during commissioning on board of the ship.
Some generator manufacturers have the required load resistances and reactances to be able to load a generator with the nominal power factor.
Water resistances are loads with power factor 1 and are thus not suitable for testing a generator at 80% current, where the nominal kW rating of the diesel engine is reached.
Water resistances are suitable to test diesel engines up to 100 % and test generators, load sharing and step loads up to 80%.
A practicable and acceptable alternative is to run the generator at no load with its own excitation.
After that a heat run with short-circuited stator and excitation by an external source in such a way that the current in the stator reaches its nominal value.
During the no-load run the machine is warmed up mainly by the iron losses and during the short-circuit run, the copper losses.

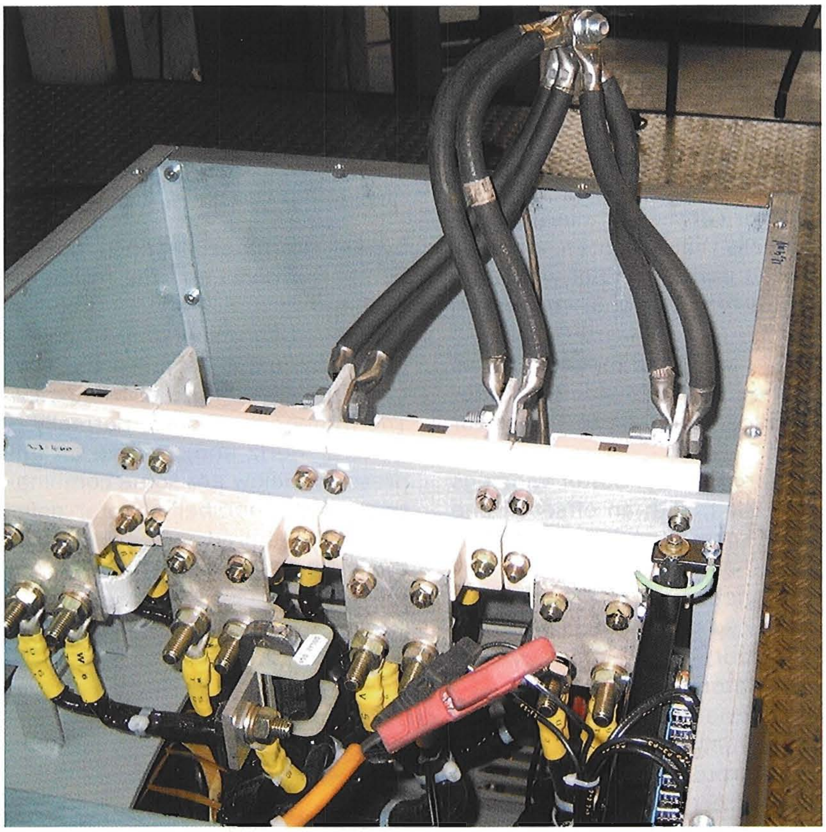
By adding the two temperatures, the total temperature rise of the machine is estimated.
Winding temperatures are normally determined by measuring the winding resistance at a known temperature.
Afterwards, measuring the winding temperature after the machine temperatures have been stabilized to the maximum value.

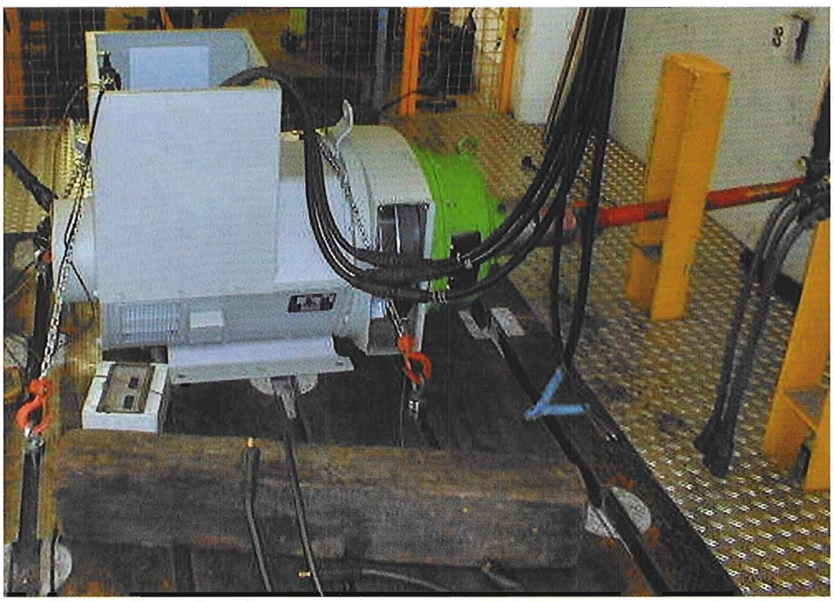
The winding resistance can only be measured when the machine is stopped and switched off.

To determine the moment that the machine has reached its maximum temperature and is stabilized, the cooling air or water inlet and outlet temperatures are measured while running.

As soon as the difference between inlet and outlet temperature is stable for half an hour, the machine has reached the maximum value.

When temperature measuring devices are present, such as embedded PT100 sensors, the temperature can be measured whilst running.
The maximum permissible temperature rise for the different insulation materials differs for the resistance and temperature measuring method.
The resistance method gives the average temperature rise for the total winding. The embedded temperature measuring devices are located at the hot spots.


Short-circuit test run


Load test of an electric generator

GENERATOR TEST SHEET 1

R1 Cold resistance at 20° C **0,015Ω**

NO LOAD TESTRUN							
TIME	VOLT	FREQ.	CURR.	SPEED	COOLING AIR OUT	COOLING AIR IN	TEMP DIFF.
	V	**Hz**	**Amp**	**RPM**	**°C**	**°C**	**°C**
8:30	450	60	0	1800	20	20	0
9:00	450	60	0	1800	23	21	2
9:30	450	60	0	1800	25	21	4
10:00	450	60	0	1800	27	21	6
10:30	450	60	0	1800	28	21	7
11:00	450	60	0	1800	28	21	7

R2 Winding resistance after no-load test **0,016Ω**

....

T1 temperature rise no-load test **15° K**

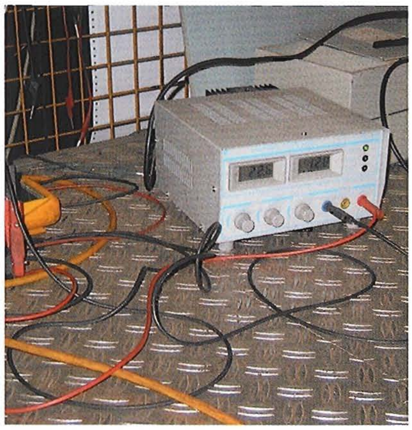
$$\frac{\left(\frac{R_h}{R_c}-1\right)}{0{,}0043} = \ ^\circ C$$

Short-circuit TEST							
TIME	VOLT	FREQ.	CURR.	SPEED	COOLING AIR OUT	COOLING AIR IN	TEMP DIFF.
	V	**Hz**	**Amp**	**RPM**	**°C**	**°C**	**°C**
12:00	450	60	500	1800	28	21	7
12:30	450	60	500	1800	30	21	9
13:00	450	60	500	1800	32	21	11
13:30	450	60	500	1800	36	21	15
14:00	450	60	500	1800	38	21	17
14:30	450	60	500	1800	40	21	19
15:00	450	60	500	1800	41	21	20
15:30	450	60	500	1800	42	21	20

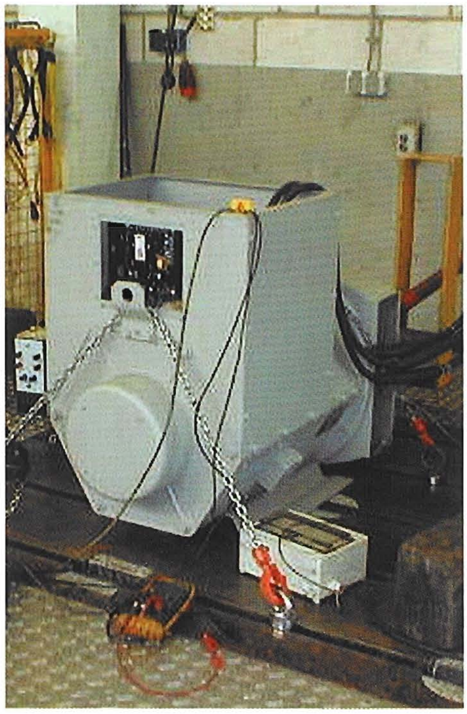
R3 Resistance after short-circuit test **0,019Ω**

T2 temperature rise short-circuit test **62° K**

Total temperature rise + T1 + T2 = 15° + 62° = 77° K



External excitation



No load test run

GENERATOR TEST SHEET 2

Meggertest 1000 V > 200 MΩ

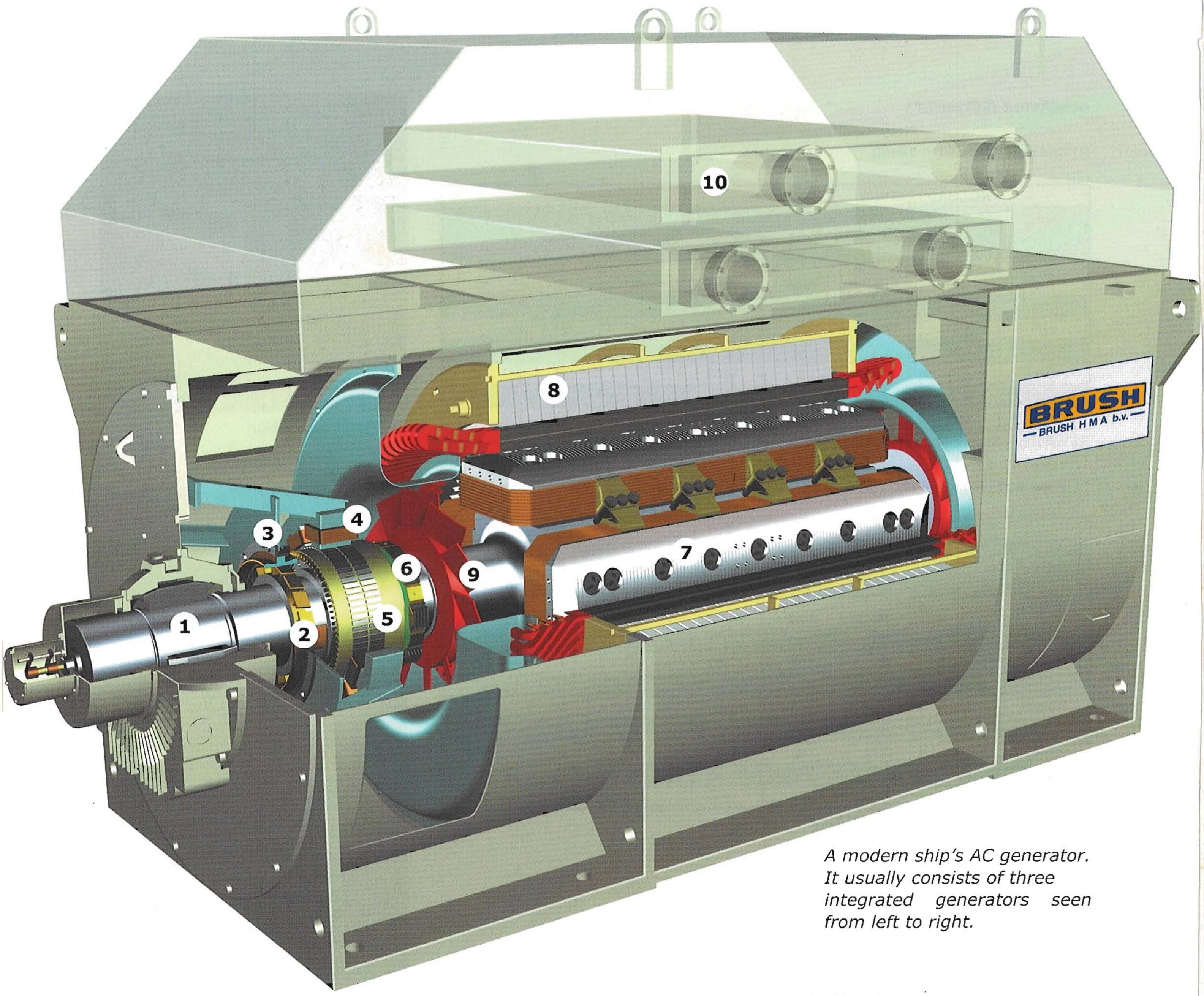
High voltage test 2500 V during 1 minute

Meggertest 1000 V > 200 MΩ

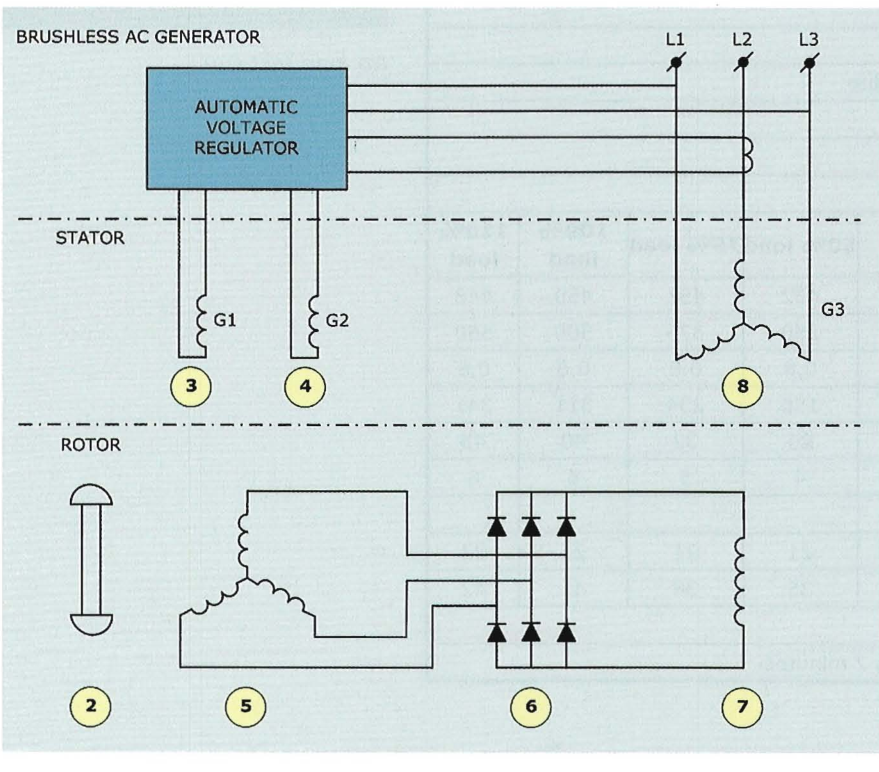
Functional test

LOAD TESTS	**No load test**	**25% load**	**50% load**	**75% load**	**100% load**	**110% load**
Voltage V	455	454	452	451	450	448
Current A	0	125	250	375	500	550
Power factor cosΦ	0	0,8	0,8	0,8	0,8	0,8
Power kW	0	78	156	234	311	341
Exciter voltage V	10	18	25	32	40	45
Exciter current A	2	3	4	5	6	6
Cooling air in °C	21	21	21	21	21	22
Cooling air out °C	29	32	35	38	41	42

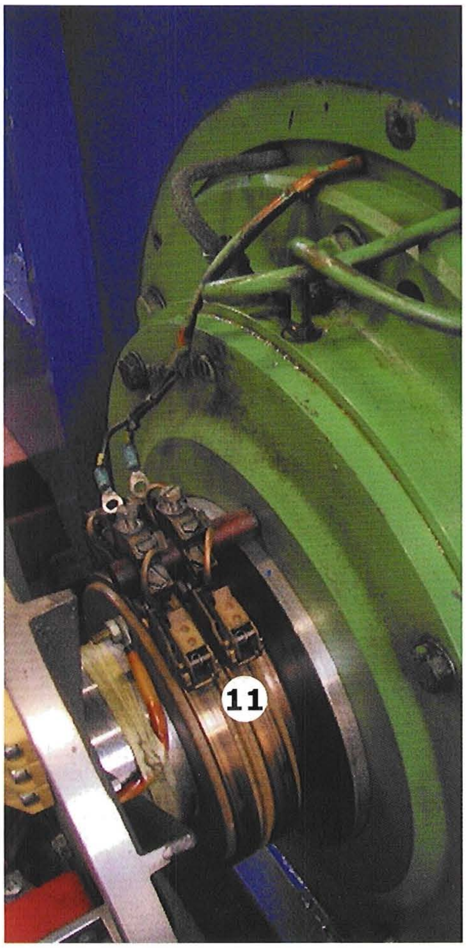
Overspeed test 120% 2160 RPM during 2 minutes

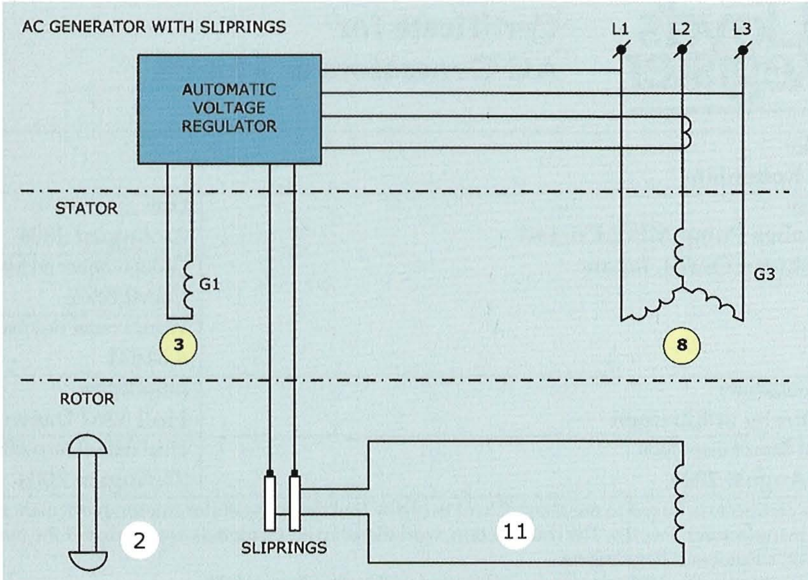


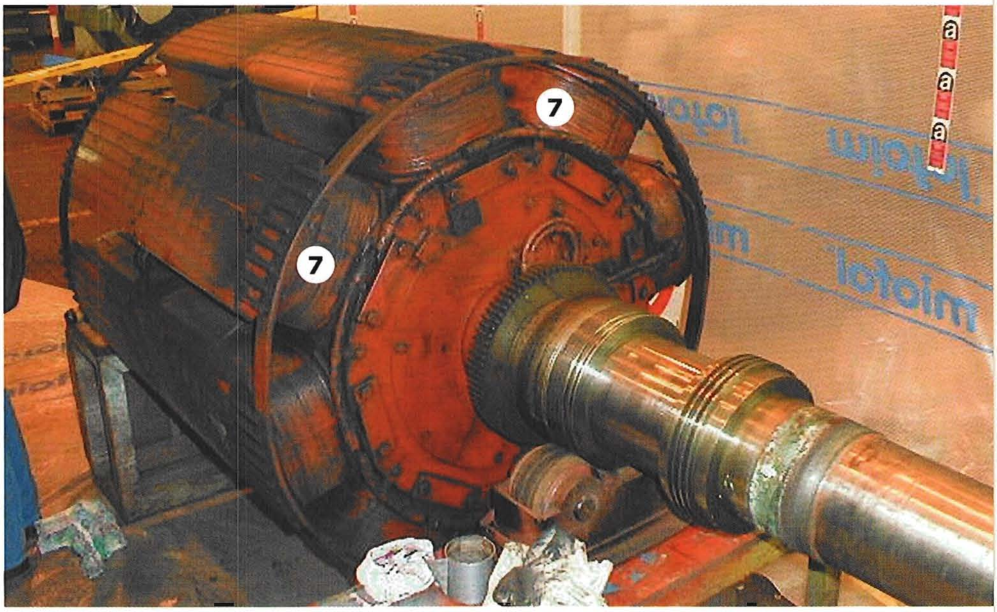
A modern ship's AC generator. It usually consists of three integrated generators seen from left to right.

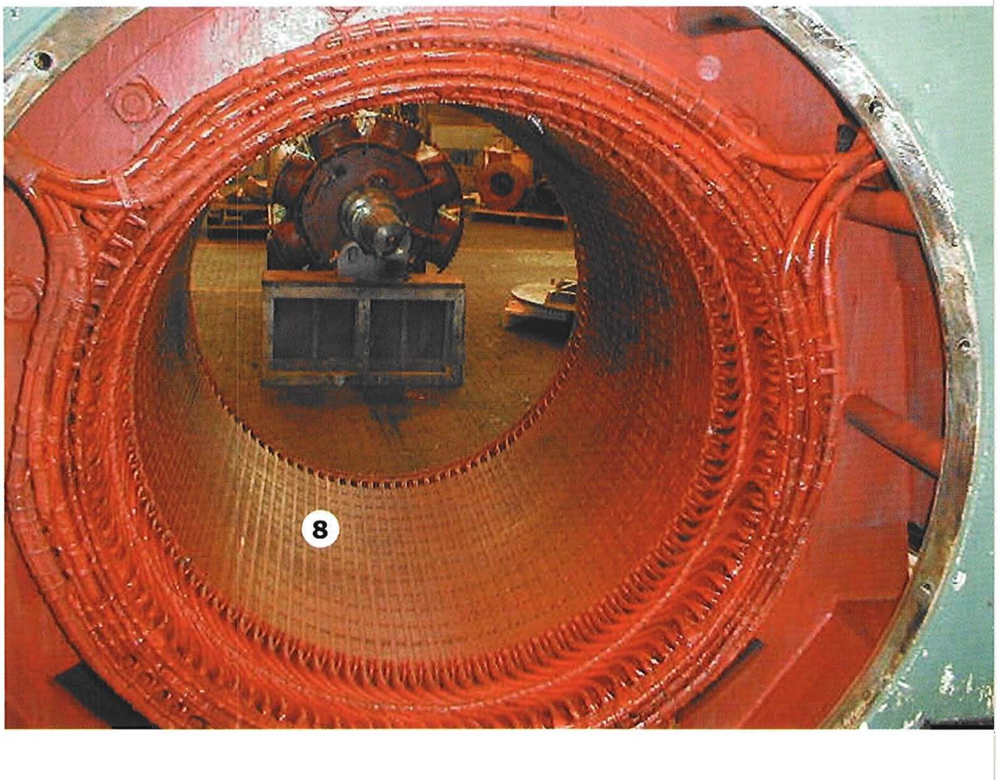


1. Bearing
2. Permanent magnets on rotor
3. Coil on stator activated by permanent magnet
4. Stator exciter winding
5. Rotor exciter winding
6. Rotating diodes
7. Rotor poles
8. Stator windings
9. Fan
10. Heat exchanger water/air
11. Slip rings, in case of an old-fashioned generator instead of items 4, 5 and 6.









A permanent magnet (2) rotating in the PM winding (3) to generate the AC start voltage as well as the voltage to the voltage regulator for the sustained short-circuit current.
The exciter (4), a second generator with the electromagnets in the stator energised by the voltage regulator.
The AC voltage in the exciter winding on the rotor (5) is rectified by rotating diodes (6) and the DC current energizes the pole electromagnets (7).
The final generator is the main stator (8) in which the rotor poles rotate. This is where three-phase rotating current is generated.
The automatic voltage regulator controls the generator output voltage as a function of rotor speed and output current.
For both electric motors and generators the allowable temperature rise depends on the size of the machine as well as the insulation material and measuring method.

Lloyd's Register

Certificate for AC Generators or Motors

ROT0403864

Page 1 of 1

Office LR Rotterdam	
Client Naniwa Pump MFG. Co. Ltd Nishi-Ku Osaka, Japan	Date 23 August 2004 Order number on Manufacturer DSME5262 Work's order number 4.51631
Manufacturer Rotor bv at Eibergen	Intended for Hull 5262 Daewo SME
First date of inspection 23 August 2004	Final date of inspection 23 August 2004

This certificate is issued to the above Client to certify that the ac generator/motor, particulars of which are given below, has been inspected at the manufacturer's works. The construction, workmanship and materials are good, and the machine complies with the relevant requirements of the LR's Rules and Regulations.
On completion the generator/motor was tested with satisfactory results.

Particulars

Type			
Auxiliary AC Generator ☐	Auxiliary AC Motor ☒	Propulsion AC Generator ☐	Propulsion AC Motor ☐
kVA (generator only)	Volts 440	Number of phases 3 delta	kW 110
Amperes 182	Hertz 60	Power factor 0,82	Rev/min 1785
Type of enclosure IP55 tropicalized		Class of insulation F	
Type number 5RN280M04A8	Serial number 0408-133/134	Date of temperature test 10 August 2004	Machine acting as motor

Results Of Tests

Duration 185 min	Rev/min 1781	Volts 440	Amperes 183
Hertz 60	Power factor 0,83	Field-volts	Field-amperes

DEGREES C (State whether resistance ("r") or thermometer ("t")		
Test	Actual	Rise
Cooling Air	25,2	2,5
Stator Winding	84,4	56,7
Rotor Winding		
Slip Rings		
Hot insulation resistance (megaohms) > 200	High voltage test volts ac for 1 minutes 2000	

Generator Voltage Regulation
If Regulation not inherent state serial number of A.V.R

Test	Full load	No load
Rev/Min		
Volts		
Amperes		

Overload test
160% 15sec 285A 440V 60Hz 944Nm

Identification Marks Mark "n/a" if not applicable	
Identification number (including office contraction code)	
Surveyor's initials RBO	Date of inspection 23 August 2004

Remarks:
temptest on 0408-133

R. Borstlap
Surveyor to Lloyd's Register EMEA

A member of the Lloyd's Register Group

Form 1059 (2003.07)

THIS DOCUMENT IS SUBJECT TO THE TERMS AND CONDITIONS OVERLEAF

DNV

DET NORSKE VERITAS

Certificate No.:
PRG 07-0945/4

CERTIFICATE FOR ELECTRIC GENERATOR

Manufacturer **SIEMENS ELECTRIC MACHINES, s.r.o.** **CZ - 664 24 DRÁSOV 126**	Works order No. **1198966/420000** Generator type **1FJ4 804-10SD22** Serial No. **178019**
Ordered by **SIEMENS A/S OSLO, Norway**	Order No. **4501054348**
Intended for **Aker Promar S.A., Id. No.. D27459**	Yard No.

THIS IS TO CERTIFY that the electrical Generator described below, has been built and tested in accordance with Det Norske Veritas' current Rules for Classification of "Ships / High Speed, Light Craft and Naval Surface Craft" and Det Norske Veritas' "Offshore Standard"

The test results can be seen from enclosed test report.

Generator specification	Voltage (V)	**6600**	Power (kVA)	**3220**	Insulation class	**H/F**
	Frequency (Hz)	**60**	Power factor	**0.90**	Degree of protection (IP)	**44**
	Current (Amps)	**282**	Speed (r.p.m.)	**720**	Ambient temperature (°C)	**45**
	Type of cooling	**IC 81W**	Excitation Voltage	**60.0 V**	Excitation current	**6.1 A**

This column is only to be filled in when the Manufacturer or his representative is authorized by Det Norske Veritas to stamp the generator.

The undersigned authorized person declares that the generator is manufactured and tested in accordance with the conditions given in Manufacturing Survey Arrangement.

No.: ....

Quality System Certificate

Marking: ....

For the identification the generator was stamped:

....

by authorised person

Place: ....

Date: ....

Name: ....
(Name)

Marking:
For identification the generator was stamped
(Fill inn as applicable):

PRG 07 - 0945/4 on the shaft face

By DNV surveyor

This product certificate is only valid when signed by a DNV surveyor:

Place: **OSTRAVA**

Date: **2008.03.31**

Surveyor: **TOMAŠ PJONTEK**

DET NORSKE VERITAS 1864

Remarks:
The inspection of the generator was carried out in accordance with the DNV Rules Pt. 4, Ch. 8 Sec. 5, Jan. 2005.

A **shore connection** is a circuit with protection devices, a connection box, and flexible cables to enable the ship to obtain electrical power from shore.

Shore connections for most ships are used only when auxiliary generators are not available or otherwise cannot be used, for instance when the ship is under repair, in dry-dock, or laid-up and no staff is onboard to control the auxiliaries.
Most cargo ships, are equipped with a shore connection facility of 300 to 500 kW. This power will normally be available at larger shipyards.
The electrical system on the majority of the cargo ships is 400V / 50Hz or 450V / 60Hz, without neutral.
Most larger shipyards have frequency converters to supply the correct frequency to a ship. When more shore power is required, or shore power with a voltage and/ or frequency that is not available at the shipyard, temporary diesel generator sets are used.

The connection between ship and shore is made with heavy duty flexible cables of sufficient size and quantity. Most of the time a ship is provided with a shore connection box that is located close to where the shore cables come on board.
The shore connection box is connected to the main switchboard with fixed cabling.

For smaller shore power supplies the connection of the shore cables to the shore connection box is made with a plug and socket combination. For large shore power supplies the shore cables are bolted to the phase bus bars in the shore connection box.

When shore cables are bolted to bus bars, the shore connection box is also provided with a phase sequence indicator, a phase sequence relay and phase change facilities. This is to check the correct phase sequence of the incoming shore supply before this is connected to the ship's system.

Small yachts in marinas in Europe can use 230V single-phase shore supplies of up to 16A. These are supplied through standard CEE-form plug and socket outlet combinations.

Larger inland waterways vessels (IWW) in Europe, like tankers, use 230/400V-63A shore power connections also supplied via standard CEE-form plug and socket outlet combinations.

In a growing number of ports, especially ports where cruise ships are frequent visitors, in connection with the growing concern about the environment (noise, smoke), generating electricity on board is not allowed, and it is mandatory to use shore electric power. This is also known as "cold ironing".

There are no international standards yet for these large shore power systems, but developments are underway.

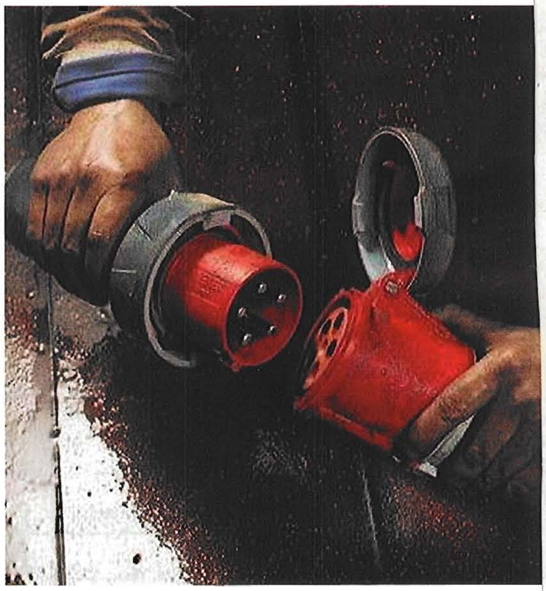
The first major large power high voltage shore power facility was in the port of Juneau in Alaska.
There in 2001 a terminal for cruise ships was equipped with a high voltage shore power system and a shore steam connecction.

Since then a number of ports in the US have followed with arrangements such as those in Seattle and Los Angeles.

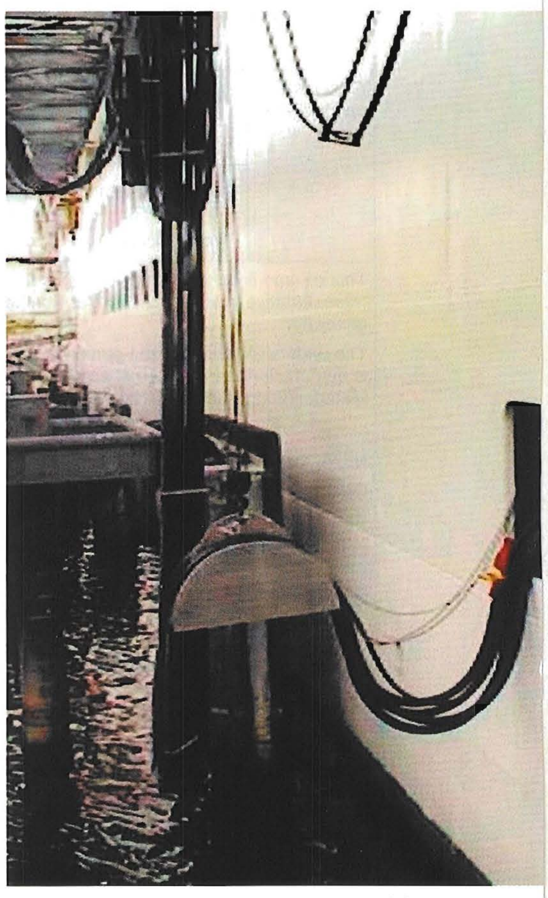
In Europe some ports have excecuted small scale projects for large power high voltage shore power connections such as for example the city of Gothenburg in Sweden.

The European Commission has started feasability studies into the possibilties of large scale introduction of large power high voltage connections in major ports such as Rotterdam, Holland.

The term "**cold ironing**" stems from the age of coal fired iron clad steam engines. When a ship with such engines would tie up at port there was no need to continue to feed the fire and the engines would cool down eventually going completely cold, hence the term "cold ironing".



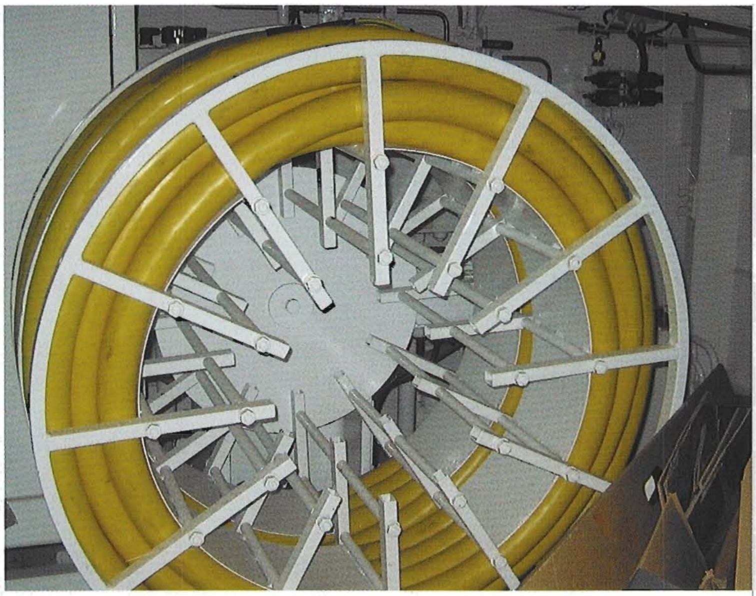
Shore connection plug and socket 125 Amp.

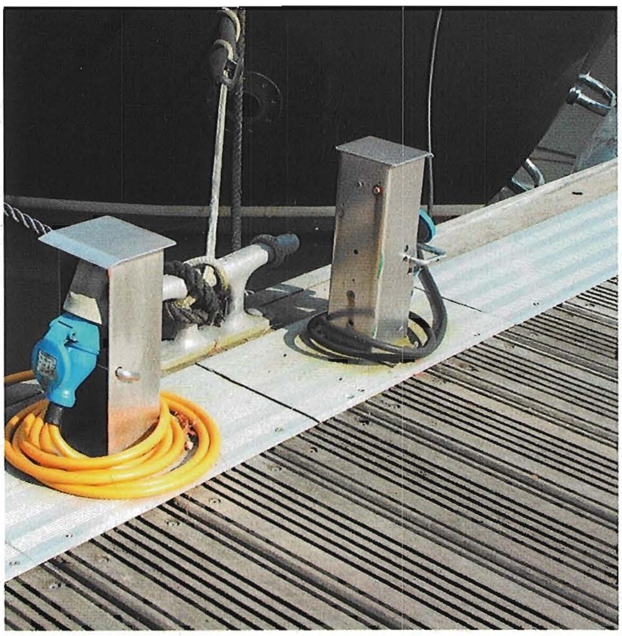


High voltage shore connection cables

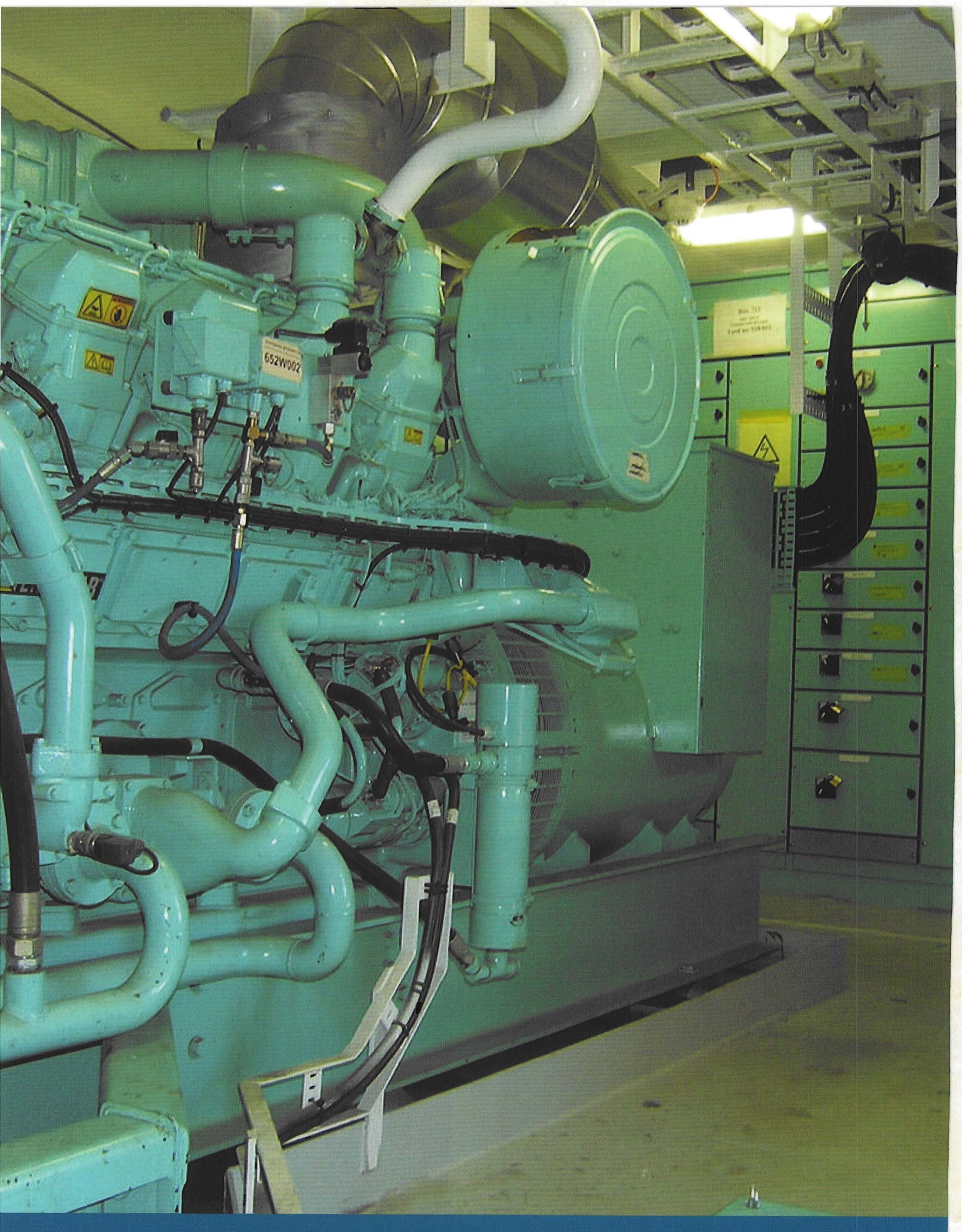
SHORE CONNECTIONS					
SHIP TYPE	SHIP'S SYSTEM	SHORE SUPPLY		BERTH	STANDARD PLUG
SMALL YACHT	12V DC	230V 16A	50Hz	YACHTING MARINA'S	CEE BLUE 230V 16A
INLAND WW SHIP	230/400V	2 x 230/400 V 63A	50Hz	IWW HARBOURS	CEE RED 63A
LARGE YACHT	230/400V	2 x 230/400 V 125A	50Hz	MARINAS	CEE RED 125A
	230/400V	300 kW	50Hz	MARINAS	MARECHALL 630A
GENERAL CARGOSHIP	3x400V 50Hz	3x400V	50Hz		NOT DEFINED
GENERAL CARGOSHIP	3x450V 60Hz	3x450V	60Hz		NOT DEFINED
CHEMICAL TANKER	3x450V 60Hz	3x450V	60Hz		NOT DEFINED
OIL TANKER	3x450V 60Hz	3x450V	60Hz		NOT DEFINED
RO-RO PASSENGERS	3x450V 60Hz	3x450V	60Hz		NOT DEFINED
RORO PASSENGERS	3x6.6kV 60Hz	4MVA	60Hz		NOT DEFINED
CRUISE SHIPS	3x6.6kV 60Hz	4-16MVA	60Hz		NOT DEFINED
CONTAINER SHIPS	3x6.6kV 60Hz	4MVA	60Hz		NOT DEFINED
LNG CARRIERS	3x6.6kV 60Hz	10MVA	60Hz		NOT DEFINED


Shore connections for a mega-yacht and for small yachts. The cable for the mega-yacht is stored on a reel.


300kW Shore cable reel and shore connection box of a mega yacht


Shore connections for small yachts in a marina.


The electrical shore connection is located in a box with sequence indicators, voltage indicators and a sequence change-over switch.



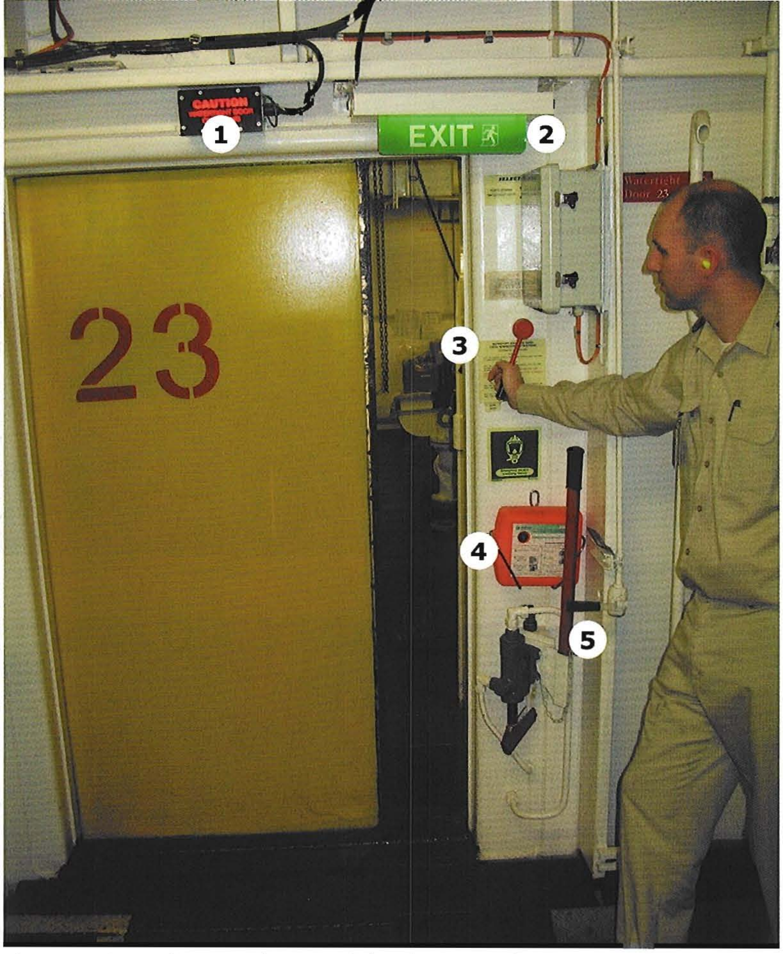
12. EMERGENCY POWER

Emergency power in general comes from batteries or when the load is large, from an emergency diesel generator.
For very large peak loads, gas turbines are used.
Emergency power is required to supply electrical emergency consumers when the normal power supply fails.
Emergency consumers include those required for alerting passengers and crew, emergency lighting to enable safe escape from the ship and those services for reducing risk such as closing fire doors and watertight doors and providing power for emergency fire pumps.

1 Emergency consumers.

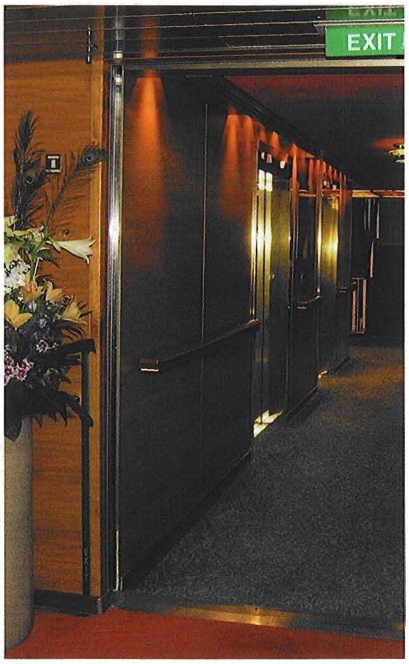
The following consumers are supplied by the emergency switchboard:
- Navigation equipment
- Navigation lighting
- Communication
- Steering gear
- Power and control systems for electrically operated watertight doors as well as their indication on the bridge
- Power and control systems to operate electric fire doors as well as their indication on the bridge
- Emergency lighting
- Fire detection systems
- Fire alarms
- Fire fighting systems, fire pumps and release alarms for CO_2 systems
- General and fire alarms
- Public address systems for passenger and cargo ships used for general and fire alarms
- Emergency fire pump
- Emergency bilge pump
- Internal communication systems
- Initial starting equipment if electrical.

Additionally on passenger ships:
- Sprinkler system
- Low location lighting
- External communication equipment.
- Transitional lighting fed from a UPS system

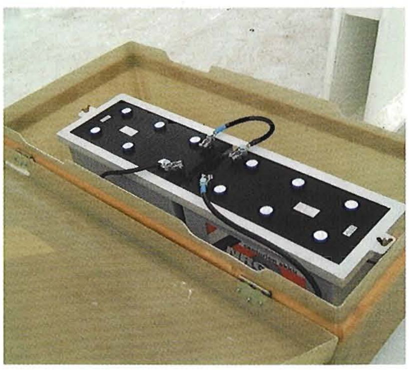


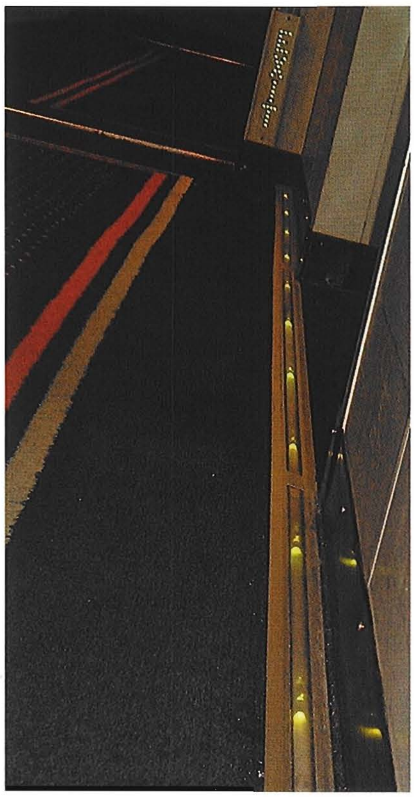
Automatic and manual watertight door number 23

1. Visual and audible door operation alarm
2. Exit sign with internal battery
3. Hand hydraulic operation handle
4. Emergency escape breathing device
5. Hand emergency opening / closing handle.



Automatic fire door


Back-up battery of the external communication equipment


Low level lighting

In **batteries** elecrical energy can be stored through a chemical process. By reversing this process, the energy can be retrieved as DC power. Emergency batteries can supply electrical energy, for a defined demand during a defined period, when the normal source, a generator, fails. When the total demand is too high, an emergency generator has to be installed.

2 Emergency batteries

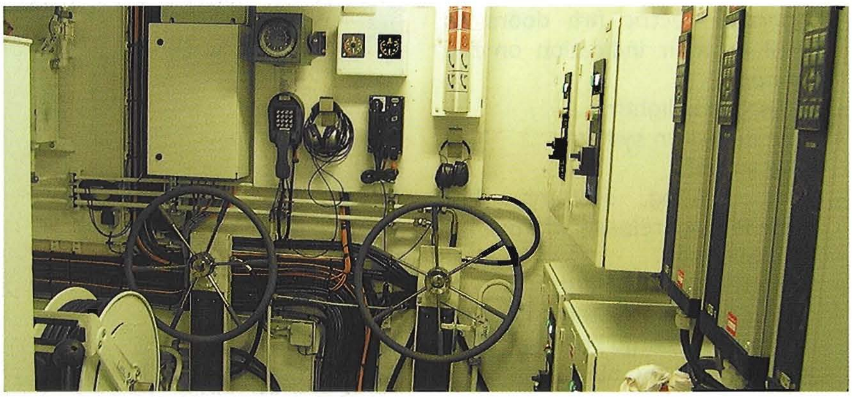
Batteries are of two basic types, the lead acid battery and alkaline. The alkaline battery is more expensive but lasts longer and can be charged with more current and more often than the conventional lead acid battery.
Battery capacity is defined in ampere hours (Ah) and indicates the multiplication of discharge amperes by maximum discharge time.
There are starting batteries capable of delivering a high current for a short time.
Emergency lighting batteries, on the other hand, need to be capable of delivering a low current for a long time, depending on the type (18 to 36 hours) of service.
The capacity required is determined by a load balance.

3 Emergency generator

An automatic starting emergency generator with its own fuel tank, double starting system and emergency switchboard is required and has to supply power for essential (emergency) services in case the main power fails.
The fuel tank must have capacity to supply the emergency generator with fuel, for running at full load, a set number of hours. For cargo ships this is 18 hours, for passenger ships 36 hours and special service craft 12 hours. Special service craft are for instance workships, often with many people on board.
The emergency services comprise the transitional lighting, emergency lighting, navigation lights, internal and external communication, fire detection including alarms, emergency firepump, emergency bilgepump, the sprinkler pump, ultrafog if applicable, steering gear, watertight doors.

Transitional battery on passenger ship

Man-overboard-boat station with preparation lights, flood lights



Emergency steering position for twin rudders with two handwheels. Displays above for course, rudder indicators. Further telephones and a talk back system

An **emergency generator** is required to run in one space with all its necessary equipment.
This space also contains the emergency switchboard and eventually the emergency lighting transformer and the emergency lighting switchboard.

The generator equipment must consist of:
- double means of starting: two sets of batteries with each a charger, one set of batteries with an alternative like a spring starter or an hydraulic starter.
- a dedicated fuel tank with capacity as earlier mentioned,
- an independent cooling system
- air supply fans
- exhaust dampers.

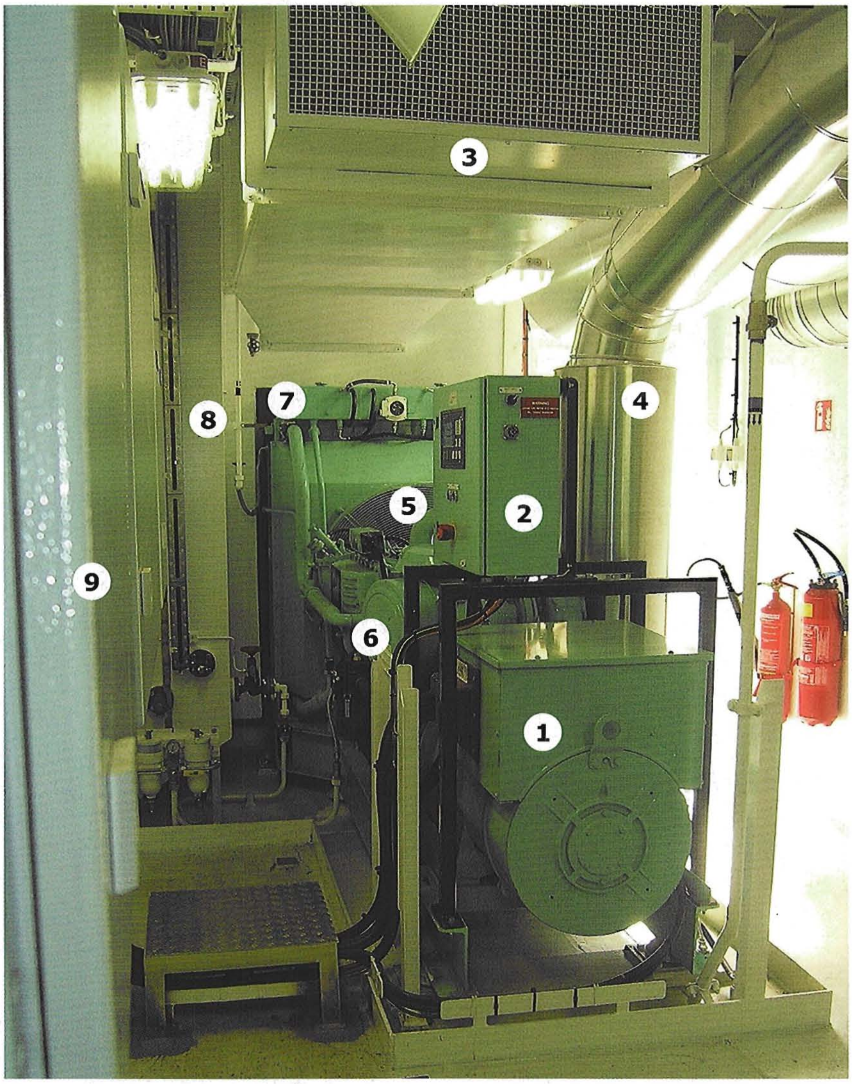
All this together in an all around A60 insulated space above the main deck, with an access door from the open deck.

An emergency generator normally is also used for 'the first starting arrangement' which is getting the ship's engine room alive again in case all generators (and of course the main engine) are stopped, and air vessels and batteries empty. This first starting arrangement can also be a small handstart air compressor capable of filling an air vessel to start an auxiliary diesel.

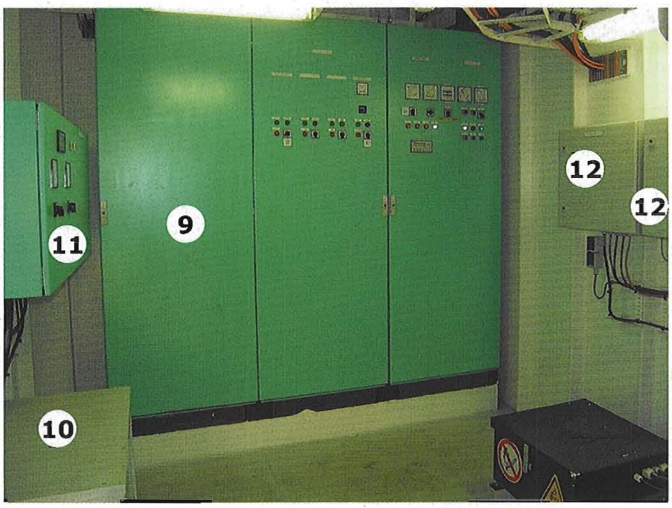
Some emergency generators have the possibility to be used as a harbour generator. If selected for harbour duty the engine protection system on high cooling water trip and lubrication oil trip shall be active.

In emergency duty these shall not be active and the overspeed trip shall be the only protection. Emergency switchboards with remote controls from the main switchboard must have these controls made such that failure of the mainswitchboard or the cables between the emergency switchboard and the main switchboard shall not effect the functioning of the emergency generator. This means that all electrical connections from the emergency switchboard outside the emergency generator room must be isolated in an emergency.

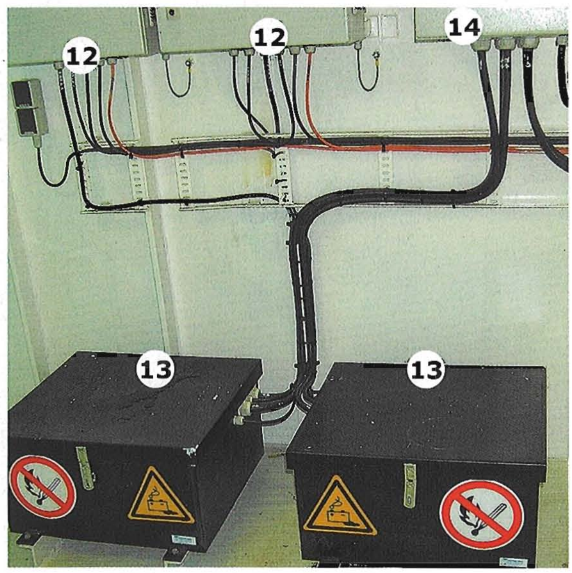
Emergency generators shall be tested regularly. Emergency generators shall be capable to be run at 100 % engine rating for the time specified with all doors closed as well as for 110% of engine rating for 15 minutes.



1. Air-cooled generator
2. Engine control panel
3. Air supply system
4. Exhaust system
5. Engine driven fan
6. Emergency diesel
7. Radiator
8. Fuel tank with level indicator and alarms
9. Emergency switchboard
10. Emergency lighting transformer
11. Emergency lighting switchboard
12. Battery chargers
13. Start batteries
14. Start battery change-over box



Emergency switchboard with emergency lighting transformer and emergency lighting switchboard



13. SWITCHBOARDS

The basic function of **switchboards** and other switchgear assemblies is to connect and disconnect generators and consumers to the main power supply system.

Another important function is the protection of the generators, cables and consumers against overload and short-circuits.

Legislation in most countries (Labour Law) gives strict rules regarding powering down a part of an installation safely, making repairs and powering up safely afterwards.
It also defines the skills and responsibilities of the operator and maintenance people.

1 Switchboards and other switchgear assemblies.

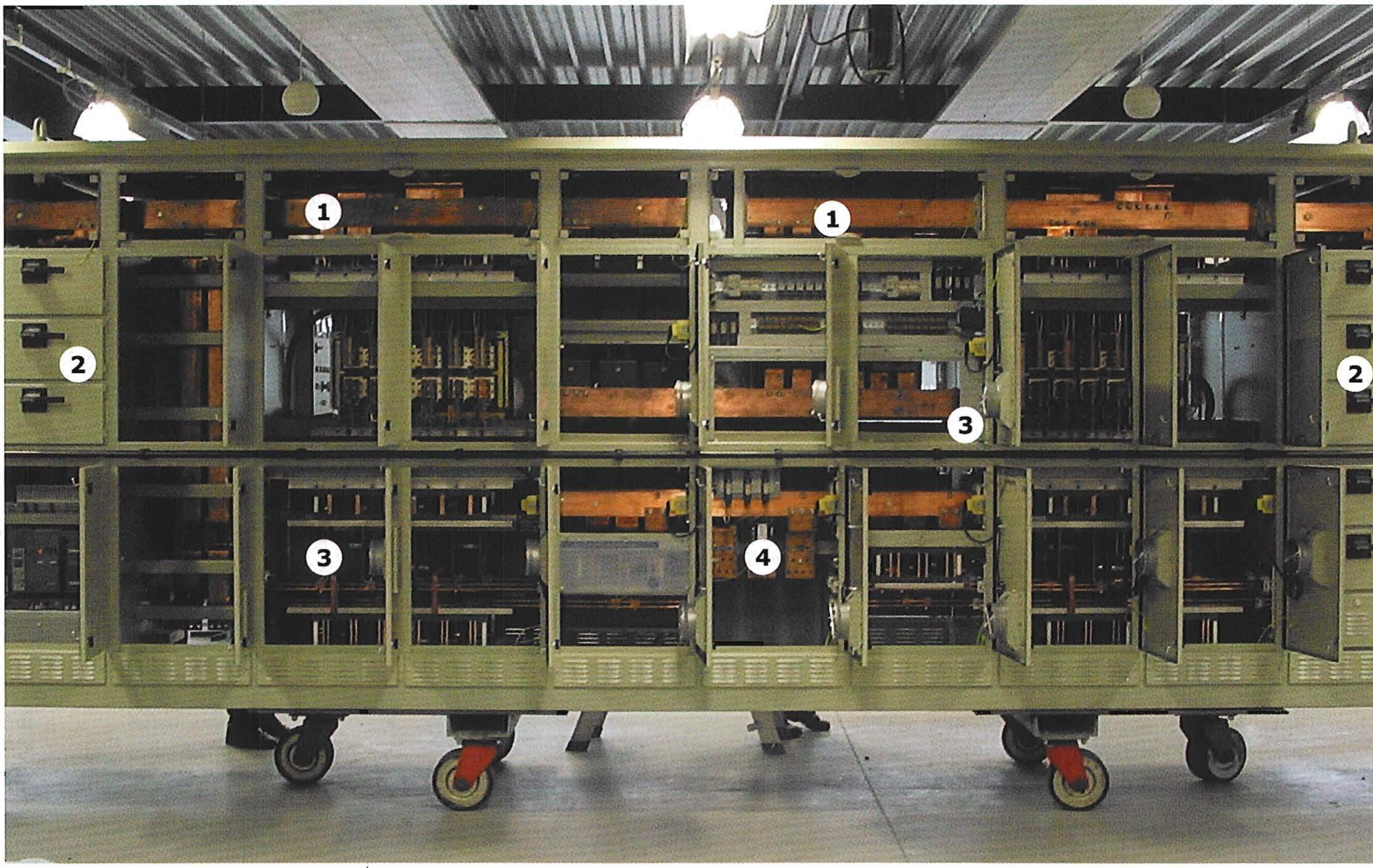
Low-voltage switchgear and control gear assemblies (Type-tested Assemblies (TTA) and Partially Type-tested Assemblies (PTTA) with a rated voltage which does not exceed 1000 V AC at frequencies not exceeding 1000 Hz, or 1500 V DC are to be built in accordance with industrial standard IEC 60439-1.
For use on ships the switchgear and control gear assemblies have to be adapted to the marine environment as detailed in the requirements of IEC 60092-302 Low-voltage switchgear and control gear Assemblies for Ships and the requirements for type-approved equipment as detailed in chapter 9 of this book.
Some of the additional marine requirements are:
Provisions for higher temperatures, humidity, vibration and the ship's movements.

Large switchboards require counter foundations to avoid stresses from the movement of the ship.
Protection class IP23 when the doors of the switchgear are closed and IP20 when these are open.

A minimum distance between phase to phase and phase to earth of:
- 14mm for a 500V earthed system
- 19mm for a 500V non-earthed system

Handrails to be provided on the front and back of switchboards.
Door catchers to be provided to hold doors in the open position.
It should be noted that the Rules and Regulations provide minimum requirements to equipment and that the Owner may have additional requirements as laid down in the contract.
Using the outcome of the short-circuit calculations (see chapter 07) the design of the switchboard bus bars can be made. Especially with large switchboards which are part of large power plants with high short-circuit values this design must be carefully made as the mechanical stress from a short-circuit can be substantial. Large switchboards, when the primary structure with the main bus bars is completed, are sometimes tested under real short-circuit conditions in a specialized laboratory which is able to generate the required currents.

1. Main bus-bar
2. Outgoing group sections
3. Generator panel
4. Bus-section panel



Switchboard under construction

Only the last emergency mode of closing by pressing the mechanical controls at the circuit breaker front, is allowed to be unprotected.
The mechanical controls on the circuit breaker should be provided with a locked cover to avoid accidental operation
Furthermore synchronizing equipment has to include a double voltmetre and a double frequency metre indicating voltage and frequency for both bus-bar and incoming machine.
The instruments may also be replaced by a multifunction instrument per generator which enables the read-out of voltages between the phases and between the phases and the neutral if applicable, phase currents, power, reactive power, frequency, etc.
Having the correct voltage and frequency still does not mean that the bus-bar and incoming machine are synchronous. This means that they have the same voltage, the same phase rotation and the same angle.
The functional test for a simple assembly can be described on a single sheet of paper.
For more complex assemblies or where a programmable logic controller is involved, the input information to the programmer, i.e., the functional specification of the program, is to be used to test the functionality.
Also failure modes of the program have to be determined. Watchdog failure alarms must be incorporated into every essential system.

The photo shows a high-voltage switchboard for a diesel electric work ship.
This switchboard is transported to the vessel in parts and prior to commissioning, the reassembled switchboard is high voltage tested on board.

Switchboards and major control gear assemblies must be tested by the manufacturer, and must at least comprise:
- A high voltage test normally 2500V for one minute between all phases
- between all phases and earth and between neutral and earth, with starpoint disconnected

2 Switchboard lay-outs

The lay-out of a switchboard should be as logical as possible to aid the operators with their work.
The location of signal lights, pushbuttons and control switches should be such that their operation is easy and when operated do not block instruments.

The internal lay-out should be equally logical and allow repair and servicing.

Instrument scales should preferably be with non-glare glass and provided with red or green marks on the scale to indicate limits or normal values.

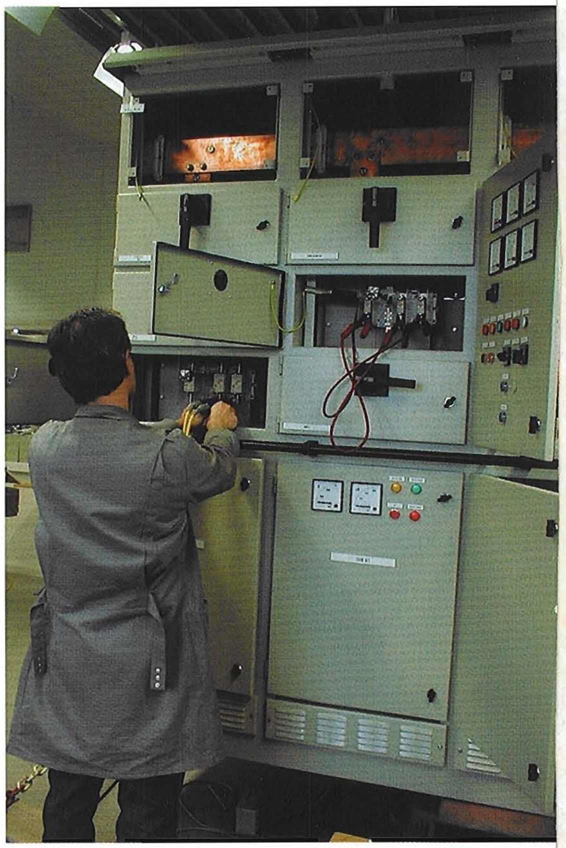
Nameplates and the lettering on them should have a size appropriate to the viewing distance.
The large nameplates above a switchboard panel, indicating its function, can be as big as 30x10cm with 6cm letters. A nameplate at a pushbutton can be 5x2cm with 3 or 4 mm lettering as the viewing distance will be short.
Using coloured nameplates, such as red with white lettering, will help to identify critical functions.

In some complicated switchboards it may help to provide the front with simple black lines and symbols to help with understanding.

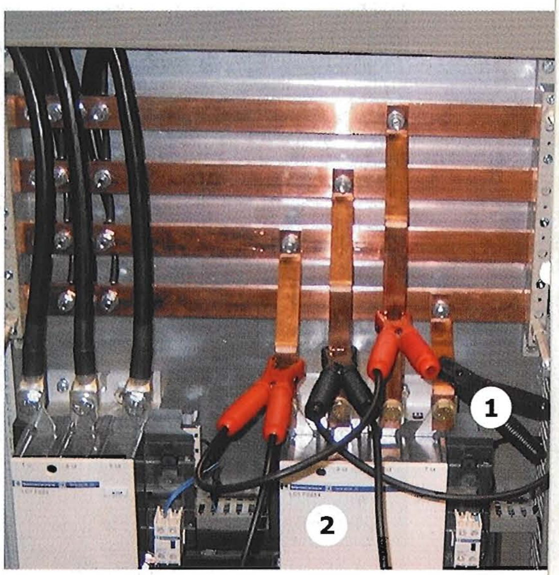
3 High voltage switchboards

For installations with a voltage above 1000 volts, IEC standard 62271 High voltage switchgear and control gear must be used.

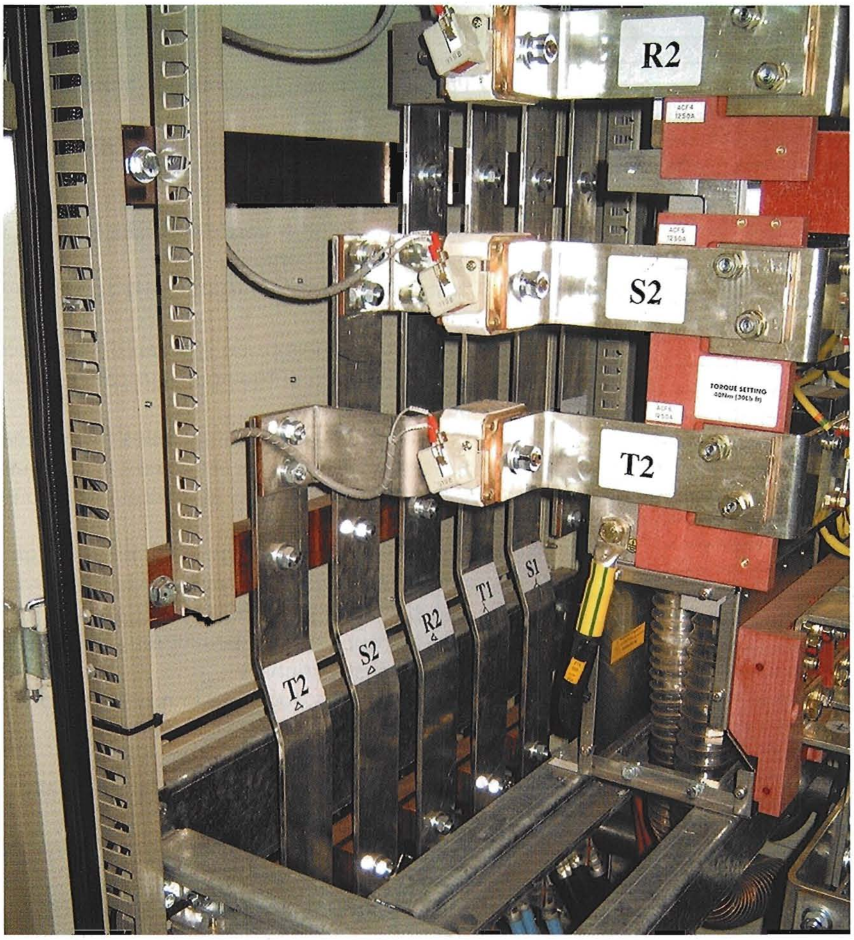
Switchboard foundations have to be aligned and flat to avoid stresses and/or misalignment in the board. Circuit breakers are fitted on rails for withdrawal, and when not properly aligned, withdrawal can be difficult.



A visual inspection to verify that the equipment is in accordance with the agreed drawings and standards - insulation distances, marking of components, nameplates, etc. and last but not least, a functional test. A Meggertest or insulation resistance test with a 1000V megger, which for new equipment should have a value of 100 M-Ohm.



1. Red phase to phase connection
2. Black phase to earth connection



Switchboards come in all sorts of shapes and sizes driven by the requirements and the preferences and experience of the designers.

On this page there are two examples of switchboard designs.

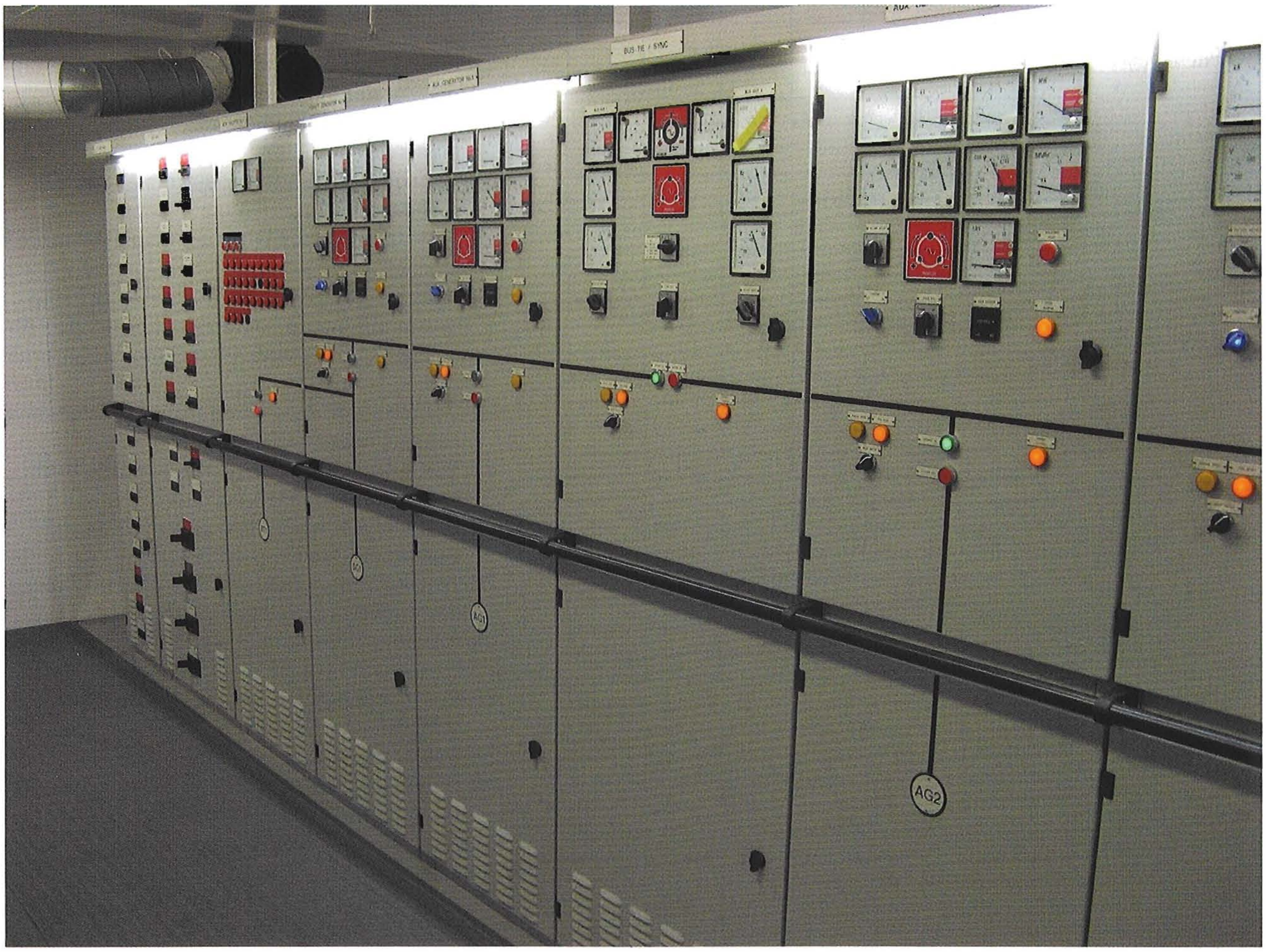
On the left is an internal view with heavy bus bar arrangement.

Below is the front of a straight-forward Main Switchboard as installed on a RoRo car ferry.

On this picture one can see from left to right the following main features of this switchboard:

- two consumer panels
- bow thruster panel with indication section for non-essential consumers first panels.
- shaft generator panel
- auxiliary generator 1 panel
- bus tie panel with common synchronization section
- auxiliary generator 2 panels

The right side of this switchboard is the mirror image of this left part.



4 Example checklist for low voltage switchboards

CHECKLIST LV SWITCHBOARDS < 1000 VOLT				
PROJECT				
PROJECT NUMBER				
CLIENT				
CLIENT'S ORDERNUMBER				
FIRST VISIT			DATE	
LAST VISIT			DATE	
DESIGN APPRAISAL DOCUMENT (DAD)		REF	DATE	
OUTSTANDINGS	YES	NO		
LIST OF TESTS				
LIST OF TESTS	OK	NOT OK	NOT APPL.	NOTE
LAY-OUT AS PER DRAWINGS				
DIMENSIONS AS PER DRAWINGS				
PROTECTIONCLASS IP23				1
SAFE WITH NORMAL DOORS OPEN IP20				2
OTHER DOORS LOCKED				3
MEGGER AND HIGH VOLTAGE TESTS				
MEGGERTEST				4
HIGH VOLTAGE TEST				5
MEGGERTEST AGAIN				
RECONNECT ELECTRONICS				
COMPONENTS TYPE APPROVED				
WIRING TYPE APPROVED				
SEPARATION BETWEEN PANELS				6
WIRING CROSS SECTION				7
Bus-bar SYSTEM TYPE APPROVED				
Bus-bar DIVISION				8
Bus-bar DIMENSIONS				9
Bus-bar SUPPORTS				10
CONNECTIONS LOCKED				11
COMPONENTS FLAME RETARDANT/LOW SMOKE				
CREEPAGE AND CLEARANCE DISTANCE				
TERMINAL CODES				12
WIRING CODES				
Bus-bar CODES				13
EQUIPMENT CODES				14
NAMEPLATES				
DOOR CATCHERS				
WIRING TO DOORS				
EARTHING DOORS				
HANDRAILS				
SEPARATION WIRING				15
INSTRUMENTATION				16
INSTRUMENT SCALES				
NOMINAL MARKS				
COLOUR CODING INDICATOR LIGHTS				
LABELS				
CIRCUIT BREAKER TEST CERTIFICATES				17
CIRCUIT BREAKER SETTING LABELS				18
FUNCTIONAL TESTS				
SHORE CONNECTION INTERLOCK				
PARALLEL INTERLOCK				
MANUAL SYNCHRONISING				
AUTOMATIC SYNCHRONISING				
LOAD SHARING				
AUTOSTART/AUTOCLOSE				
EMERGENCY STOP				
VOLTAGE AND FREQUENCY ALARMS				19
EARTHFAULT ALARMS				20
REVERSE POWER TRIP				21
POWER MANAGEMENT SYSTEM OPERATION				
NON ESSENTIAL TRIP				
BLACK OUT START				30
MECHANICAL TESTS				
DOORS/LOCKS				22
WITHDRAWABLE CIRCUIT BREAKERS				23
WITHDRAWABLE STARTERS				24
WITHDRAWABLE SUPPLY CIRCUITS				25
TESTS ON BOARD				
MECHANICAL ALIGNMENT				26
Bus-bar STRESS				27
FOUNDATION				28
SEAFASTENING				29

NOTES

1 Switchboards in engine rooms shall be at least IP 23

2 Panels which can be opened without tools, at least IP 20

3 Doorlocks shall be of a suitable type

4 Preferably with a 1000V Megger

5 S earthed versus R and T, R and T earthed versus S, S and N earthed versus R and T, R and T earthed versus S and N
Testvoltage 200V for 400V 50Hz and 2500 V for 450V 60Hz

6 Generator panels to be separated from each other and from outgoing group panels by a suitable partition

7 Cross section wiring as per rules for applicable temperature class single cores. Too many full loaded powercores in a wiring duct to be avoided.

8 Bus-bars of high voltage systems and high powered low voltage systems shall be divided

9 Bus-bar loads at 45 °C about 2 A/mm^2

10 Bus-bar supports for peak fault level as per makers instructions

11 Springwashers, locknuts in main bus-bar, temperature rise to be considered

12 Terminals shall be clearly marked

13 Bus-bars shall be arranged systematically and marked

14 Equipment to be clearly coded, referring to drawings

15 Intrinsically safe wiring to be separated

16 Instrumentation as per IEC requirements, nominal values to be clearly marked

17 Circuit breakers to be tested at manufacturers and certified

18 Circuit breaker settings to be indicated on permanent labels
Fuse ratings shall be indicated on permanent labels

19 Voltage and frequency alarms as per IEC standard

20 Earthfault alarms when an insulated system is used

21 Reverse power trip for machines capable to run in parallel. Differential protection for machines >1500kW, initialising circuit breaker trip.

22 Doors to non safe compartments shall have keys or require tools

23 Test interchangeability, retest when the switchboard is fixed on board

24 Test interchangeability, retest when the switchboard is fixed on board

25 Test interchangeability, retest when the switchboard is fixed on board

26 Measure alignment, check for any deformation

27 Bus-bars shall not be exposed to mechanical stress

28 Check foundation alignment

29 Check seafastenings, no mechanical load to switchboard

30 After a black-out a generator shall automatically start and restore power at the main-switchboard. Essential propulsion auxiliaries shall sequentially restart automatic

DET NORSKE VERITAS — Certificate No.: **ROT-08-5234-1**

DNV

CERTIFICATE FOR SWITCHGEAR ASSEMBLY

Type of assembly *(Main/Emergency Switchboard, Motor Control Centre, etc.)* **Main Switchboard MSB-1**	Id.No **D27932**
Manufacturer **GTI SUEZ**	
Certification ordered by **IHC Krimpen Shipyard B.V**	Purchase order No. **90193.1**
Intended for **IHC Krimpen Shipyard B.V.**	Yard **IHC Krimpen Shipyard B.V.**

THIS IS TO CERTIFY that the switchgear assembly described below, has been built and tested in accordance with Det Norske Veritas' current Rules for Classification of "Ships", "Mobile Offshore Units" and "High Speed, Light Craft and Naval Surface Craft".

Switchgear specification	Voltage (V) **440**	Power (kW) **1280**	Frequency (Hz) **60**
	Current (A) **2099**	Short circ. Level. (kA) **35**	Degree of protection (IP) **42**
	Distribution system **3** Phase **4** Wire	☒ Insulated ☒ Earthed	Ambient temperature (°C) **50**

High voltage test: **2.5** kVolts for **1** minutes
High voltage test: **2.5** kVolts for **1** minutes

Insulation test: **<200** MOhm("Megger test")

Remarks

Function test: *(specify)*

According FAT procedure 95.022.3#26

Marking

For identification the assembly was stamped: **NV ROT 085234-1**

This product certificate is only valid when signed and stamped by DNV surveyor

Place: **Rotterdam/Barendrecht** Date: **2008-05-02**

Paul de Niet
Surveyor

If any person suffers loss or damage which is proved to have been caused by any negligent act or omission of Det Norske Veritas, then Det Norske Veritas shall pay compensation to such person for his proved direct loss or damage. However, the compensation shall not exceed an amount equal to ten times the fee charged for the service in question, provided that the maximum compensation shall never exceed USD 2 million. In this provision "Det Norske Veritas" shall mean the Foundation Det Norske Veritas as well as all its subsidiaries, directors, officers, employees, agents and any other acting on behalf of Det Norske Veritas.

DET NORSKE VERITAS, VERITASVEIEN 1, NO-1322 HØVIK, NORWAY, TEL INT: +47 67 57 99 00, TELEFAX: +47 67 57 99 11
Form No.: 70.40a Issue: November 2006 Page 1 of 1

14. PARALLEL OPERATION

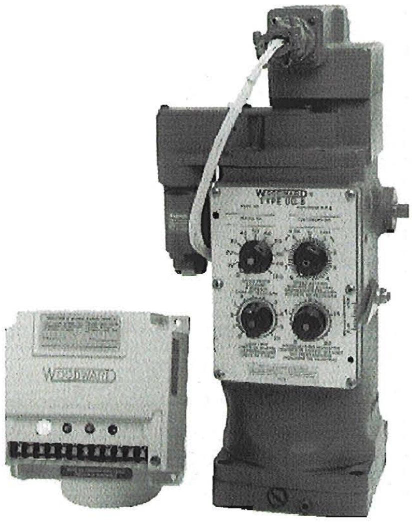
The process of **synchronization, parallel operation and load-sharing** of identical machines as well as of machines different in rating both in droop and in isochronous mode is explained in this chapter.
The machine which is to be synchronized and coupled to the main bus-bar is called an incoming machine.

1 Parallel running

Alternating current and rotating current generator sets, intended to run in parallel, share their loads, the diesel-engine power in kW and the generator current in ampere.
When generators do not share load, when increasing the total load, that load can be increased until one engine runs at maximum power while the others have not yet reached that power.
The power of the engines which are not running at maximum load cannot be used.
Similarly, with generators, when increasing the total load and one generator has reached the maximum current while the others have not, the current capacity of the non-maximum loaded generators cannot be used.

2 Governors

The load control of prime movers is carried out by the governors. This is a control device which controls the amount of fuel to a diesel engine to keep the speed of that diesel at a desired RPM, or in accordance with a desired speed curve.
A governor can also control the steam input to a turbine to keep the speed of that turbine constant or according to a desired curve.
Prime movers such as diesel engines or steam turbines which have to share load, must have identical curves.
The reduction in speed (droop) related to the increase in load has to be the same percentage over the total load range of both machines. Size of the machine is not important as long as the percentage is identical.



Engine Governor WOODWARD UG8, controlling the position of the fuel rack, which controls the quantity of fuel to the cylinders.
This is a governor for conventional engines with a conventional fuel injection system.

The small box is an electronic governor for modern common-rail injection diesel engines.

A **governor** is a control unit on a diesel engine that adjusts the fuel and thereby the speed, or when running in parallel, the load on the engine.
The working is based on "droop". Speed droop is similar to voltage droop. The same name is used for both phenomena.

Droop is the name for a speed regulating system of the engine governor, which controls the fuel to the engine in such a way that the speed of the engine decreases 2 to 4 per cent from no-load to full-load.

Or:

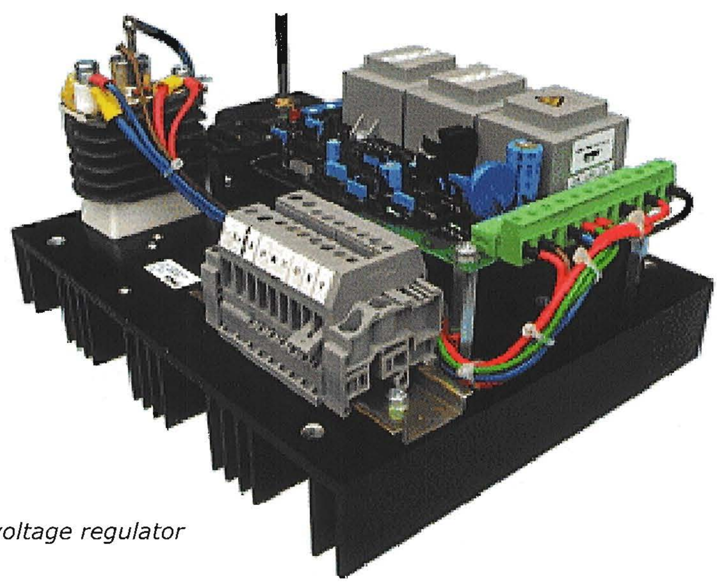
Droop is the ratio of the quotient of the change in frequency and the nominal frequency to the quotient of the change in power and the nominal power af a rotating machine.

3 Automatic voltage regulator

An automatic voltage regulator (AVR) is a control unit that controls the generator voltage. **Droop** is the name for a voltage regulating system that controls the voltage of a generator in such a way that it decreases approximately 2 to 4 % from no-load to full-load.
It keeps the voltage steady by adjusting the excitation voltage in accordance with a droop curve depending on the current.

The AVR can be connected to the exciter of the brushless generators or to the slip rings of an old-fashioned generator.

For parallel operation of identical machines the droop must be the same in volts from no-load to full-load current.
For parallel operating machines of different ratings the droop must be the same percentage.
In this way the different machines share current by each taking a proportion of the rated current of each machine.



Automatic voltage regulator

4 Examples voltage and current droop of identical machines

A conventional fuel system of a diesel engine consists of a low pressure fuel pump feeding high pressure (piston) fuel pumps activated and timed by the cams of the camshaft. The fuel goes from the high pressure pumps through the high pressure fuel line via de injectors into the cylinders.
The amount of fuel is controlled by the radial position of the piston of the high pressure fuel pump.
In the early common-rail diesel engines, the fuel is brought under constant high pressure in an accumulator.
The fuel is released into the cylinder via the injectors through solenoid valves which are operated by an electronic control unit.
The electronic unit handles the moment of opening and how long each valve is open.
This increases the efficiency of the engines and reduces exhaust emission.
Common-rail engines make use of very high pressure pumps and electronically piezo-electric valves.
The electronic control unit can also inject a small amount of fuel just before the main injection, such as a pilot injection, reducing explosiveness and vibration.
The speed setting is sent to the electronic control unit by a voltage signal from the switchboard or by a voltage signal from the synchronizer load sharing unit.

If the speed droop is not the same in the machines, they will not share load over the total load range but only a certain total load.

5 Examples test sheets of identical machines

The performance of each generator set has to be checked, which means that the reaction of the diesel engine to a change in load has to be tested as well as the change in voltage due to a change in load.

Each generator set should be tested individually and if the individual figures are alike, sets in parallel, also. When the voltage droop of the generators, from no-load to full-load, is adjusted and found identical, the speed droop of the diesel engine is verified and adjusted as necessary. Hereafter, both sets can be synchronized and run in parallel mode. The load sharing is adjusted so that both generators share the load 50/50 at one load setting, usually maximum load.
The sets should now share load from zero to 100% without any further adjustment.

Diesel Test Sheet 1					
Full load test					
Water resistance cosQ=1					
Time	10:00	10:15	10:30	10:45	11:00
Voltage V	450	450	450	450	450
Frequency Hz	60	60	60	60	60
Current A	400	400	400	400	400
Power kW	250	250	250	250	250
Lubricating oil press Bar	3	3	3	3	3
Lubricating oil temperature°C	50	60	70	80	80
LT coolwater temperature°C	20	25	30	35	35
HT Coolwater temperature°	50	60	70	80	80
Exhaust gas temperature °C	50	350	375	400	400
For large motors >1500kW also					
Exhaust gas temp °C Cylinder1	50	350	375	410	415
Exhaust gas temp °C Cylinder2	51	351	380	400	405
Exhaust gas temp °C Cylinder3	50	350	360	410	415
Exhaust gas temp °C Cylinder4	49	349	365	420	480*
Exhaust gas temp °C Cylinder5	50	350	360	410	415
Exhaust gas temp °C Cylinder6	51	351	380	430	430
Deviation alarm					
For very large motors > 2250kW					
Bearing temperature°C Bearing1	50	60	70	80	80
Bearing temperature°C Bearing2	50	65	70	80	80
Bearing temperature°C Bearing3	50	54	70	80	80
Bearing temperature°C Bearing4	50	57	70	80	80
Bearing temperature°C Bearing5	52	58	70	80	80
Bearing temperature°C Bearing6	49	59	70	80	80
Bearing temperature°C Bearing7	51	65	70	80	80

POWER %	POWER kW	VOLTAGE V	CURRENT A	FREQ. Hz	SPEED RPM
0	0	455	0	60,00	
50	60	454	125	59,80	1800
70	125	452	250	59,50	
100	185	452	375	59,30	1785
75	250	450	500	59,00	
50	185	451	275	59,30	1770
20	125	452	250	59,50	
0	60	454	125	59,80	
	0	455	0	60,00	1800

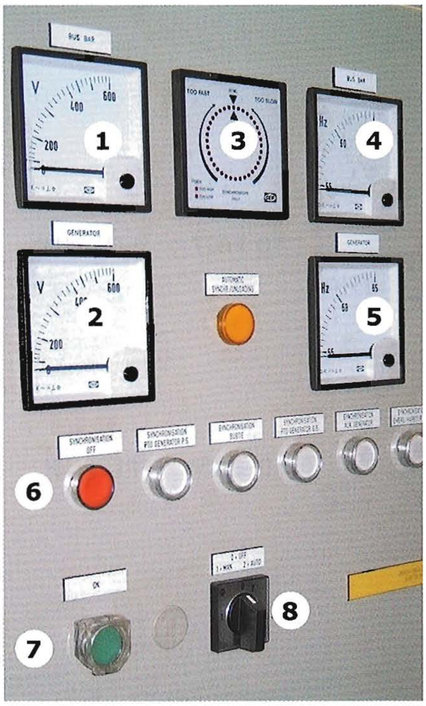
Diesel test sheet 2. Diesel generator set individual

TOTAL RATING %	DIESEL GENERATOR 1 POWER Kw	CURRENT A	FREQ Hz	DIESEL GENERATOR 2 POWER Kw	CURRENT A	FREQ Hz
0	0	0	60,00	0	0	60,00
25	60	120	59,80	60	130	59,80
50	125	250	59,50	125	260	59,50
75	185	370	59,30	185	380	59,30
100	250	500	59,00	250	500	59,00
75	185	370	59,30	185	380	59,30
50	125	250	59,50	125	260	59,50
25	60	120	59,80	60	130	59,80
0	0	0	60,00	0	0	60,00

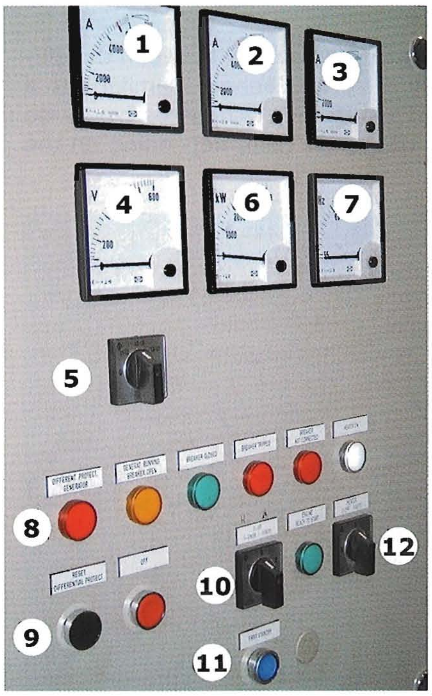
Diesel test sheet 2 Diesel generator sets parallel

6 Synchronising and generator panels

The pictures show examples of a synchronising and a generator panel of a main switchboard which are used to safely connect an unconnected generator to a live bus-bar.



Synchronising panel



Generator panel (incoming machine)

Picture left top:

1. Voltmetre bus-bar
2. Voltmetre incoming machine
3. Synchronoscope with LED's
4. Frequency metre bus-bar
5. Frequency metre incoming machine
6. Circuit breaker open push-button
7. Circuit breaker close push-button
8. Selector switch incoming machine

Picture left bottom:

1. Amperemetre R-phase
2. Amperemetre S-phase
3. Amperemetre T-phase
4. Voltmetre
5. Phase selector switch voltmetre
6. kW metre
7. Frequency metre
8. Indication lights
9. Circuit breaker on / off
10. Function selector switch
11. Standby light
12. Standstill heating switch

7 Principle of manual synchronisation

To make two engines run in parallel the speed of the incoming no-load engine must be adjusted until its speed is slightly more than the on-load engine(s), synchronized and switched to parallel.
Connecting two engines in parallel without synchronising will cause extreme mechanical stress, especially with larger units, which can damage these beyond repair.

When connected, the fuel setting of the in-coming engine is increased to share the load. The fuel setting of the on-load engine will be reduced in connection with the reduction in load.
Without further adjustments the engines will now share load from zero to maximum load.

To determine that the phase of the incoming engine is identical to the phase of the bus bar a synchronoscope is used of which there are various types.

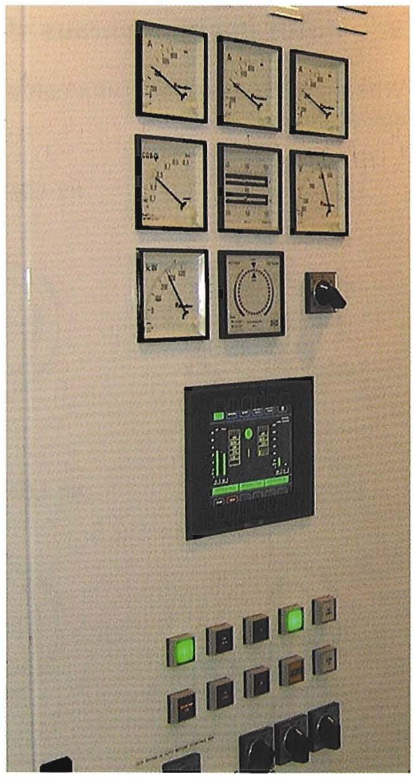
A pointer synchronoscope uses a small electric slip-ring motor with the stator connected to the bus bar and the rotor connected to the incoming generator.
A pointer is mounted on the rotor to visualise the speed difference between the engines connected to the bus bar and the incoming engine.
When the phase of the incoming generator is ahead of the bus bar phase, the engine runs too fast and vice versa.

The speed of the incoming engine is increased or decreased by the governor control switch on the switchboard.

When the incoming machine is in phase with the bus bar the pointer on the synchronoscope will be on the 12 o'clock position. When the pointer is dead slow approaching the 12 o'clock position the generator circuit breaker can be closed.
Normally the closing command is given at the 5 to 12 position to allow for some switching delays.

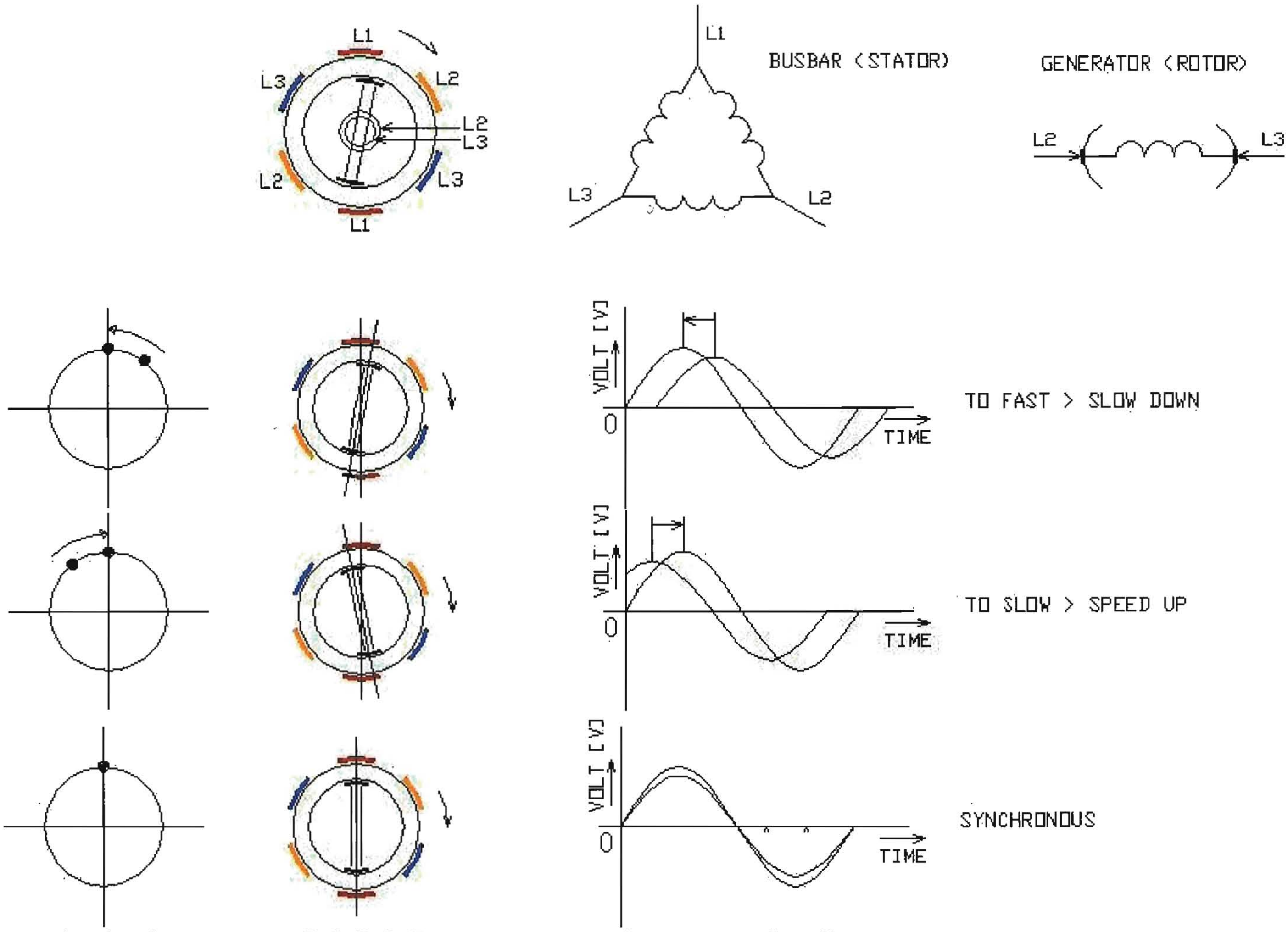
See the next paragraph for a diagram and principle of the pointer synchronoscope

Modern synchronoscopes are fully electronic and use red and green LED's for indication.



Generator panel with manual and automatic synchronising

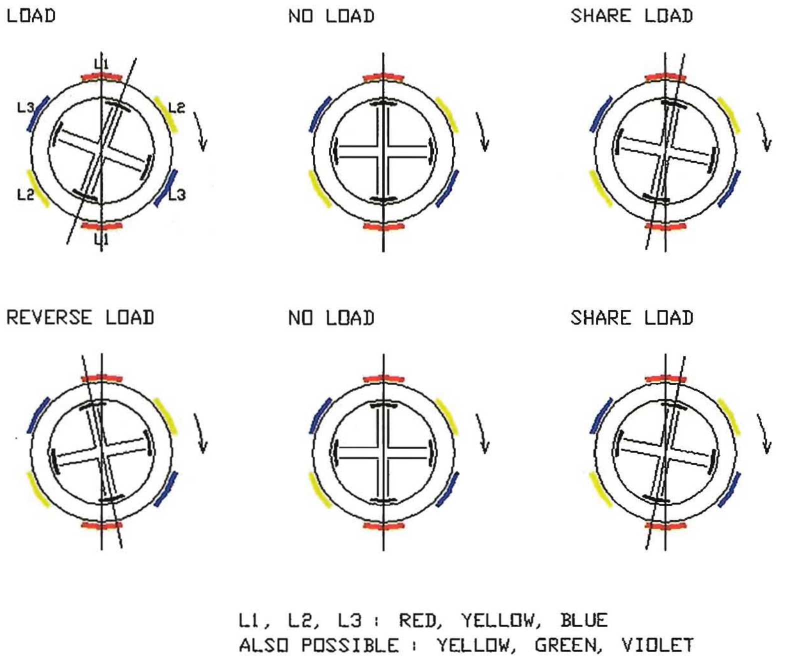
8 Principle of pointer synchronoscope



9 Rotor position versus stator field

When diesel generators run in parallel, there can be no speed difference.

The generators act as a rigid gearbox between the diesels. The rotor inside the stator behaves similarly to a flexible coupling and moves a few degrees clockwise or anti-clockwise in the stator field, depending on the load.



Load sharing means that the current and power are equally divided over identical machines or proportionally divided over machines of different rating.
Load sharing is obtained when each machine supplies the same kW power, that is, each machine's fuel supply is such that the slip of each machine is equal. At no-load the slip is zero and the rotor rotates synchronous in the stator.
When the generator absorbs load, the rotor runs behind the stator field. When the generator supplies load, the rotor field runs forward of the stator field. When the machines share load both rotors run forward of the stator fields, all at the same rpm.

10 Principle of automatic synchronisation

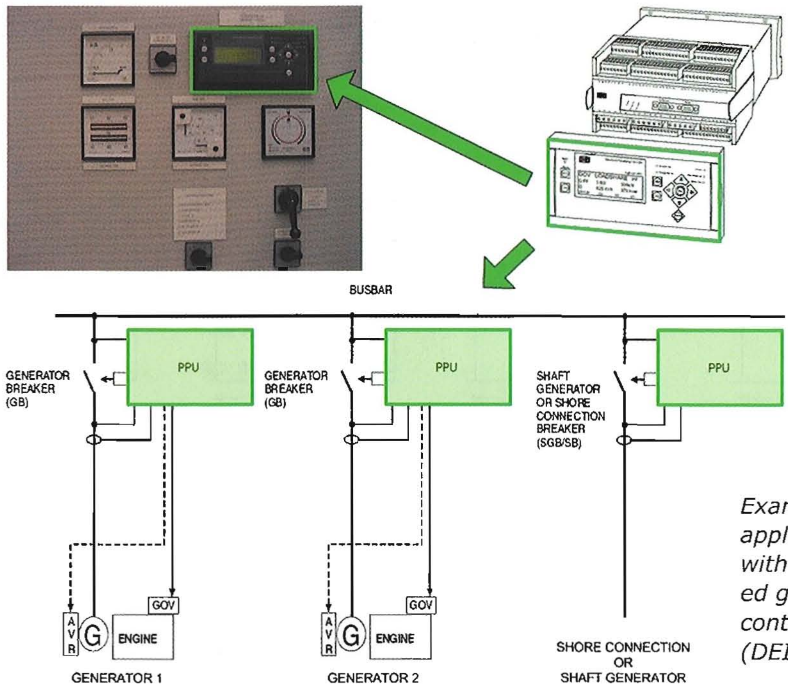
Manual synchronisation, as described before, is most of the time only used as a back-up for a fully automatic synchronisation system.

Fully automatic systems are based on the same principles as for manual synchronising. Incoming signals like voltage, frequency and current are processed and the result fed to a governor on the engine and eventually to the circuit breaker to be closed or opened.

Example of application with integrated generator control unit (DEIF)

Automatic systems can be made from individual electronic components such as check synchronisers, voltage en current units and reverse power relays but these functions are more often combined in one unit as in the example below.

More sophisticated systems are computer based with monitors for the graphic display of the operational status with dynamic parametres.

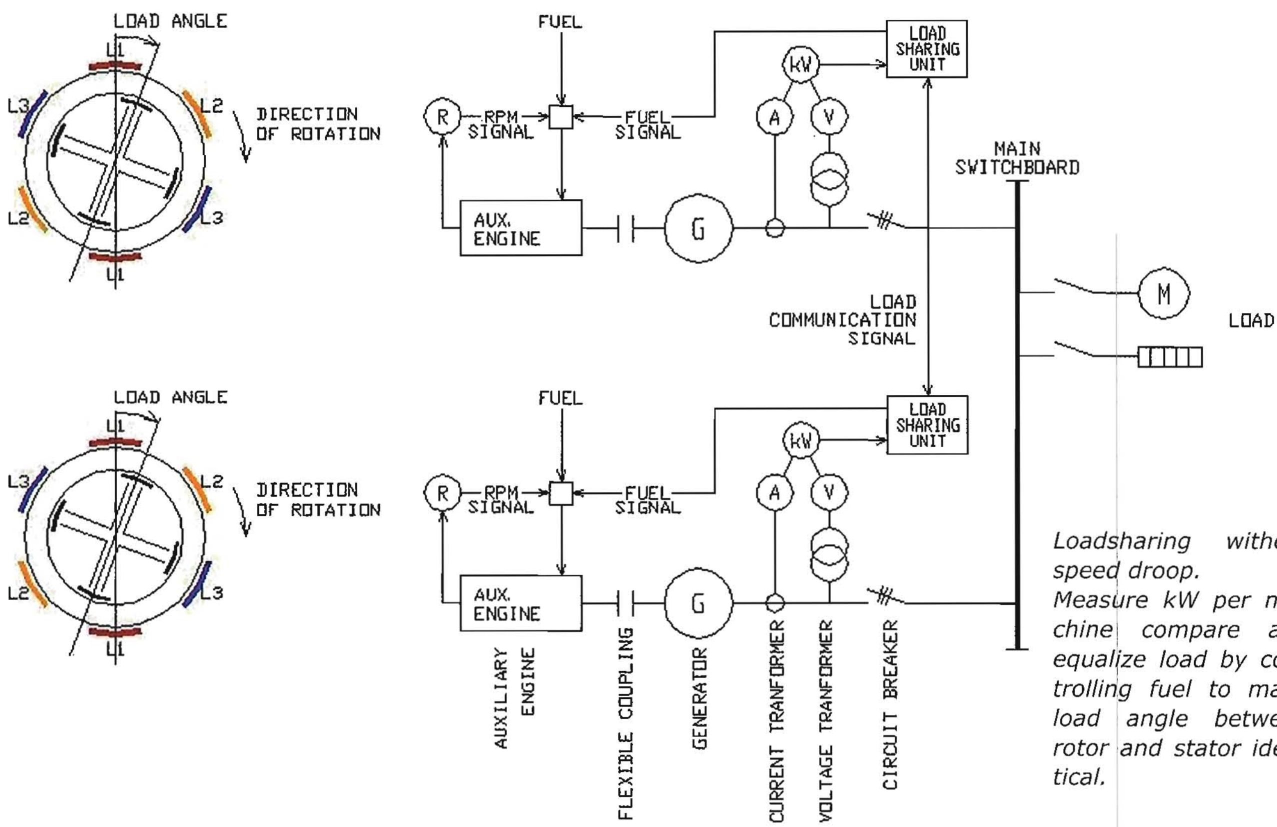


Example of application with integrated generator control unit (DEIF)

These systems more often are used in Power Management Systems for complicated electrical networks such as on Dynamic Positioning vessels.
There they will also control the starting and stopping of a stand-by diesel on power demand and the allocation of power to large consumers.

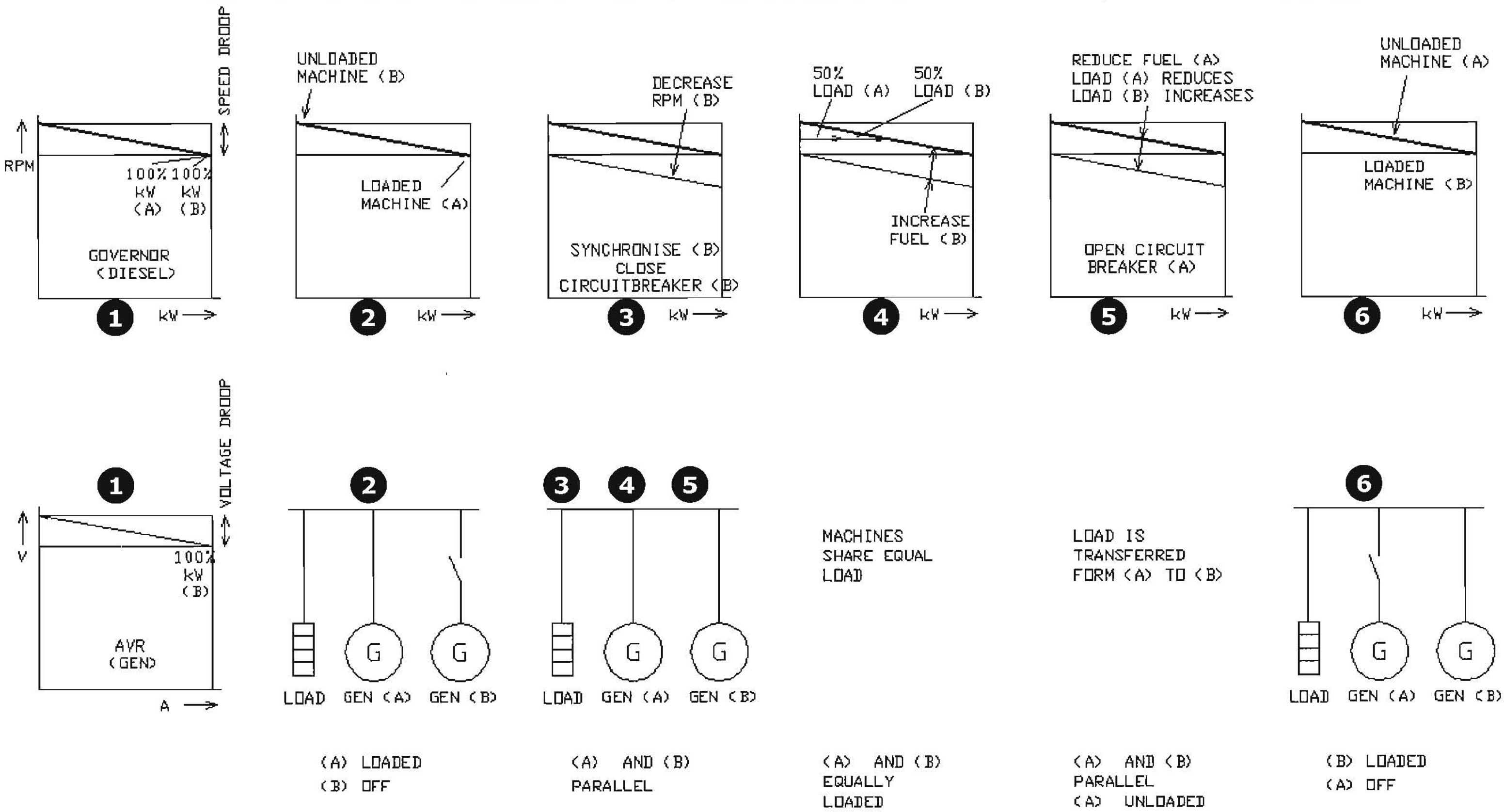
Another method of parallel operation is **isochronous**, which means constant speed over the total load range and no droop.
Voltage current and power of each machine is measured and compared with the capabilities of the sets. Fuel to the diesel engines is controlled resulting in the desired load sharing. Zero droop.

11 Principle isochronous parallel operation

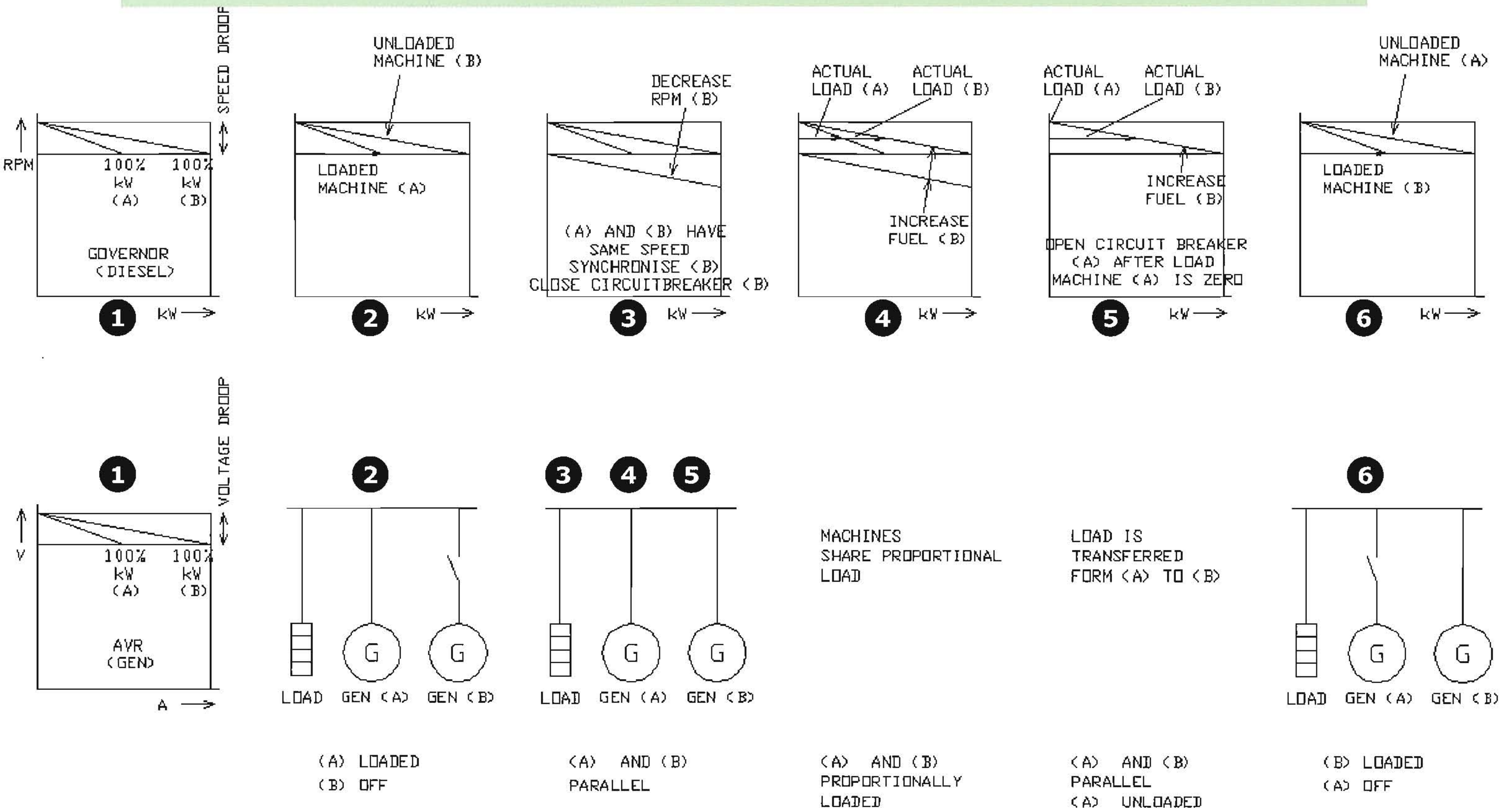


Loadsharing without speed droop. Measure kW per machine compare and equalize load by controlling fuel to make load angle between rotor and stator identical.

Synchronizing and switching parallel equally rated machines



Synchronizing and switching parallel differently rated machines



Equally rated machines

1. Check of speed, voltage and droop of both (or more) machines. This is done during commissioning at newbuilding and after extensive repair or replacement of any of the parts such as governor or AVR. Once set the settings shall not be changed.

2. Machine (A) is on-line and has all load. Machine (B) is off-line, unloaded and runs at a slightly higher speed.

3. Decrease speed of machine (B) by governor control knob, till the speed is the same as machine (A). As the machines are not running in parallel, the speed of each motor can be adjusted. As soon as the machines run in parallel, changing of individual speeds is not possible anymore. Synchronize the fases of (B) with (A) and close circuit breaker of (B).

4. Machine (A) and (B) run now in parallel. Machine (A) loaded and machine (B) unloaded. Increase fuel to machine (B) with same knob, resulting in machine (B) taking load. Increase the fuel supply until load is evenly distributed between the machines. From that moment on, any load will be equally shared by the two machines from zero till 100% of the total capacity of the two machines. This is the normal situation for two parallel running equally rated machines.

5. When the total required load or the sailing condition permits, it is possible to go back to one running generator. Reduce fuel to machine (A) until the load is nearly zero and machine (B) takes all the load. Open circuit breaker (A), taking generator (A) from the net.

6. Machine (B) is on-line and loaded. Machine (A) is off-line and remains running at about the same speed.

Different rated machines.

In the example machine (A) has 50% capacity of machine (B)

1. Check of speed and voltage droop. This is done during commissioning and after extensive repair or replacement of any of the parts such as governor, AVR. Once set the settings shall not be changed.

2. Machine (A) is on-line and on load. Machine (B) is off-line, unloaded and runs at a slightly higher speed. Circuit breaker (B) is open.

3. Decrease speed of machine (B) by governor control switch. As the machines are not running in parallel the speed of each motor can be adjusted. As soon as machines run in parallel, changing of individual speeds is not possible anymore. Synchronize the fases of (B) to those of (A) and close circuit breaker (B). Machine (A) and (B) run now in parallel with (A) loaded and (B) unloaded.

4. Increase fuel to machine (B) with same knob and machine (B) takes load. Increase fuel until load is distributed over the machines in proportion of available power. Any load will be proportionally shared by the two machines from zero till 100% . This is the normal situation for two parallel running but differently rated machines.

5. When the load or the sailing condition permits it is possible to go back to one running generator. Reduce fuel to machine (A) until the load is nearly zero and machine (B) takes all the load. Open circuit breaker (A).

6. Machine (B) is on-line and loaded. Machine (A) is off-line and runs at a slightly higher speed.

12 Selection of droop or isochronous

If there is a large difference in rating of the prime movers with similar generators, the large machine may have an unacceptable performance at full load.

The main engines of for instance ferries, apart from driving the propellers, are also provided with a shaft (PTO) generator. Generators of about 4 MVA are driven by 3.2 MW auxiliary diesels but also by the 10 MW main engine power take-offs.
A droop of 2% for the auxiliary-engine driven generator over its full range would lead to a droop of about 6% for the main engine.
At 94% speed the propellers do not consume the maximum available power and this is not acceptable.

To overcome this problem, load sharing is not arranged by droop but through a control system that measures load on the generators and adjusts the fuel of the auxiliary engines to share the load.
The main engines are master in this case and provide the power at constant speed for the propellers.

Parallel operation with a kW sharing control system is called isochronous operation.
To obtain parallel operation of different machines, these machines have to be synchronized, switched in parallel and the load has to be shared.
When machines have the same characteristics, as verified in 4 and 5 respectively, after manual load sharing and synchronizing for a certain load, the load sharing will be correct for the total load range of the machines.

Machines of different ratings can also share load as long as the voltage droop and speed droop is the same percentage.

The choice of 2-4 % droop depends also on the accuracy of the control equipment.

15. MOTORS AND STARTING DEVICES

Electric motors convert electrical energy into mechanical (rotating) energy and with that have the reverse function of generators.

1 Electric motors

Electric motors come in all shapes and sizes and suitable for a wide range of power supplies. As with generators the applied frequency and the number of poles in the stator determine the speed of the motor.
The major categories are related to an AC or DC power supply but then the choice is endless from the very small step-motors used in robotic applications to very large motors in the MW range.
Nowadays the most widely used electric motors are the 3-phase alternating current asynchronous motors with a squirrel cage rotor. An overview of this type of motor, in the range from approximately 0.3kW to 160kW, for various voltages, frequencies and speeds is shown on the next page.

This chapter will concentrate on this type of AC-motors. When using variable speed drives AC-motors can be precisely controlled for starting, speed and torque.

Electric motors are available in different housings for foundation or flange fitting. See the table on page 106 for details.

They are also available with different protection classes against the ingress of solid particles and water (IP-class) and for use in an explosive environment (Ex-class).
Ex-motors are available with the following classes :

- increased safety Ex-e
- flameproof Ex-d
- pressurized Ex-p.

Electric motors are available in IEC standard machines, suitable for 45 °C cooling air or 32 °C cooling water temperature.

When the temperatures for cooling air or water are different from the standard values correction factors must be used for which the applicable Rules & Regulations must be consulted.

When additional cooling capacity is required an extra cooling fan can be installed on the main electric motor. When such a motor is also totally enclosed these motors are also referred to as TEFC for Totally Enclosed, FanCooled [motors].

1.1 Testing AC-motors

All AC-motors have to be tested and when the power rating is above 100kW they have to be certified by the classification society.

The basic AC-motor test consists of:

- Meggertest,
- High voltage test
- Meggertest again

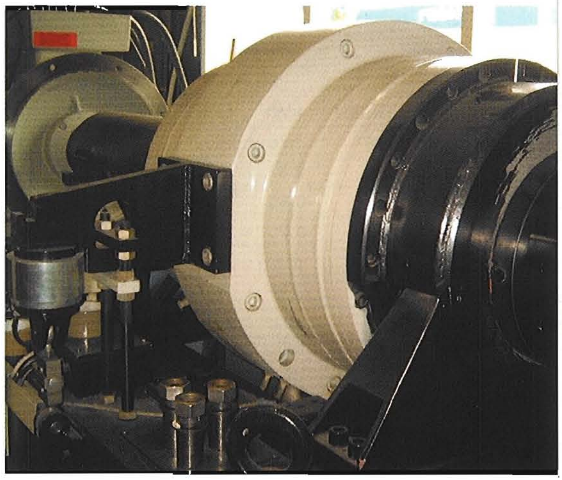
The second meggertest is to verify if the isolation values are still intact after the high voltage test.

The following tests and measurements are to be documented at nominal voltage and frequency:

- start current
- no-load current
- full-load current
- consumed power
- supplied power
- efficiency
- power factor
- start torque
- nominal torque
- speed range
- housing temperature
- winding resistance cold
- winding resistance hot after the full-load test.
- heat run to determine the maximum winding temperature under continuous load

The maximum permissible winding temperature depends on the type of winding insulation used, the temperature of the cooling air or the temperature of the cooling water. As an example the table on page 105 gives an overview of limits to temperature rise for air-cooled rotating machines.

The maximum temperature rise is determined in a heat run.
The heat run is a test where the motor is loaded with nominal load until the temperature of the housing stabilizes. Before the start of the test, the temperature of the motor and resistance of the windings at this temperature is measured.



A motor test stand at a motor manufacturer showing the motor under test and the water brake (dynamo metre).

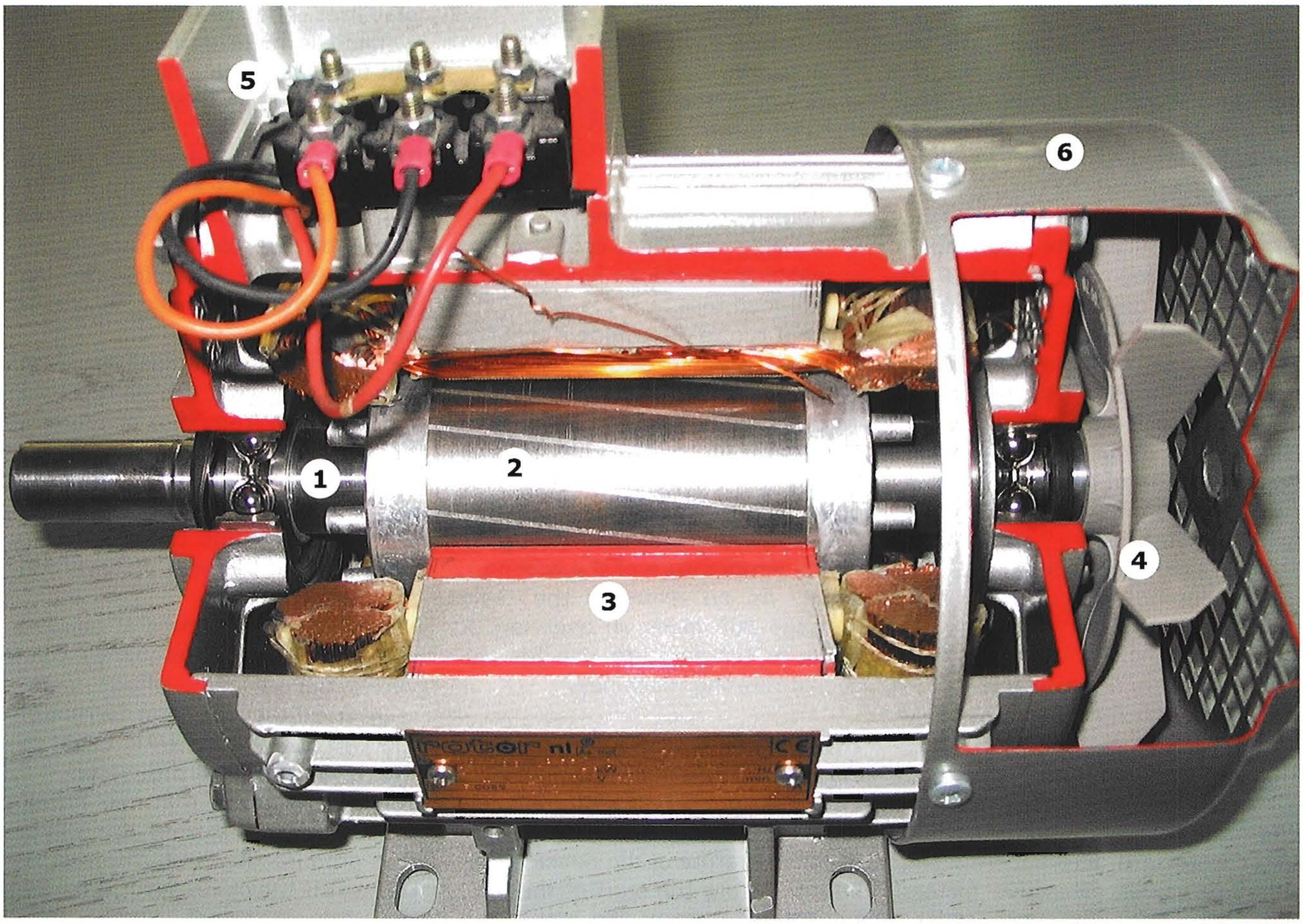
TIME	AIR IN ° C	AIR OUT ° C	DIFF ° C
8:00	18	18	0
8:30	18	20	2
9:00	19	22	3
9:30	20	25	5
10:00	21	30	9
10:30	21	36	15
11:00	22	43	21
11:30	23	44	21

When the housing temperature stabilizes the resistance of the winding is measured again. From the two values obtained, the temperature rise can be calculated

The equipment necessary for a heat run is called a dynamometer, a brake which converts power produced by the electric motor into heat. This brake is also free moving so that torque can also be measured.
For large motors the heat run, with a mechanical load, can be replaced by using two frequency converters to supply the motor.
One frequency converter supplies the motor with the rated voltage and frequency and the other with a lower than nominal voltage and frequency.
With the motor running at no-load speed on the first frequency converter the variable voltage is increased so that the total current of the two power sources is equal to the rated current of the motor.
The advantage is that the power consumed comes from the losses that produce the heat. The rest of this test is the same as for the heat run as described above.

	2-pole				4-pole				6-pole				8-pole			
	3 x 380 V		3 x 440 V		3 x 380 V		3 x 440 V		3 x 380 V		3 x 440 V		3 x 380 V		3 x 440 V	
	50 Hz		60 Hz		50 Hz		60 Hz		50 Hz		60 Hz		50 Hz		60 Hz	
Frame size	**kW**	**rpm**	**kW**	**rpm**	**kW**	**rpm**	**kW**	**rpm**	**kW**	**rpm**	**kW**	**rpm**	**kW**	**rpm**	**kW**	**rpm**
63 K	0.28	2800	0.30	3420	0.18	1360	0.2	1685	-	-	-	-	-	-	-	-
71 K	0.37	2780	0.44	3400	0.25	1385	0.3	1690	0.18	920	0.21	1125	-	-	-	-
71 G	0.55	2920	0.65	3400	0.37	1370	0.4	1685	0.25	890	0.30	1120	-	-	-	-
80 K	0.75	2285	0.90	3340	0.55	1400	0.7	1710	0.37	915	0.44	1125	0.18	690	0.21	845
80 G	1.1	2835	1.3	3440	0.75	1400	0.9	1710	0.55	915	0.65	1120	0.25	695	0.30	845
90 S	1.5	2850	1.8	3470	1.1	1410	1.3	1720	0.75	935	0.90	1140	0.37	700	0.44	850
90 L	2.2	2850	2.6	3460	1.5	1400	1.8	1710	1.1	935	1.3	1135	0.55	695	0.65	850
100 L	3.0	2850	3.6	3470	2.2	1420	2.6	1720	1.5	945	1.8	1145	0.75	705	0.90	855
112 M	4.0	2900	4.8	3500	4.0	1435	4.8	1735	2.2	950	2.6	1150	1.5	705	1.8	850
132 S	5.5	2860	6.6	3430	5.5	1440	6.6	1730	3.0	950	3.6	1140	2.2	705	2.6	855
132 M	7.5	2880	9.0	3460	7.5	1440	9.0	1730	4.0	950	4.8	1150	3.0	700	3.6	840
160 M	11.0	2900	13.0	3480	11.0	1440	13.0	1730	7.5	960	9.0	1155	4.0	710	4.8	850
160 L	18.5	2920	22.0	3510	15.0	1455	18.0	1750	11.0	965	13.0	1160	7.5	720	-	865
180 M	22.0	2935	26.0	3540	18.5	1455	22.0	1750	-	-	-	-	-	-	-	-
180 L	-	-	-	-	22.0	1470	26.0	1765	15.0	965	18.0	1160	11.0	720	13.0	865
200 L	30.0	2935	36.0	3540	30.0	1465	36.0	1760	18.5	965	21.0	1165	15.0	725	18.0	870
225 S	-	-	-	-	37.0	1470	44.0	1765	-	-	-	-	18.5	725	22.0	880
225 M	45.0	2940	54.0	3530	45.0	1470	54.0	1765	30.0	973	34.0	1170	22.0	730	26.0	875
250 M	55.0	2955	66.0	3545	55.0	1475	66.0	1770	37.0	973	42.0	1170	30.0	730	36.0	875
280 S	75.0	2965	90.0	3555	75.0	1480	90.0	1775	45.0	980	54.0	1180	37.0	735	44.0	880
280 M	90.0	2970	105.0	3565	90.0	1480	105.0	1775	55.0	980	66.0	1180	45.0	735	54.0	885
315 S	110.0	2975	132.0	3565	110.0	1480	132.0	1775	75.0	985	90.0	1185	55.0	740	66.0	890
315 M	132.0	2975	158.0	3570	132.0	1480	158.0	1775	90.0	995	108.0	1185	75.0	740	90.0	890

Code of standardized frames for the various types of standardized electric motors.



Squirrel cage motor

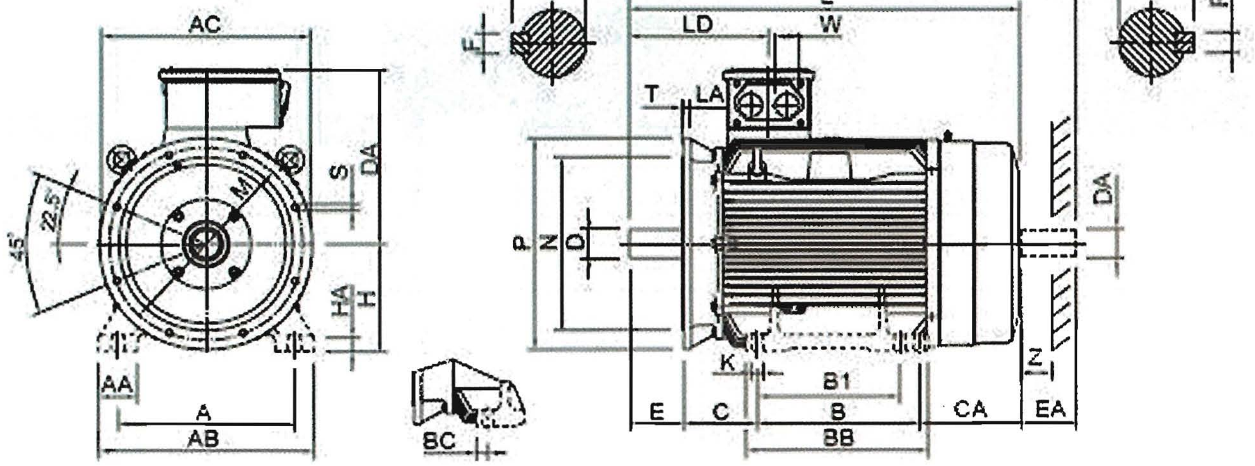
1. Shaft with bearing
2. Squirrel cage rotor
3. Stator Windings
4. Cooling fan
5. Connection box
6. Protection cover

Windings of electrical machines can be insulated with different materials. The properties of the insulating material determines the maximum allowed temperature. Insulating materials are divided in classes. When a higher insulation class is selected this will allow a higher temperature when in operation. The higher temperature allows a higher current, which is the source of the heat, and with that a higher power rating of the motor. This also applies to other electrical equipment such as generators and transformers.

LIMITS OF TEMPERATURE RISE AIR COOLED ROTATING MACHINES								
PART OF MACHINE			METHOD OF TEMP MEASUREMENT	INSULATION CLASS				
				A	E	B	F	H
1.	(a)	a.c. windings of machines having output of 5000 kVA or more	ETD	55	–	75	95	115
2.	(b) Windings of armatures having commutators	a.c. windings of machines having output of less than 5000 kVA	ETD	55	–	80	100	115
			R	50	65	70	95	115
3.	Field windings of a.c. and d.c. machines having d.c. excitation other than those in item 4		R	50	65	70	95	115
4.	(a) Field windings of synchronous machines with cylindrical rotors having d.c. excitation		R	–	–	80	100	125
	(b)	Stationary field windings of d.c. machines having more than one layer	R	50	65	70	95	115
	(c)	Low resistance field windings of a.c. and d.c. machines and compensating windings of d.c. machines having more than one layer	R, T	50	65	70	90	115
	(d)	Single-layer windings of a.c. and d.c. machines with exposed bare or varnished metal surfaces and single-layer compensating windings of d.c. machines	R, T	55	70	80	100	125
5.	Permanently short-circuited insulated windings		T	50	65	70	90	115
6.	Permanently short-circuited uninsulated windings		T	The temperature rise of these parts shall in no case reach such a value that there is a risk to any insulation or other materials on adjacent parts or to the item itself				
7.	Magnetic cores and other parts not in contact with windings		T					
8.	Magnetic cores and other parts in contact with windings		T	50	65	70	90	110
9.	Commutators and slip-rings open and enclosed		T	50	60	70	80	90

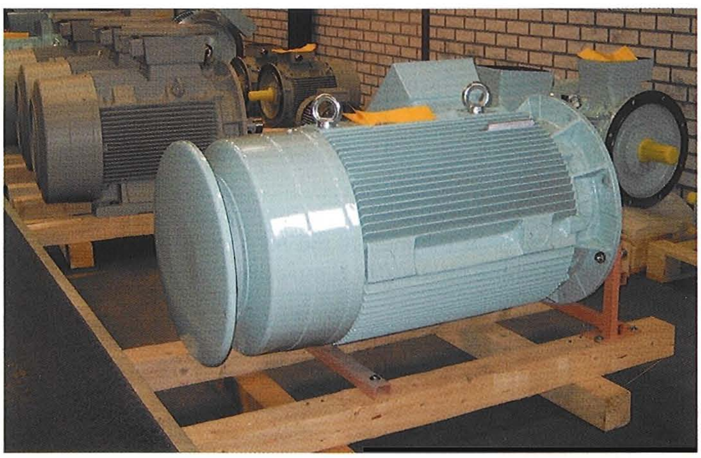
NOTES	
1	Where water cooled heat exchangers are used in the machine cooling circuit the temperature rises are to be measured with respect to the temperature of the cooling water at the inlet to the heat exchanger and the temperature rises given shall be increased by 10°C provided the inlet water temperature does not exceed 32°C
2	T = thermometre method
3	R = resistance method
4	ETD = embedded temperature detector
5	Temperature rise measurements are to use the resistance method whenever practicable.
6	The ETD method may only be used when the ETD's are located between coil sides in the slot.

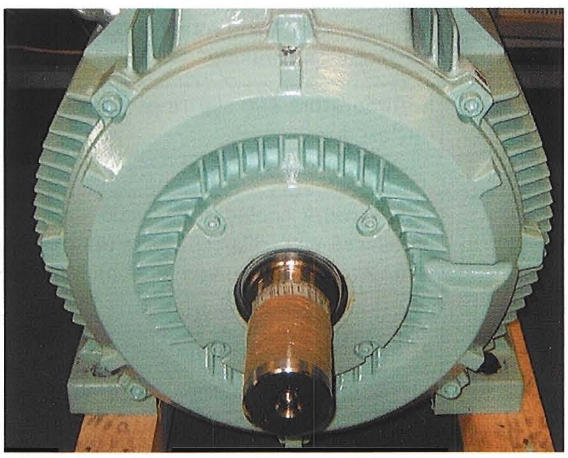
IM 2001 (IM B35)
IM 3001 (IM B5)



Frame size	Shaft dimensions		Feet mounted machines				Flange mounted machines				
	Shaft height mm	Shaft diam. Mm	Position fixing holes			Fixing holes K mm	M mm	N mm	Number fixing holes	S mm	Max. T mm
			A mm	B mm	C mm						
63 K	63	12.5	100	100	40	5.8	115	95	4	10	3
71 K	71	16	112	112	45	7	130	110	4	10	3.5
71 G	71	16	112	160	45	71	130	110	4	10	3.5
80 K	80	21.5	125	125	50	10	165	130	4	12	3.5
80 G	80	21.5	125	180	50	10	165	130	4	12	3.5
90 S	90	27	140	100	56	10	165	130	4	12	3.5
90 L	90	27	140	125	56	10	165	130	4	12	3.5
100 L	100	31	160	140	63	12	215	180	4	14.5	4
112 M	112	31	190	140	70	12	215	180	4	14.5	4
132 S	132	41	216	140	89	12	265	230	4	14.5	4
132 M	132	41	216	178	89	12	265	230	4	14.5	4
160 M	160	45	254	210	108	14.5	300	250	4	18.5	5
160 L	160	45	254	254	108	14.5	300	250	4	18.5	5
180 M	180	51.5	279	241	121	14.5	300	250	4	18.5	5
180 L	180	51.5	279	279	121	14.5	300	250	4	18.5	5
200 L	200	59	318	305	133	18.5	350	300	4	18.5	5
225 S	225	64	356	286	149	18.5	400	350	4	18.5	5
225 M	225	64	356	311	149	18.5	400	350	4	18.5	5
250 M	250	69	406	349	168	24	500	450	8	18.5	5
280 S	280	79.5	457	368	190	24	500	450	8	18.5	5
280 M	280	79.5	457	419	190	24	500	450	8	18.5	5
315 S	315	85	508	406	216	28	600	550	8	24	6
315 M	315	85	508	457	216	28	600	550	8	24	6

Sizes of shaft, feet or flanges of standard electric motor, in relation to code.





Electric motors are produced in accordance with international standard dimensions.

A **starting device** connects a piece of equipment, like a motor, to its main power supply.

2. Starting devices

A starting device is the general term for a piece of equipment with one or more contactors that allows the connection of a consumer to its main power supply.

Starting devices can also be used to limit the inrush current of a consumer to an acceptable value when connected to the main power supply. An acceptable value is one that does not disturb the proper functioning of the prime source of power like a generator as this would also disturb other equipment in the installation.

Limiting the starting current will also limit the starting torque of an electric motor. This may be necessary to protect for instance a delicate gearbox from the harmful forces of direct on-line starting.

Some examples of starting devices are:
1. direct on-line starters
2. star-delta starters
3. autotransformer starters
4. frequency converters
5. high voltage choke starters

Each of these examples is discussed below.

2.1 Direct on-line starter

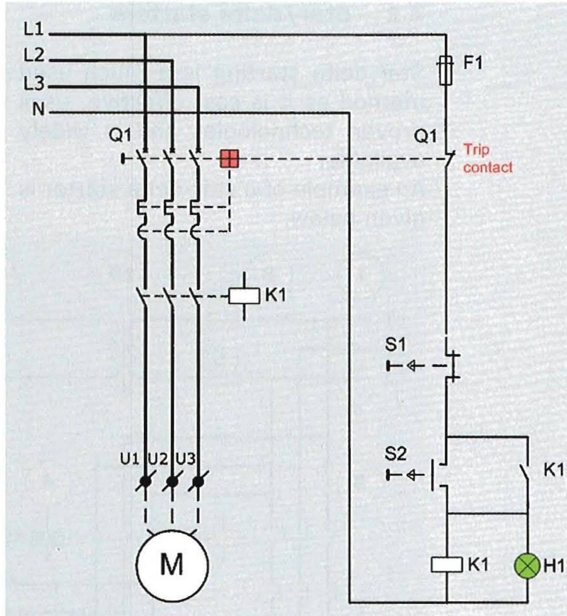
The simplest way of starting an AC motor is the direct on-line starter. With this device the starting time is minimal, the starting torque is maximal at full voltage but the voltage drop, also at other consumers, is maximal.

Values for voltage drop levels can be calculated when the starting data of consumers is known as well as capability data of generators.

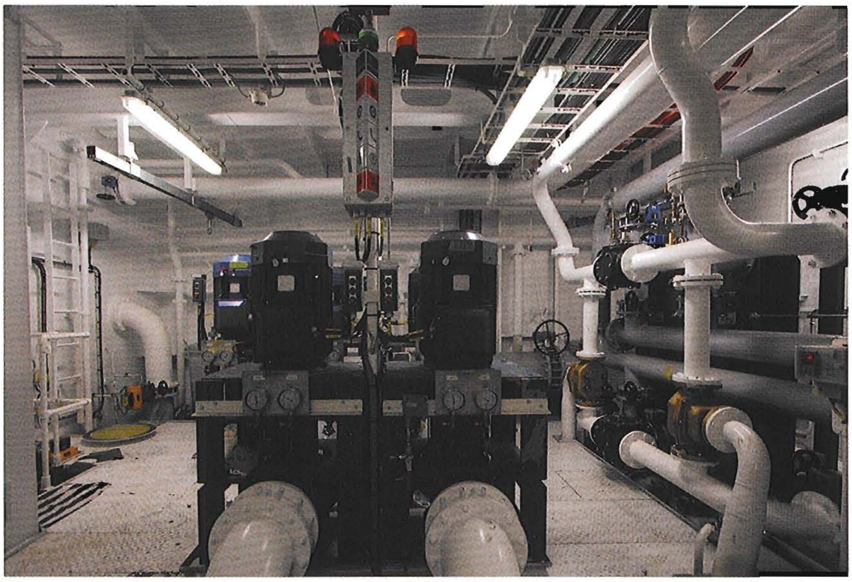
In general, a generator is able to supply a sudden overload of 50 % of its kVA-rating, resulting in a voltage drop at the generator terminals of less than 15%.

This allows another 5% voltage drop in the distribution network, in order to stay under the maximum allowed voltage drop of 20% during starting of a large consumer.
The voltage drop is a result of the capabilities of the generator as the load on the driving diesel engine during starting is determined by the power factor, usually less than 0.4 during starting.

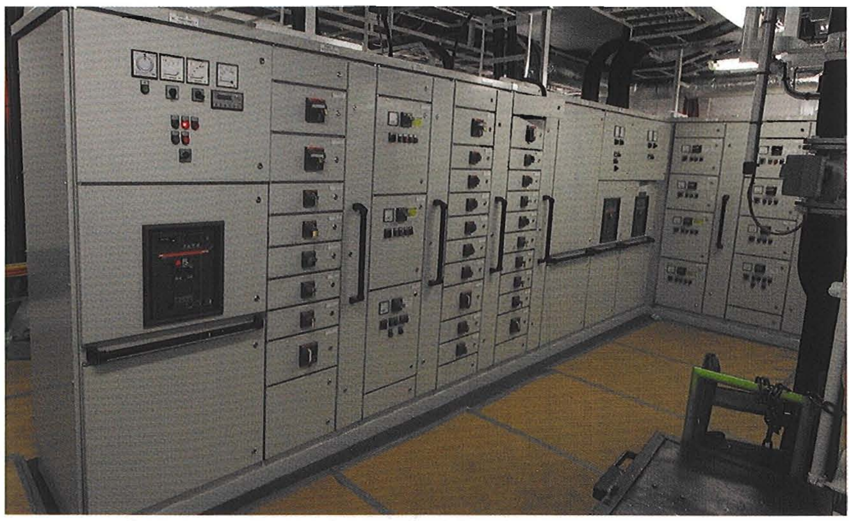
A diesel engine should be capable of handling a load step of 20% or more without a frequency dip of more than 10%, which should be recovered within 15 seconds.
The minimum requirement for step loads on diesel engine generators is 33%. However, modern common-rail and constant pressure electronic injected diesel engines have some difficulty handling such step loads.



Example direct on-line starter



Example of an engine room without local starter boxes. Starters for these pumps are installed in MCC's (see below)



Example of a Motor Control Centre (MCC) where all starters for the engine room are installed. The panel on the far left is for the connection of the incoming main power.

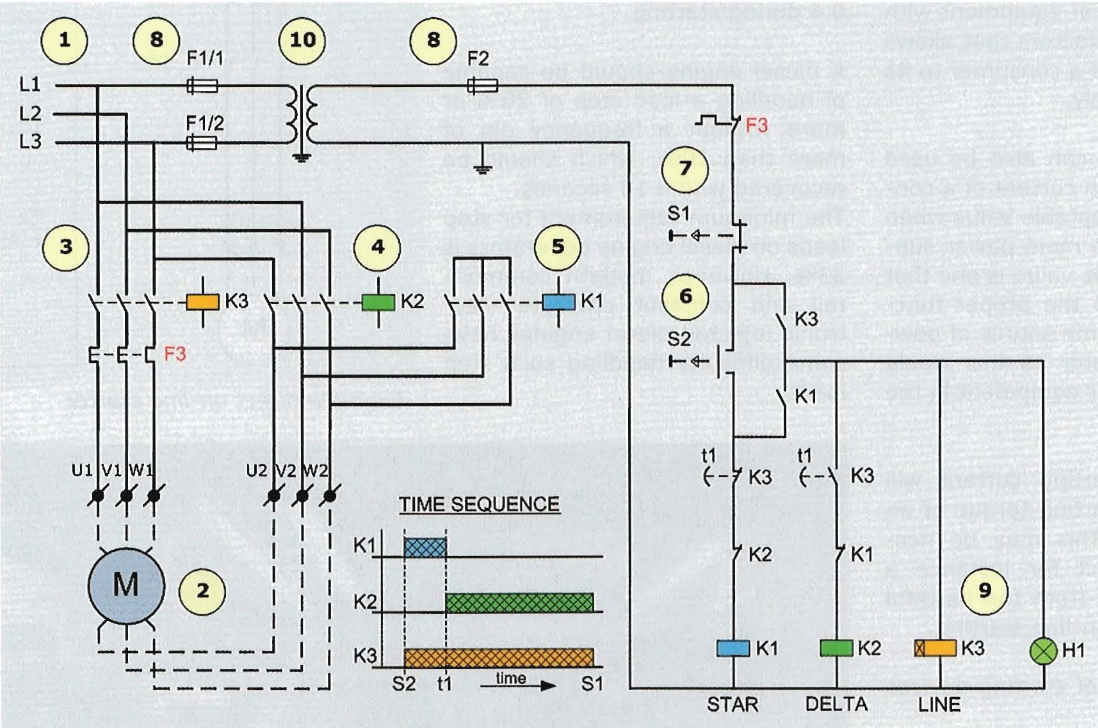
2.2 Star/delta starters

Star-delta starting is a much used method as it is cost effective, uses proven technologies and is widely available.
An example of a star-delta starter is given below.

For large motors, which require large contactors (K1,K2 and K3), these contactors can be supplied from the primary voltage instead of from the voltage transformer.
The main contactors as shown will then be replaced by auxiliary contactors.

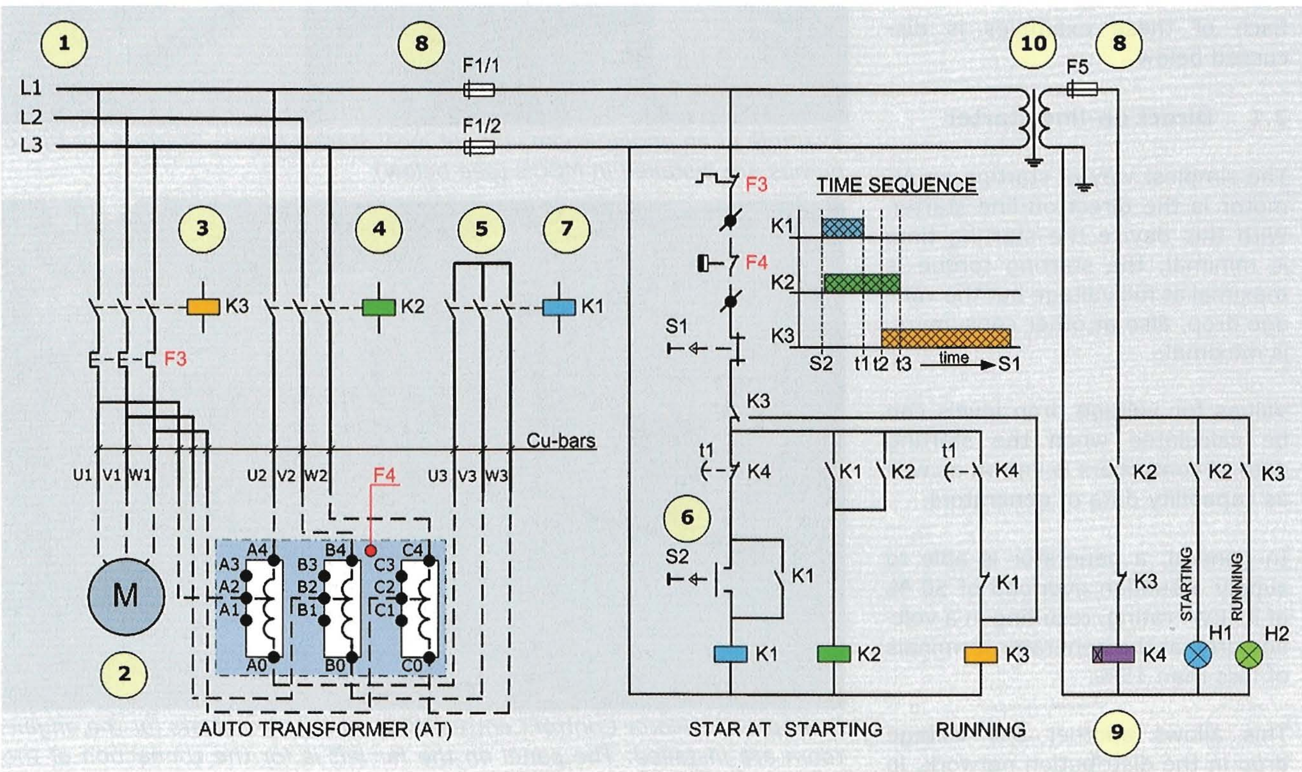
Star-delta starters reduce primary values as follows:

- voltage by 1.7
- starting current by 1.7
- starting torque by 1/3
- the load on the engine by 1/3



Example of star-delta starter

1. Incoming voltage
2. Electric motor
3. Contactor K3
4. Contactor K2
5. Contactor K1
6. Start button
7. Stop button
8. Control fuses
9. Time relay
10. Transformer



Example of Auto transformer starter

2.3 Auto-transformer starters

Auto-transformer starters are based on the reduced voltage starting method whereby the starting current is reduced in proportion to the starting voltage. The start torque, however, is reduced proportional to the voltage square. This means that this starting method can only be used for low torque (no load) starting.
But when designed well the motor rating connected to this type of starter can be considerable, sometimes in the MW range.

An example of low torque, high power starting is a starter for a bow thruster where the propeller blades are put in zero position before starting.

Autotransformer starters are normally provided with a number of secondary voltage tappings. This allows a change of starting voltage, and with that of starting torque, during commissioning a system.

The values of these secondary voltage tappings are normally in the range of 55 -70 % of nominal voltage. Lower values would increase the starting time, higher values would increase the starting currents. Both effects are undesirable.

On the previous page an example of an electrical diagram for an autotransformer starter is given.

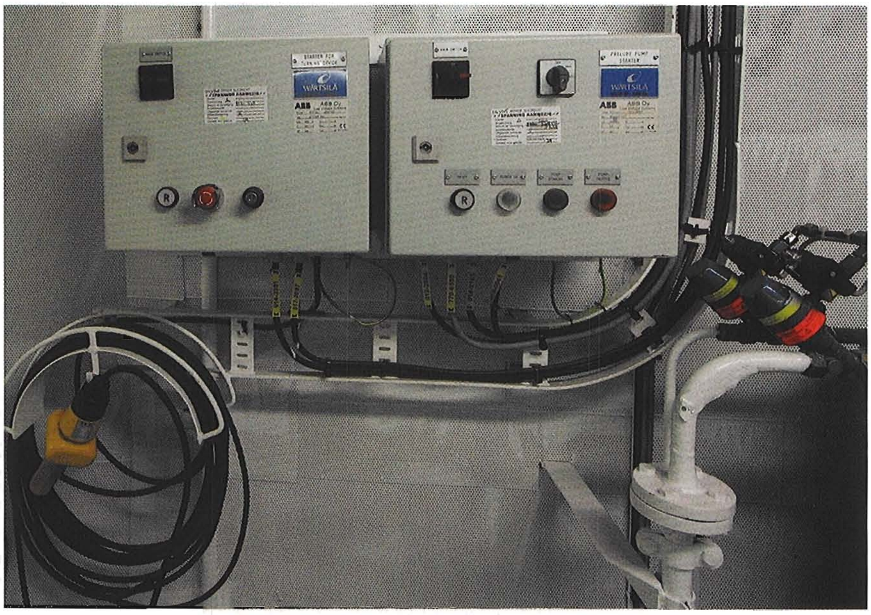
2.4 Frequency converters

Frequency converters and other electronic control devices can control current, power and torque of an electric motor.
They limit the starting conditions on the generators, arrange the maximum performance of the consumer.

2.5 High voltage choke starter

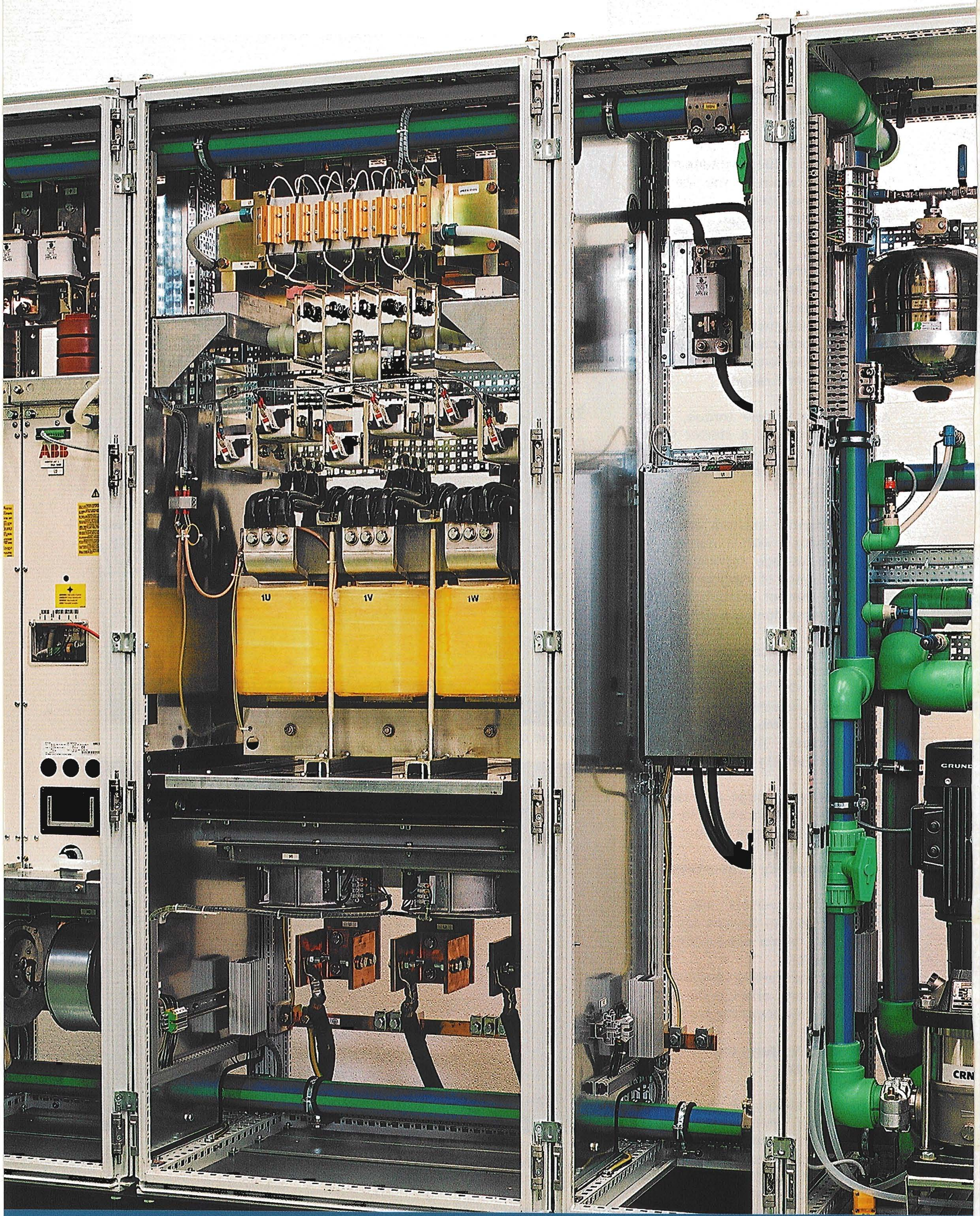
As for low voltage, for high voltage starters the direct-on-line (DOL) type is the most cost effective.
But starting direct on-line could cause too much peak-load on the generators or driven equipment.
In that case the current can be limited by inserting a choke in the supply line to the motor.

An example of a high voltage choke starter



Starter box and remote control of turning gear, and starter box of pre-lubricating pump

This choke, when designed properly, will reduce the starting current. As the torque will also be proportionally reduced, the effects of inserting a choke must be carefully evaluated to avoid stalling of a motor during start-up.



16. TRANSFORMERS AND CONVERTERS

Converting equipment converts input electrical power from high to low voltage whereby the current changes inversely in proportion. A converter does not generate electrical power.

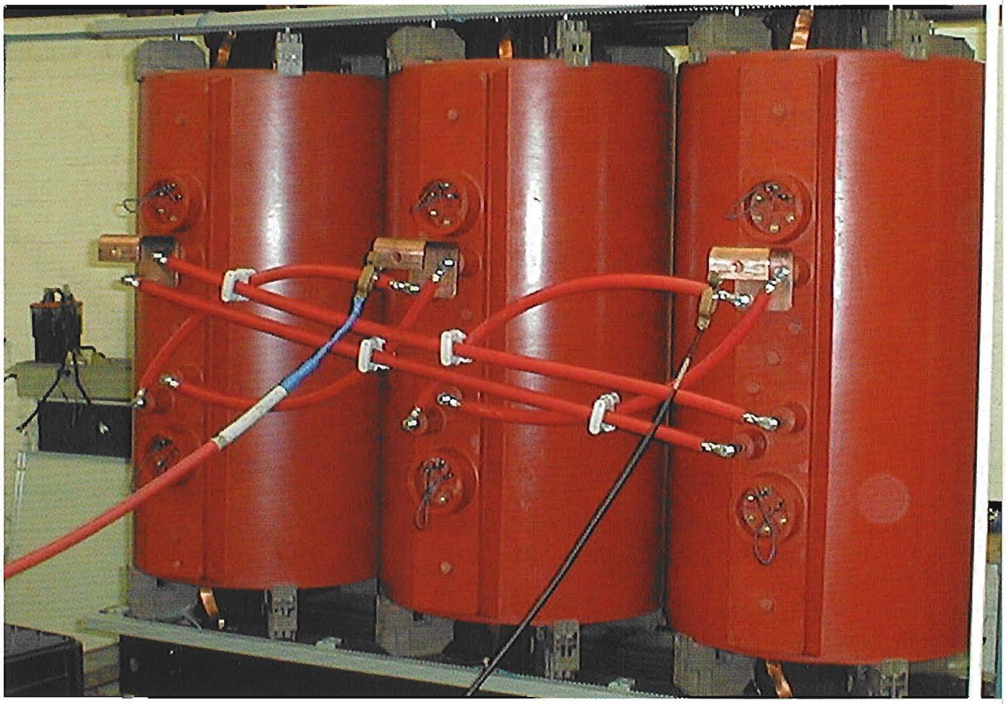
1 General

The simplest converter is a transformer, transforming or converting one voltage into another voltage, for instance 440 V into 110 V.
Transformers have losses, as heat is produced during this conversion. The efficiency is usually between 90 and 98 percent, depending on size, a reason to avoid transformers in power distribution systems.
The European 400V/230V 3-phase 4-wire distribution system does not require transformers, contrary to the American 450V60Hz sytems which have a phase to neutral voltage of 260 V. For the latter systems no equipment is standardized, being the reason that in the USA where 110 V/60 Hz or 230 V / 60 Hz is used (onshore) for small consumers, transformers are necessary for lighting and low power circuits.
The multiplication of input voltage and current and output voltage and current is approximately equal.

More complex converters can also change voltage from AC to DC and can also change the frequency.
Small converters are used to adapt the power voltage to another system, such as a 400V signal into a 10V or 20mA signal.

2 Transformer

A transformer consists of two windings around a metal core.
The primary windings magnetize the core, which induces a voltage and current in the secondary winding. Any voltage ratio can be obtained, but is dependent on the winding ratio of the primary and secondary windings.
With separated primary and secondary windings there is also a galvanic separation between the primary and secondary circuits.
In that case an earth fault detection system must be installed on the secondary side. Every isolated system is required to have this as per Class requirements.



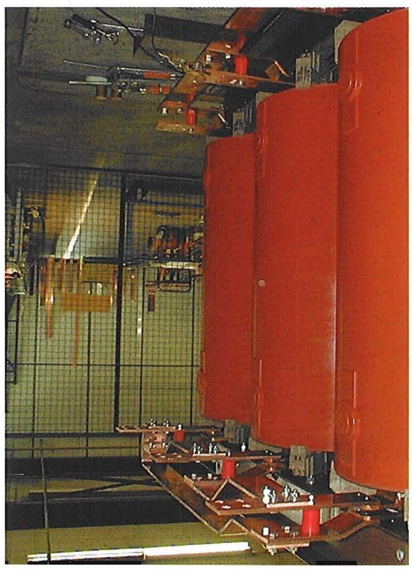
Double stock 1600 kVA transformer, for supply of a frequency converter, during high voltage testing. The rear side of this transformer can be seen below. Secondary windings produce voltage in star and delta configuration. The red cables are the connections of the primary windings. The secondary windings still have to be connected.

The pictures on this page show a large double stock transformer to supply a frequency converter. One set of secondary windings supplies 690V in star and the other 690V in delta to the AC/DC rectifiers in 12-pulse frequency converter. The aim of this set-up is to reduce harmonic distortions from the frequency converter to pass to the primary side.
Short-circuit currents for transformers are determined by the short-circuit voltages of the transformer, defined as:
'the voltage applied at the primary side of the transformer with the secondary side short-circuited resulting in the full-load current primary'. The maximum secondary short-circuit current at the secondary side is then determined by:

$$I_{k(sec)} = \frac{U_{nom}}{U_k \times I_{nom(sec)}}$$

Three single-phase transformers in one housing makes a cost effective three-phase transformer. By adding a fourth single-phase transformer in the same housing as spare, creates redundancy as this fourth transformer can be used to replace a faulty transformer quickly by just reconnecting wires.

Auto-transformers, i.e. transformers with a single winding, are only acceptable for start circuits and not for distribution systems. The reason for this is that a failure of the starpoint connection would result in full primary voltage on the low voltage circuits.
Especially large transformers may have a high inrush current due to the build-up of the magnetic field in the steel cores. To avoid this inrush current, which may trip the circuit breaker in the supply, a small premagnetising current is applied for a couple of seconds.



3 DC/AC converters

On small ships such as yachts, where the power supply is only obtained from batteries (a DC system), the choice of electrical equipment is restricted.

It is difficult to find TV sets, audio equipment, microwaves, refrigerators, deepfreezes, fluorescent lighting, etc. suitable for a DC power supply. If available at all, they are expensive.
For that reason DC/AC converters are used.

The most common converters are:
- Incoming supply: 12V, 24V and 48VDC
- Outgoing supply: 120V and 230V (50 and 60Hz)
- Capacity: up to 6 kW

4 DC/DC converters

DC/DC converters are used for the same reason DC/AC converters are used.
For example, on small ships with 12V DC incoming and only 24V DC consumers available, a DC/DC converter can solve the problem.

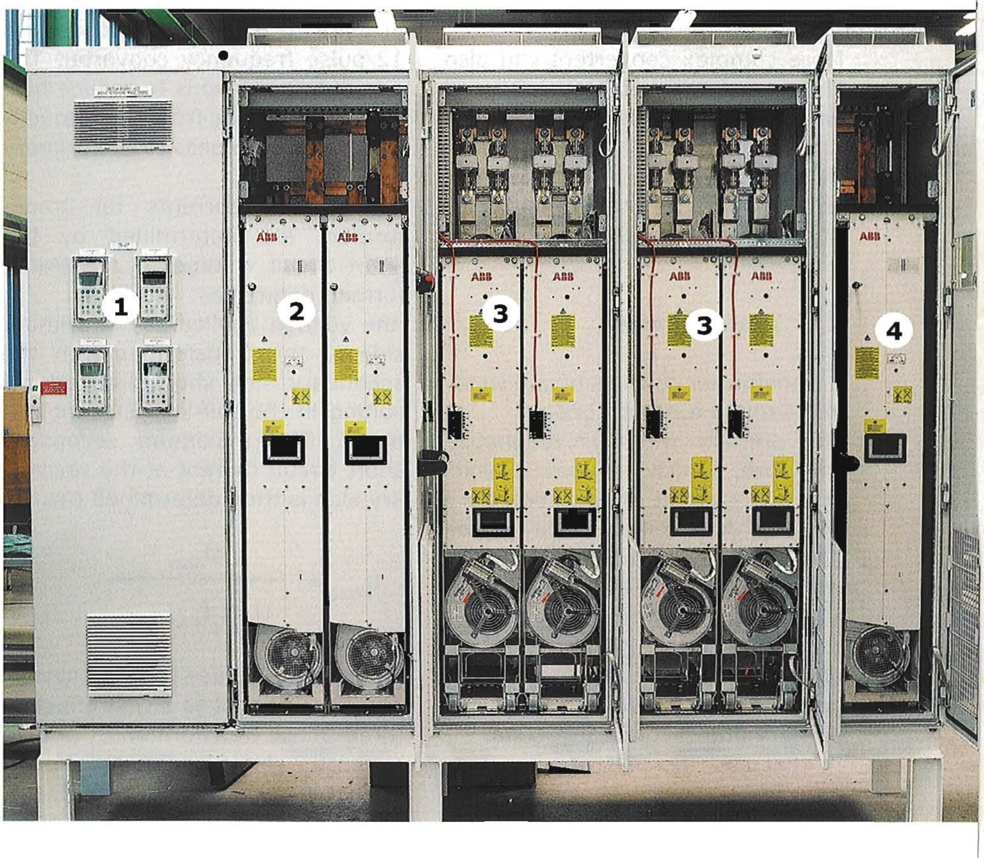
5 Rotary converters

A rotary converter consists of an electric motor driven by the ship's power, mechanically connected to a generator. The generator is designed and constructed to produce the required voltage and frequency.

Rotary converter

Air cooled AC/AC converter closed, and with open doors

1. Control panel
2. Main switches
3. Active front end inverters making DC from AC and reverse
4. Inverters making AC out of DC and reverse.



6 AC/AC converters

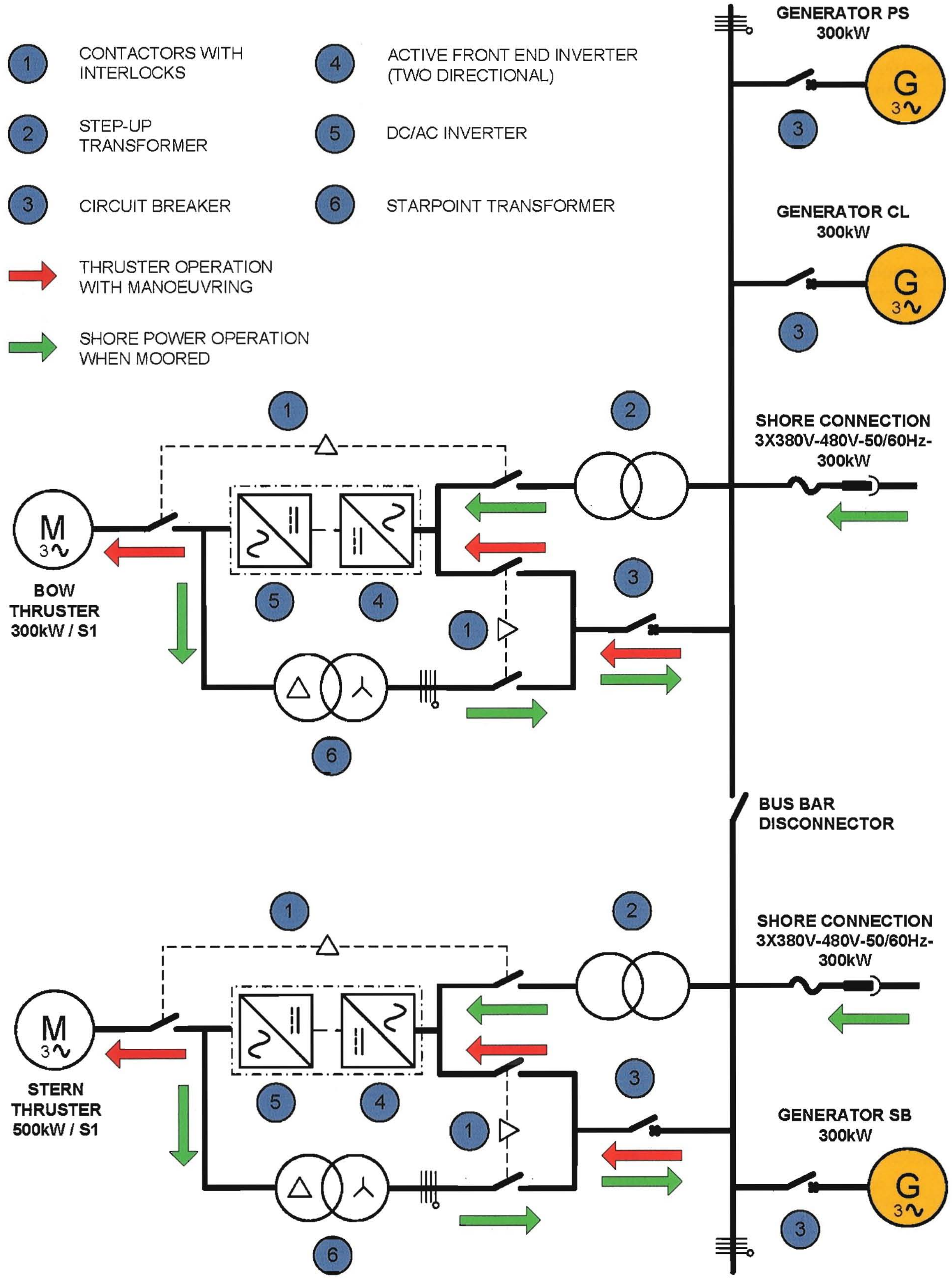
The diagram below shows two double purpose converters.
One converter produces the necessary current to the stern thruster supplied by the ship's switchboard when the ship is manoeuvring.

The other converter supplies the bow thruster during manoeuvring.

When the ship is moored, the same converter produces current to the ship's switchboard, fed by the shore supply.

The arrows in the scheme show both purposes.

The reason for this dual purpose function choice is the high cost of converters and the space required.



Of all converters the types that convert a primary AC input into a controlled AC output, the AC/AC converters, are the largest group. These converters are widely used as starting and control systems for AC motors.

AC/AC converters control input currents from the net and can provide a controlled output of speed and torque to motors. They can also change the direction of rotation of an AC motor.

Using AC/AC converters can make an installation more cost effective as pumps or fans can be fine tuned to the process to which these are connected.

For example the flow of a cooling water pump can be set to the actual temperature requirement of the system where such a pump would normally be running at full speed with a three-way valve controlling the cooling water temperature.

In the same way the speed of ventilators or the motors of chiller units for an air-conditioning system can be controlled by an AC/AC converter.

The result will be that in the end less electrical energy will be consumed and that there will be less switching on and off of consumers. AC/AC converters are also used to control a wide range of large AC motor applications such as:
- propulsion motors
- thruster motors
- dredging pump motors
- etc

AC/AC converters are available with voltage and current ratings to match the majority of 3-phase AC-motors.

Low voltage AC/AC converters, up to 690V on ships, are available for motors rated 0.2 kW up to several megawatts (MW).

Medium voltage AC/AC converters are designed to operate at 3.3kV and up to 10 kV for use with motors rated 350kW and above.

AC/AC converters with higher ratings should be considered to be one-of-a-kind designs.

Large water cooled AC/AC converter

AC/AC converters, in their simplest form, consist of the following main components:
- a supply transformer and rectifier converting AC into DC voltage
- a converter converting DC to AC with stepless controlled voltage and frequency

A rectifier is not able to transfer reverse power to the power generation system. Thus when a motor is driven by the load, like can happen with for instance a winch or when lowering the load in a crane, the power generated cannot be dispersed. To overcome this braking resistors are added in the DC circuit which will convert the reverse power to heat.

When an AC/AC converter has controlled rectifiers it is called an Active Front End (AFE) drive.
The advantage of an AFE drive is that the controlled rectifiers and filter inductors in the supply lines can make the AC current nearly sinusoidal, doing away with harmonic distortions.

An additional advantage of an AFE drive is the ability to feed back the energy from the DC side to the AC grid, doing away with the braking resistors mentioned earlier, should these be required.

In order to obtain a wider input range, step-up transformers can be installed.

An example is the diagram on the previous page where step-up transformers are indicated. The step-up transformers transform the voltage from 320V (equal to 400V -20%) to 400V, creating an output of 400V-50Hz from an input range of 320 to 480V 50-60Hz.

AC/AC converters mostly consist of the following parts:
- Transformers to adapt input or output voltage
- Rectifiers to change AC to DC
- Inverters to correct fixed input voltage and frequency into desired voltage and frequency
- Active inverters the same as above but working in both directions as required
- Inverters to convert DC voltage into fixed AC voltage and frequency in both directions

Large AC/AC converters are in general water cooled

The same converter as on the previous page but now without doors

1. Fast fuse
2. DC/AC converter
3. Ventilator
4. Cooling water outlet piping
5. Water cooled rectifier
6. Support isolators
7. Fuses
8. Connections to transformers
9. Transformers
10. Foundation
11. Outgoing connection
12. Outgoing phase cable
13. Cooling water pipe
14. Fuses
15. Braking chopper
16. Expansion vessel
17. Actuator
18. Cooling water regulating valve
19. Pressure indicator
20. Cooling water piping
21. Electric motor
22. Heat exchanger
23. Cooling water pump
24. Cooling water inlet
25. Cooling water outlet

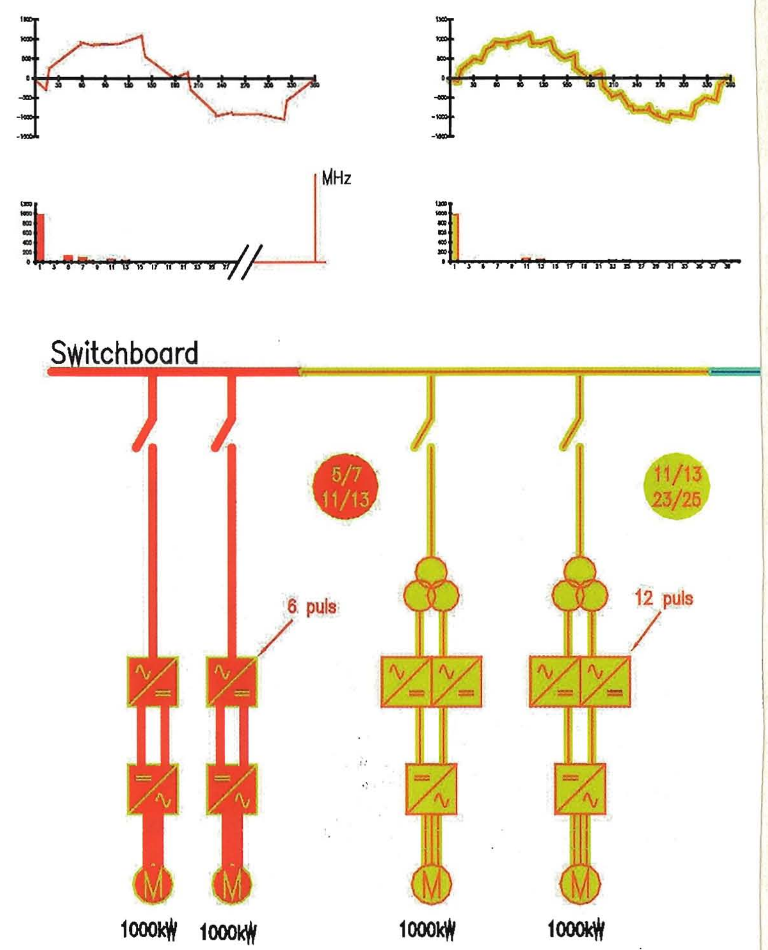
7 Harmonic distortion

Harmonic distortion of the main power supply is a phenomenon caused by switching, particularly of high speed power switches as can be found in Variable Frequency Drives.
This high speed switching causes harmonics currents which are usually the multiples of the supply fundamental frequency, produced by 'non-linear' loads such as the AC to DC power conversion circuits in the Variable Frequency Drives.
For example, on a 50Hz supply, the 5th harmonic is 250 Hz, 7th harmonic is 350 Hz, etc. These are called 'integer harmonics' - i.e. exact multiples of the supply frequency.
The average value of all the harmonics is the **Total Harmonic Distortion** or THD.
With the increased use of large variable frequency drives the danger of the effect of high THD levels has increased too.
Classification societies use a value for the THD of 5% or less for use on ships.
The main effects and dangers of high THD levels are:

- reduction of efficiency of power generation
- aging of the installation due to excessive heat
- malfunctioning and failure of electronic equipment
- overheating and failure of electric motors
- resonance due to interaction of capacitors with harmonics
- overloading and overheating of distribution transformers and neutral conductors
- excessive measurement errors in metreing equipment
- uncontrolled operation of fuses, circuit breakers and other protective equipment
- electromagnetic interference with TV, radio, communication & telephone systems

By good design and installation practices THD problems can be prevented.
As the biggest source of THD values will be large variable frequency drives selecting the right type in relation to the network can be a big advantage. The rating of the generators supplying the system and their reactance Xd" are a factor with the calculation of the THD.

Xd"	Ik"	6-Puls	12-Puls
16%	6xIn	18,7	10,6
10%	10xIn	13,4	6,99
Losses drive		2-2.5%	2.5-3%



Total Harmonic distortion

The following basic types of variable frequency drive systems are available which are shown in the diagram on this page:

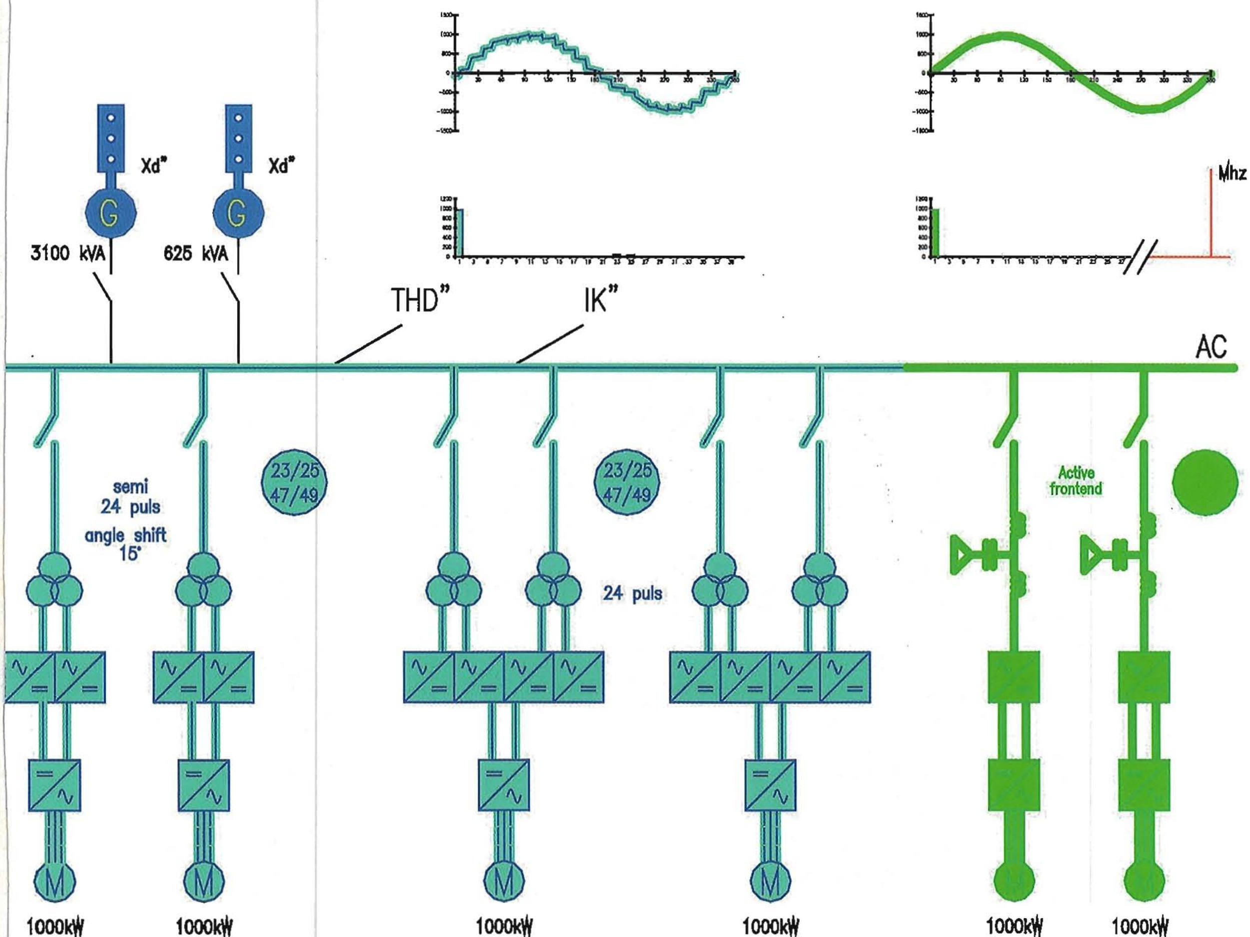
1. one-way rectifier, 6-pulse
2. two double one-way rectifiers, 12-pulse with primary one double stock transformer
3. two double one-way rectifiers, 12-pulse with primary one double stock transformer with 15 degrees phase shift creating semi 24-pulse system.
4. four one-way rectifiers, 12-pulse with two primary double stock transformers creating 24-pulse system.
5. Active Front End Converter.

The diagram shows the effect of the different types of variable frequency drives on the THD. The values used to make the calculations are in the diagram.
The results show that an AFE drive would have the lowest THD levels.

1. One-way rectifiers (Amber)
The 3-phase AC from the switchboard main bus-bars is rectified by 6 diodes into 6 currents DC which are brought together resulting in a pulsating DC. See diagram. This DC is the sum of the three phases, where the negative part of each sinus is made positive. This forms a DC current with 6 pulses per original cycle, and no possibility of feeding back to the switchboard. This DC is transformed into 3-phase AC again through inverters with adjustable voltage and frequency.

2. One-way rectifiers (Yellow)
Between the bus-bar and the rectifiers, behind the main switches,

	24-Puls	Active frontend
	5,33	≲ 3%
	3,77	≲ 2%
	2.5-3%	3.5-4.5%



transformers of the double stock type are installed. A double stock type transformer has two secundary windings, one in star and one in delta, so producing 6 sinus curves each. The output of one transformer is brought out of phase as much as 30 degrees. The voltage is not necessarily changed. The thus produced 12 currents are rectified similarly to the situation above, and is rectified to a 12-pulse DC. This 12-pulse DC is changed into the desired current in inverters, in voltage and frequency. This output is used in two consumers, running in phase. The distortion on the main bus-bars is considerable reduced.

3. One-way rectifiers (Blue).

The same as above, but the output of the second transformer is shifted another 15 degrees. The consumers, identical, are using 12 pulses each, but 15 degrees out of phase relative to each other. The distortion on the bus-bar is now 24 pulses, and has less effect again.

4. One-way rectifiers (Another blue).

Each inverter supplied by two double stock transformers, resulting in 24 pulses to each consumer, a further reduction of the distortion.

5. Active front-end converter (Green).

This means that the input is not just a rectifier which is controlled by the input voltage, but a controllable device. Controllable devices can stop and pass voltage without the restrictions of a rectifier, so independent of the input voltage. These devices, thyristors, transistors, IGBT's and whatever types are used, can lead power from the switchboard to the consumer and back from the consumer to the switchboard.

Active also means that the converter takes power from the switchboard in a controlled way, thus minimising harmonics. Transformers are only required when the voltages differ substantially.

Harmonics created by converters, supplying consumers, are absorbed by the generators energising the switchboard. The impedance of the generators gives an indication of the capability to absorb harmonics. A low impedance will absorb more harmonics than a high impedance, but is also capable to create a higher short-circuit current, requiring more expensive switchgear.

17. ELECTROMAGNETIC COMPATIBILITY (EMC)

The shortest definition of **EMC** is that this is the capability of an electric system to neither disturb or be disturbed via radiation or transferred through the connection cables.
It also includes disturbance by signals in cables not connected to the disturbed unit but signals running through cables parallel to cables of the disturbed unit.

1 EMC management

Determining if an installation fulfills the EMC requirements is a complicated and time consuming exercise. It starts with listing the sensitive equipment and verifying their acceptance limits, followed by listing the disturbing equipment and testing their disturbance levels.
A lot of this work is done by the suppliers under the type-approval schemes.
The publication IEC 60945 defines the susceptibility and disturbing criteria for navigation and nautical equipment.
The figures in that publication present the normal environment which is to be expected on the open deck and inside the wheelhouse of a normal ship.
Most navigation and nautical equipment has been tested to be able to cope with this environment.
This is simple insofar as the environment is under our control.
However, also radio and radar signals from other ships or shore based traffic guidance systems influence the ship's environment.

The maintenance and development of the **IEC standards** is a joint exercise of industry, equipment suppliers, shipowners, shipbuilders, classification societies and governments and also forms the basis for the rules and regulations of all classification societies.
IEC TC18 standards are published by the **I**nternational **E**lectro technical **C**ommision, Geneva, Switzerland, as IEC 60092 series and are available at the national standards institutes.
Individual references are given in the respective paragraphs.

Cable and pipe tunnel, with power cables situated below in the tunnel and the control cables, above.

For detailed information and procedures, reference is made to IEC 60533 Electromagnetic Compatibility for Electric Installations onboard Ships. Navigation and nautical equipment has been tested in accordance with IEC 60945 and therefore, suitable for the outside maritime environment.

2 EMC environment

Electromagnetic immunity means equipment is capable of operating satisfactorily under the following conditions:
- Conducted low frequency interference 10% under AC supply voltage 50 Hz-900 Hz
- 10%-1% under 900 Hz-10 kHz
- 10% under DC supply voltage 50 Hz-10 kHz
- Conducted radio frequency interference under supply of 3V rms. 10 kHz-80 MHz
- Radiated interference 10 V/m between 80 MHz-1GHz
- Fast transients (bursts) 2kV differential on AC power ports, 1kV common mode on signal and control ports
- Slow transients, power supply variation, power supply failure, and electrostatic discharge (the phenomenon that happens when you touch a system in winter in dry conditions), with a static discharge voltage of more than 6000 Volts are also considered.

Equipment should not transmit conducted or radiated signals that disturb the correct functioning of other equipment.

Normally the conducted emission is not a problem but the radiated emission limit between 156MHz and 165MHz of only 24 dBμV/m is only slightly above the environmental noise level of today.
This is a frequency band associated with VHF emergency communication.
Equipment used on board ships should not radiate any signal in this frequency.
Also frequencies of processors in programmable logic computers and other electronic control systems have to be checked against the environment and tested if any possibility of interference exists.

Conducted radio frequency interference 3V rms. 10 kHz-80 MHz
Radiated interference 10 V/m 80 MHz-1GHz.
These figures are for open deck areas and inside the wheelhouse.

3 EMC measures

To limit the exposed systems, the following measures are implemented:
Cables outside the steel structure of the ship have to be screened or installed in steel pipes. The most effective means is to limit the quantity of cable exposed to the outside environment by installing those inside the mast or inside a structure, only exposing them to the outside when absolutely necessary.
This also prevents incoming interference.

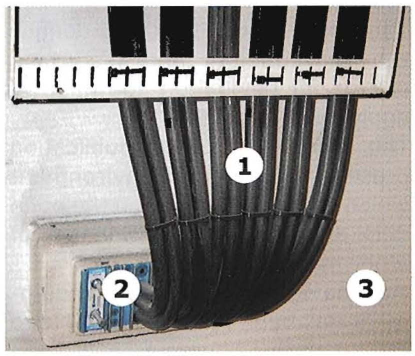
A cable located outside will act as a receiving aerial and a transmitting aerial inside the ship if not protected. The actual aerials for radio and radar reception have been designed to cope with the environment.
They should not become damaged by excessive signals such as lightning or directional radar or track antennas' signals.

The rest of the disturbing signals come from the installation itself.
Disturbing signals come from radar, radio and echo-sounder and sonar transmitters.
Most suppliers advise how to install their equipment, what type of cable should be used and how it should be routed in relation to other cables and equipment.
These instructions are based on the equipment in their tested housing; therefore, no equipment should be dismantled to fit into a console.

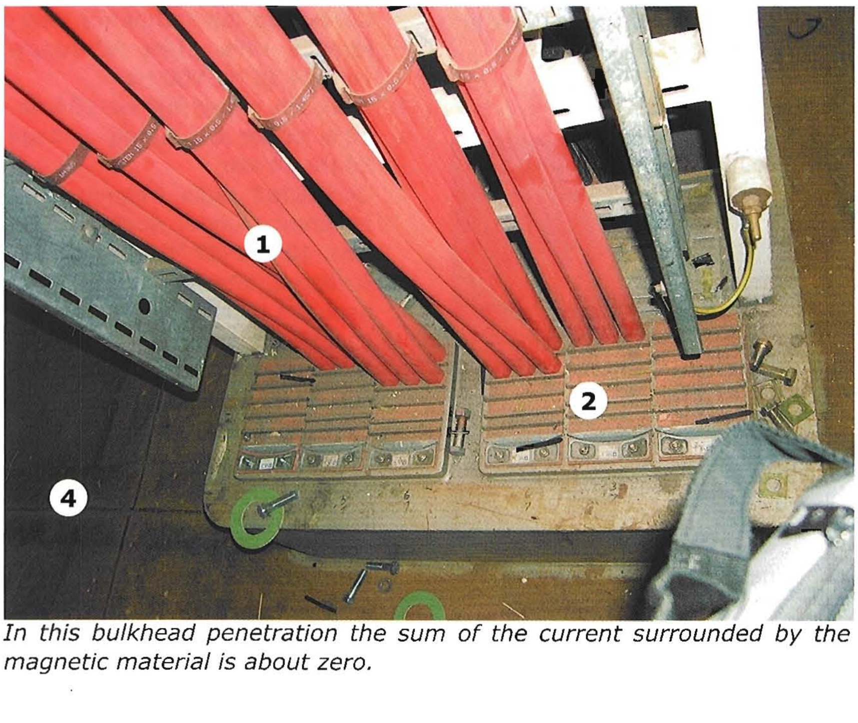
Cables must be selected and routed according to the type and strength of signal they transport.
Therefore, suppliers of the equipment have to state what signal group their cables belong to.

Single-core cables with a current exceeding 200 Ampere per core must be routed in a three-phase triangular formation to eliminate the magnetic fields around the single cables.
These magnetic fields cause disturbance to all visual display units and cause eddy currents to flow in magnetic materials like ordinary steel which as a result may heat up.
Therefore, gland plates for single-core cables must be of a non-magnetic material, like stainless steel.

A wheelhouse console is a collection of all type and make of equipment.
Most of those are tested for EMC. This equipment shall be installed in the original housing as it was tested to be sure the required compatibility is maintained.
Also earthing and type of cables shall be as used during the tests



1. Single core cable
2. Multi Cable Transit (MCT)
3. Bulkhead
4. Deck



In this bulkhead penetration the sum of the current surrounded by the magnetic material is about zero.

4 EMC plan

The following describes how to build up an EMC plan for a customs patrol vessel, with a complete nautical and navigation package as well as a hydraulically driven bow thruster.
This is a good guide of how to make an EMC plan.

4.1 General project information

This ship is a modern high speed patrol and rescue vessel with a semi-displacement hull for coastal and offshore services. The patrol craft is built with a steel hull and an aluminium superstructure.

The propulsion system consists of two electronically controlled common-rail diesel engines driving controleble-pitch propellers.
The electric installation 400/230V 50Hz 3 phase 4-wire neutral earthed is powered by two electronically controlled common-rail diesel generator sets.
The bowthruster is hydraulically driven. All engines are electrically started from batteries. Emergency power is also from batteries.

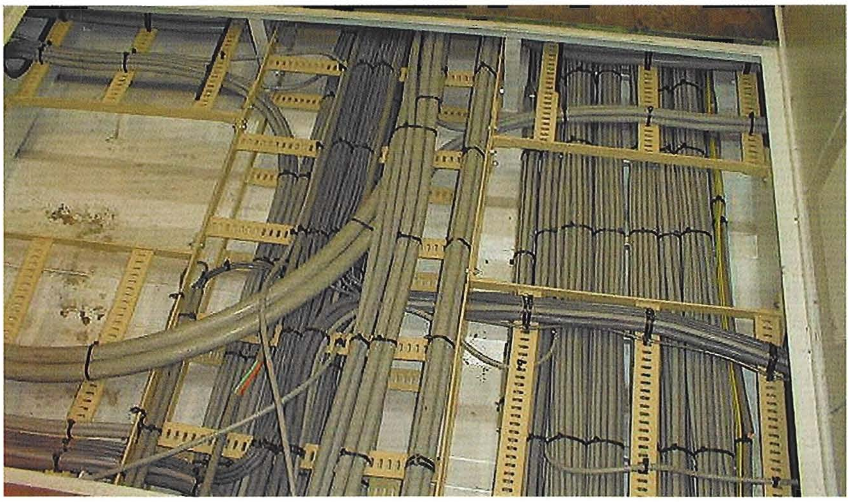
4.2 Definition of EMC

Electromagnetic Compatibility (EMC) is the ability of equipment and/or combinations of equipment to function properly together as well as within the ship's environment.

Type-tested electronic and electric equipment is tested by a certified testing laboratory in order to be certain that it will function properly in the expected ship's environment.

Requirements for type-tests can be found on the web sites of the classification societies as well as International standard IEC 600945 and IEC 600533.
Parts of these tests are related to EMC and are also related to the disturbance of low level emergency transmission signals such as VHF signals in the 156-165 MHz range.

For more extensive definitions of EMC see IEC 533 electromagnetic compatibility onboard ships.



Power and control cables in a double floor

4.3 General arrangement plan

This plan is used to achieve the first impression how to start with EMC. It helps to derive the guidelines and recommendations for technical measures to achieve electromagnetic compatibility in ships and of ships' equipment.
These preventive measures concern electric and electronic equipment and in special cases, non electric equipment.
The following general measures are applicable to EMC:

a. Decoupling
b. Reduction of the interference level at its source
c. Increase of the susceptibility level of the affected equipment or system.

4.4 Decoupling

Space is limited in ships, especially in small ships.
The installation of equipment in an other space or at sufficient distance from each other to prevent interference, is difficult.
To find the best compromise for the location of radio and navigation aerials, a listing of the aerials in sequence of importance is made and then a suitable position is found.
Aerials do interfere when fitted close to each other.
In order to ensure proper television reception, it is advisable to install the omni-directional television aerial above the everyday working VHF aerials.

4.5 Reduction of interference level at its source

After having established the location of the different aerials, the effect on the equipment onboard has to be determined.
Then the distance to the other equipment has to be considered and the measures defined.
The first source of interference is the outside environment, such as other ships or shore-based ship guidance systems.
All equipment located in the above deck zone must be suitable for an EMC environment according to IEC 801-3 frequency range 27 MHz-500 MHz field strength level 10 V/m.

Near ship's aerials these levels are far exceeded, for example:

- A 15 metre transmitting wire aerial connected to a 250 W 500 kHz transmitter creates a field strength of up to 12000 V/m at 3 metres, reaching the 10 V/m at a distance of 40 metres
- A 1.8 metre rod aerial connected to a 40 W 40 MHz VHF transmitter creates a field strength of up to 59 V/m at 1 metre, reaching the 10 V/m at a distance of 3 metres
- A 3 cm X-band 7 ft navigation radar antenna connected to a 25 kW 10 GHz radar transceiver creates a field strength of 57 V/m, reaching the 10 V/m at a distance of 128 metres
- Naval communication and radar systems create field strengths of multiples of the above figures, reaching the 10 V/m value miles away
- Consequently the antenna plan must also be reviewed for the environmental impact to onboard signals.

4.6 First source of interference

The **environment** is the first source of interference with signals originating from other ships and shore systems. This environment has been defined in standards.
All type-approved equipment fulfills the standard and is suitable to operate in the ship's environment.
Outside the ship's structure the signals are stronger than inside the metal structure.
The environment can be divided into:
- above deck zone 10 V/m 80 Mhz - 1 Ghz
- below deck zone.

Due to the large window area, the wheelhouse is considered 'above deck zone'.
Cables running in the 'above deck zone' act as aerials and transport the signals into the 'below deck zone' and to other electronic equipment.
To avoid this, all outside cables must either be run in galvanized steel pipes or be screened.
This screen has to be earthed at both ends, preferably as close as possible to the location where the cable enters the steel structure.

4.7 Second source of interference

The second source of interference is the system of **cables** within the steel and aluminium structure, transporting all sorts of signals through the ship.
The type of signal transported through a cable determines what type of cable has to be used and the group to which the cable belongs:
(This is the basic matrix linking signals to measures. Every application has to be provided in detail.)

Group 1 – indifferent
Normal non-screened cable
- Power circuits
- Lighting circuits
- Control circuits
- Analogue and digital data signals
- Approximate signal range:
  10 V - 1000 V DC
  50-60 Hz 400 Hz

Group 2 – sensitive
Single-screened cable, additional twisted pairs
- Computer interfaces
- PLC interfaces
- Reference voltage signals
- Low level analogue and digital data signals
- Approximate signal range:
  0.5 - 115 V DC, 50-60 Hz, audio-frequency

Group 3 - extreme sensitive
Coaxial cables
- Receiver antenna signal
- Microphone signal
- Video signal
- Approximate signal range:
  10 µV - 100 mV across 50 - 2000 Ω DC, audio frequency to high frequency

Group 4 - extreme jamming
Coaxial cables screened power cables
- Transmitter antenna cables
- High powered pulse signal cables
- High powered semi-conductor converter cables

Approximate signal range:
10V - 1000 V broadband signals

To keep the coupling between the cables small, all lengths must be as short as possible.

In order to avoid interference between the cables of the different groups these must not be run close together for longer lengths and a separation distance must be used.

Also, the distance between the steel or aluminium deck or bulkhead must not exceed the figures from the table below.

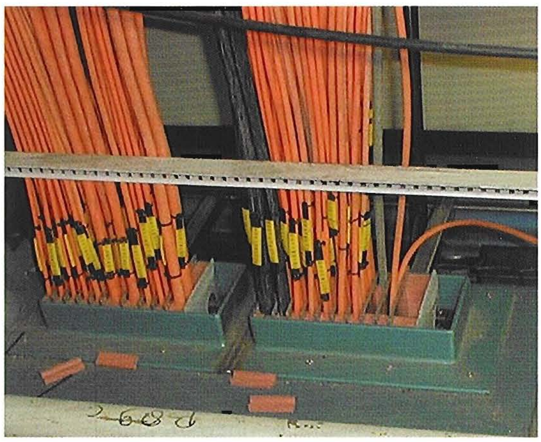
Example of separation distance in cm to be maintained between cables of several groups.

Cables terminating in one piece of equipment do not require separation from each other.

Screened cables
- Screened power cables must be constructed with a galvanized steel wire braiding with a flat braided earthing lead of tinned copper wires underneath
- Screened communication cables must be constructed with a copper wire braiding with a braided earthing lead of tinned copper wires underneath.

Earthing
- All consoles, terminal boxes and distribution boxes, where screened cables terminate, shall have an earth connection.
  This connection should be close to the glands or cable transits to ensure that the connection of the cable's earthing leads is as short as possible
- The earth connection to the steel or aluminium structure of the ship must also be as short as possible
- Earthing screens of power cables have to be earthed on both ends
- Earthing screens of sensitive cables only have to be earthed on the end where the signal is used
- Earthing of aluminium superstructure to steel hull has to be done at the joint.

	Maximum distance cable to cable (mm)			max. distance from metal surface
GROUP	1	2	3	4
1	0	5	10	10
2	5	0	5	15
3	10	5	0	20
4	10	15	20	20



Throughpass Multi Cable Transit (MCT) with fire resistant cables.

4.8 Third source of interference

The third source of interference is the **power supply** system.
Again, the following is the basic standard which must be detailed for the specified project.

The project power system supplies a three-phase four-wire neutral earthed system with two diesel driven generators.
Neutrals are earthed in the generators. The generator circuit breakers have four poles.

All equipment is also adapted to the "mechanical" aspects of a ship's environment with respect to temperature, ship's movement and vibration.

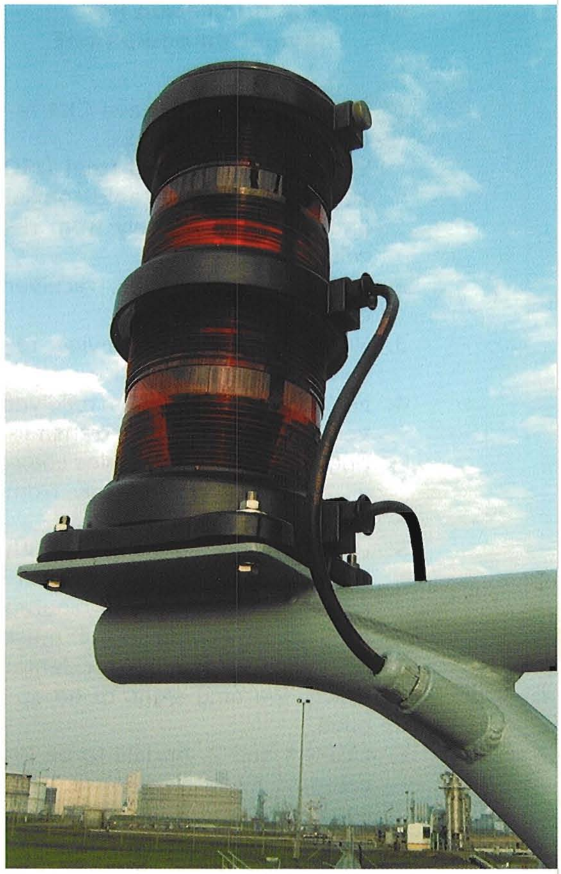
This supply system is very similar to onshore industrial installations. Standard industrial frequency converters with standard filters limit the harmonic distortion to acceptable levels as defined below.

All equipment must function correctly when supplied from an AC power supply system with the following characteristics:

4.9 Increase of the susceptibility levels

Remote control and automation systems are often distributed systems, with intelligent local units, with suitable filtering and limitation circuits, to allow non-screened cables for digital input and output.

The data communication between the local units and the workstations must be performed with screened cables and routed separately from power cables.
Data communication has to be installed using coaxial cables or the signal has to be amplified to such a level that the susceptibility levels exceed the interference levels from the power cables. In that case no separation is required.
This solution can also be used when, during Harbour Acceptance Tests (HAT) and Sea Acceptance Trials (SAT), unexpected interference is found.



Cables directly into the structure to reduce interference.

AC POWER SUPPLY TOLERANCE	MAX DEVIATION	
Line to line voltage (continuous)	6%	-10%
Line to line voltage tolerance incl. line voltage unbalance (continuous)	7%	-12%
Line voltage unbalance (deviation)		3%
Voltage cyclic variation (continuous)		2%
Transients (seconds e.g. due to load variation tolerance)	20%	-20%
Peak impulse voltage (e.g. caused by switching)	5.5 x nom. voltage	
Rise time / delay time	1.2 µs / 50 µs	
Total Harmonic Distortion (THD)	< 5 %	
Single Harmonic Distortion	< 3 %	
Frequency tolerance (continuous)	5%	-5%
Frequency cyclic variation deviation	5%	
DC POWER SUPPLY TOLERANCE	**MAX DEVIATION**	
Voltage tolerance (continuous)	10%	-10%
Voltage cyclic variation (continuous)	5%	
Voltage ripple	10%	
Peak impulse voltage (e.g. caused by switching)	1.2 µs / 50 µs	
24 V DC systems	500V	
110 V DC systems	1500V	
220 V DC Systems	2500V	

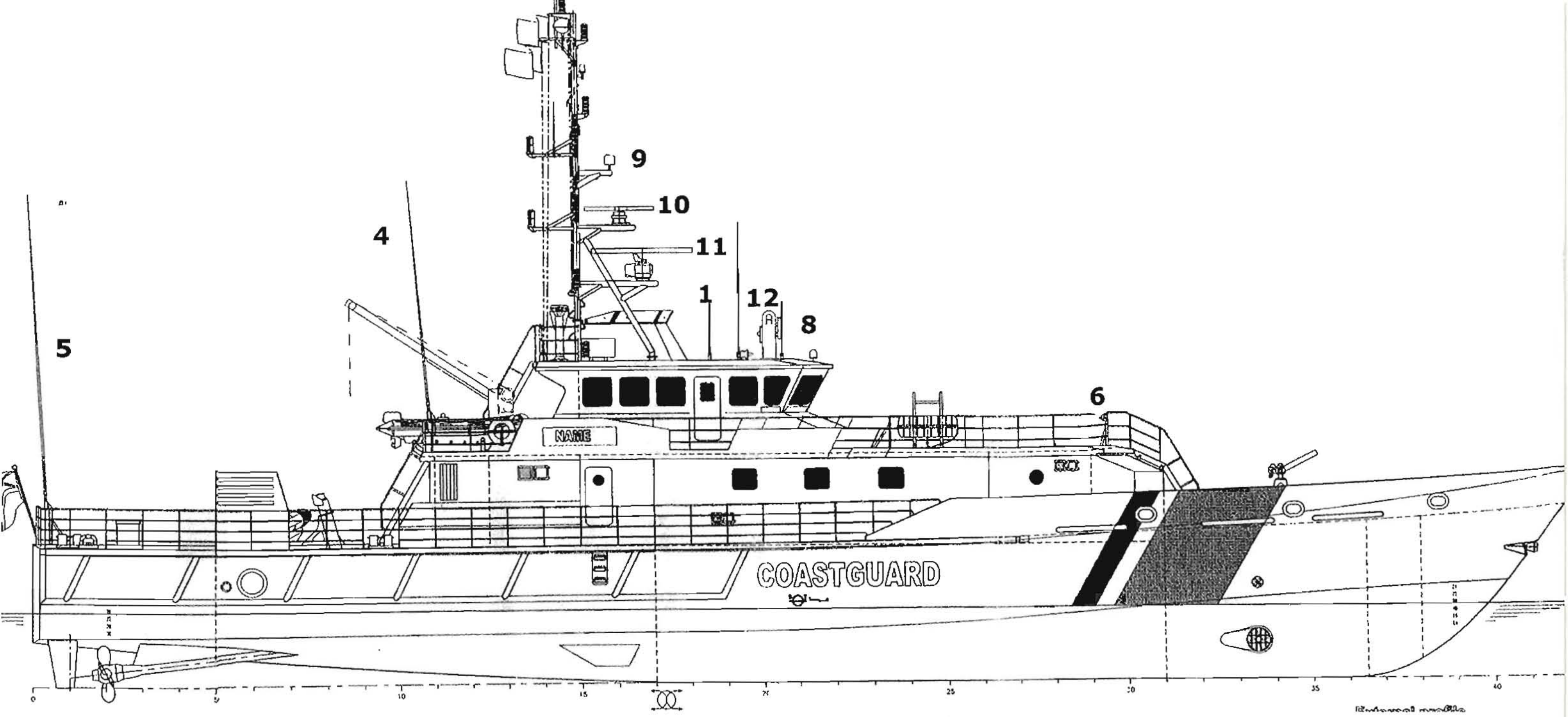
4.10 Communication and navigation equipment

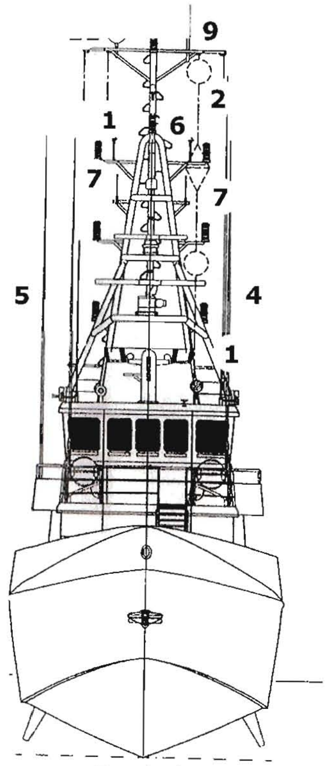
1. VHF 1 and 2: Cell wave CX4 radio telephone with DSC:
   VHF aerial separated from DSC aerial, transceiver cable coaxial and routed separately from receiver cables.
2. VHF NAVTEX receiver: receiver cables coaxial.
3. HF 2182 kHz homing device: receiver cables coaxial.
4. MF/HF receiver unit receiver aerial shielded from transmitting aerial, receiver cables coaxial and routed separately from transmitter cables.
5. MF/HF transmitter unit with antenna tuner 150W transmitter cable coaxial and routed separately. MF/HF aerial must be shielded against accidental touch. Warning signs to be applied.
6. DGPS 1 and 2. Aerials to be located to avoid similar blind areas GSM 1 and 2.
   Aerials to be located to avoid similar blind areas as AIS.
   Transceiver cable coaxial.
7. Satcom C1 and C2. Aerials to be located to avoid similar areas. Transceiver cables coaxial and routed separately from receiver cables.
8. Satcom Mini-M transceiver cables coaxial and routed separately from receiver cables.
9. TV/FM/AM antenna to be located free. Cable coaxial.
10. X-band Radar (3 cm wave lenght). 6ft Aerial to be located above S-band radar. Transceiver is integrated. Composite cables to operator station separation group 3 sensitive. Composite cable not to be interrupted.
11. S-band Radar (10 cm wave lenght). 12ft Aerial to be located free from X-band antenna, transceiver is integrated. Composite cables to operator station are separation group 3, as per supplier's recommendations. Signal cables are also separation group 3. Sensitive communication cables are group 2. Composite cables not to be coupled in mast junction box but routed directly. Both radar aerials to be located in such a way to avoid similar blind sectors due to steel structure.
12. Magnetic compass to be fitted free from magnetic (ferrous) structures.
13. Wind speed and direction transmitter to be installed unobstructed.

Other equipment:

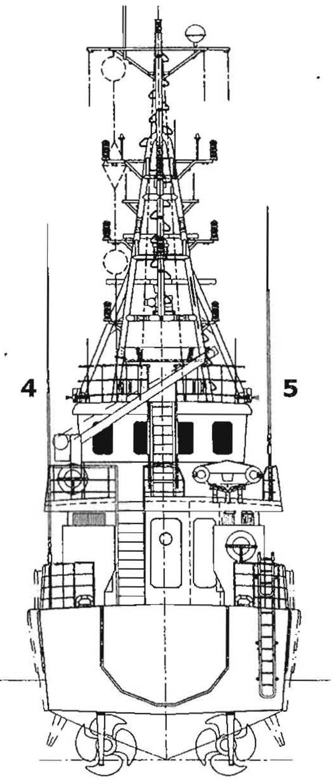
- Gyrocompass: signal outputs screened
- Electromagnetic log and echosounder
- Echosounder. Cables usually coaxial and separated from other cables
- Steering system: non-screened cables not routed in the wheelhouse area
- Power supply cables to above equipment: if routed in wheelhouse area other than inside a metal-clad cubicle, must also be screened
- All exposed cables in wheelhouse area must be screened
- Automatic telephone system: screened twisted pair cables, no separation, telephones in wheelhouse area installed into metal-clad console
- Amplified batteryless system: screened twisted pair cables, no separation, telephone in wheelhouse area installed in metal-clad console
- Public address system: non-screened cables, no separation, microphones in wheelhouse area installed in metal-clad console.

Warning signs to be positioned near the stairs to the top deck:
Danger electromagnetic radiation.





Front view



Rear view


Conning position


Communication position (GMDSS)

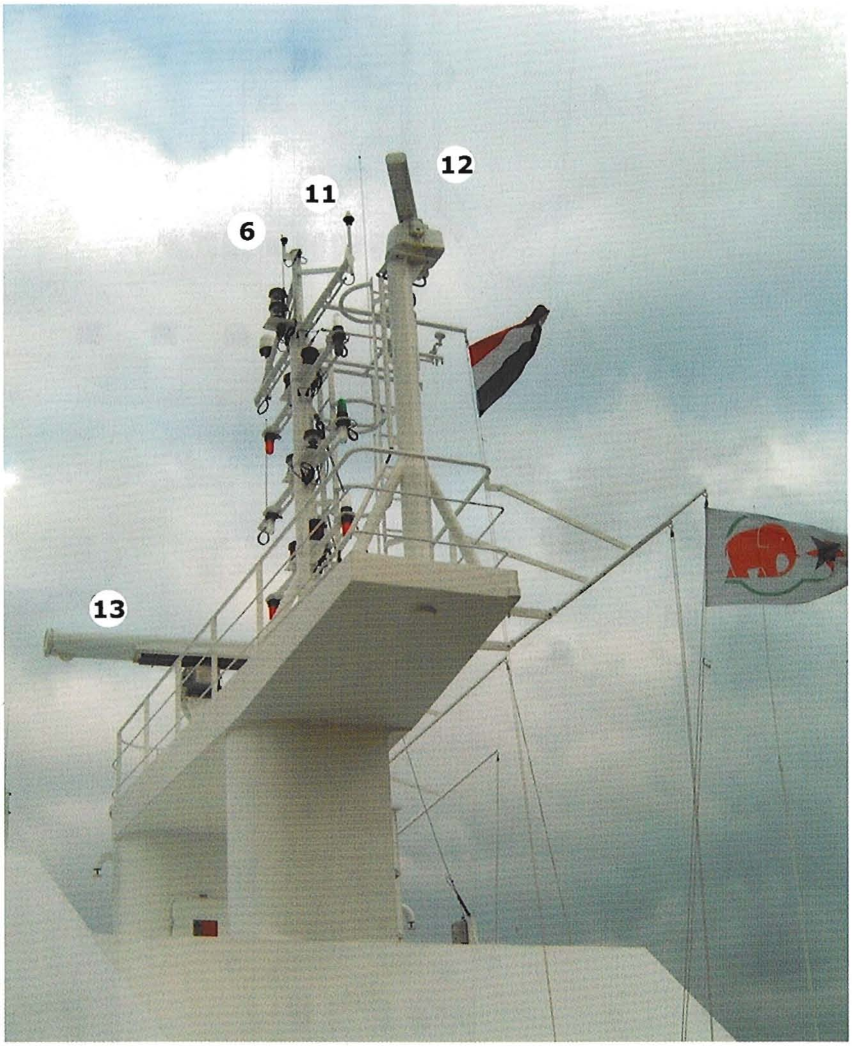

Nautical position

Cables for energy generation and energy conversion.

- Navigation lights:
  outside cables must be screened and run in pipes with open bends, exposed length limited to 20 cm per bend
- Whistle:
  outside cables run in pipes with open bends
- General alarm system:
  non-screened cables, no separation
- Main generators: non-screened cables, no separation
- 24 V DC systems:
  non-screened cables and no separation, with exception supply circuits into the wheelhouse area if not installed inside a steel-clad console. These cables have to be screened, but no separation is necessary
- Starters:
  both for power and control circuits non-screened cables and no separation
- Lighting: cables to outside lighting must be routed through galvanized steel pipes with open bends. The cable length exposed shall be limited to 20 cm per bend. Non-screened cables and no separation necessary. For wheelhouse area, screened cables and no separation
- Cables between frequency converters and motors must be screened, earthed at both ends, separated from other cables and to be considered as extreme jamming (group 4).

Switchgear and control systems.

- Switchboards/motor control centers: both for power and control circuits non-screened cables and no separation.
- Main lighting switchboard: non-screened cables and no separation, with the exception of supply circuits into the wheelhouse area, if not installed directly inside a steel-clad console. These cables have to be screened, but no separation.
- Emergency lighting switchboard: non-screened cables and no separation, with exception supply circuits into the wheelhouse area, if not installed inside a steel-clad console. These cables have to be screened, but no separation.



6. DGPS - aerial
11. TV/FM/AM antenne
12. X-band (3 cm) radar
13. S-band (10 cm) radar

- Lighting distribution panels non-screened cables and no separation, with the exception of supply circuits into the wheelhouse area, if not installed inside a steel-clad console. These cables have to be screened, but no separation.

Signal processing equipment.

- Fire detection systems screened cables, no separation
- The remote control and automation system can be a distributed system with intelligent local units with suitable filtering and limitation circuits. Non-screened cables for digital input and output is sufficient, but may be executed with screened cables without separation. Analogue input must be executed with screened cables without separation. Data communication between the local units and work stations must be executed with screened cables routed separately from power cables or with coaxial cables.

Non-electric outfit

- Rigging shall be earthed.

Integrated equipment

- Voyage management system: video signals coaxial, network coaxial cables
- Enclosures of equipment in e.g. wheelhouse consoles shall not be taken off or modified without permission of the manufacturer.

Equipment located in hazardous areas

- Cables for intrinsically safe circuits must be screened and clearly marked, for instance, by colours and separated from other cables
- Cables for power circuits in hazardous areas must be screened for earth fault detection.

4.11 Mast construction and cable routing

The masts of some ships are removable. Therefore, junction boxes are fitted for cables to the equipment in the mast. These junction boxes have to be watertight and have a metal-clad cover, preferably bolted and separately earthed. The mounting plate should be metal and separately earthed. The screen of the cables has to be coupled through isolated terminals.

All cables must be routed inside the mast and/or in steel or aluminium pipes with open bends to avoid interference from Radars and MF/HF aerials.
Cables of group 4 Transceiver cables have to be routed separately from other cables as well as separate from each other.

This can be achieved by introducing mounting hatches and fastening strips in two legs of the mast, or in pipes.

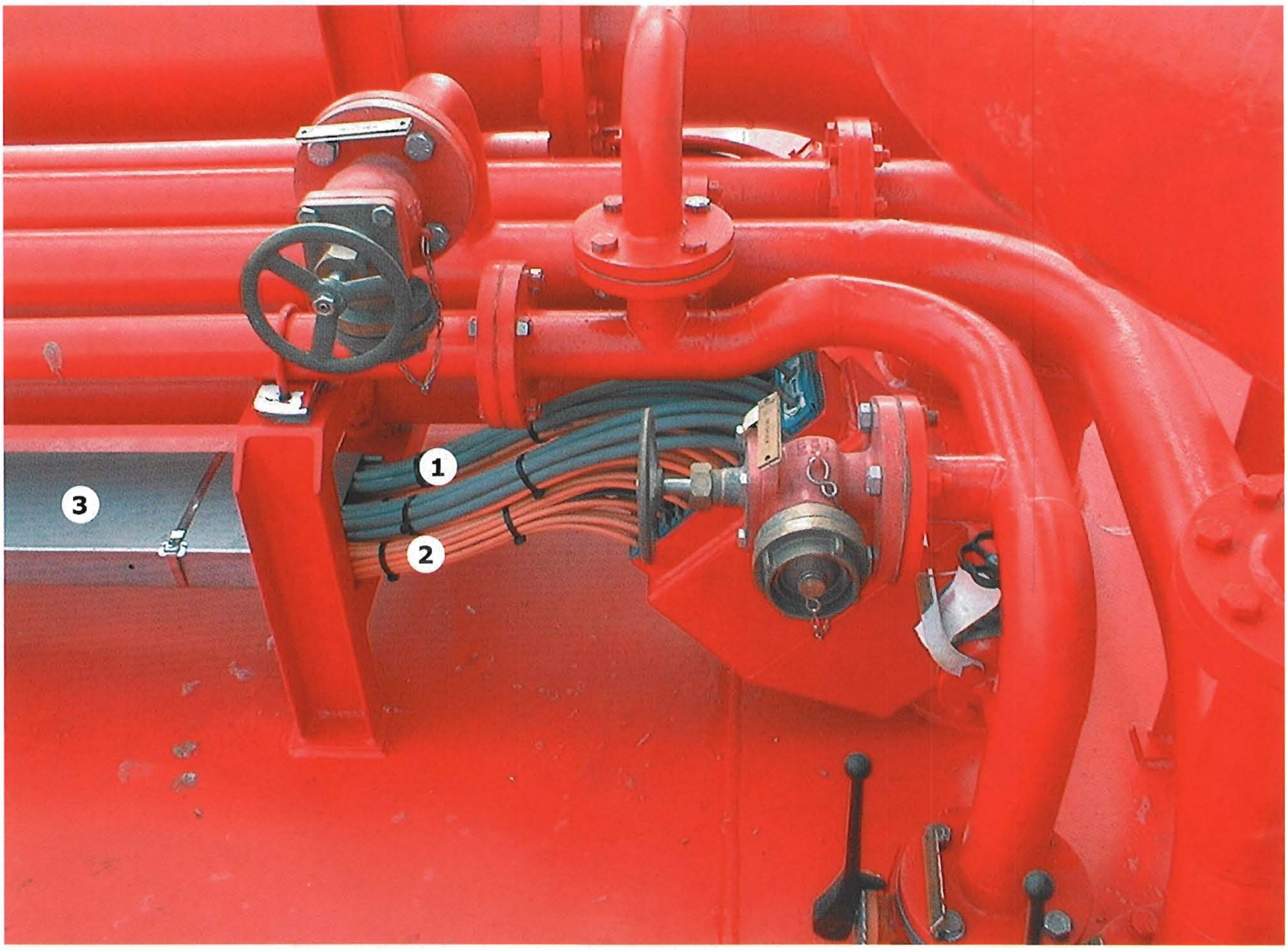
One pipe to be used for groups 1, 2 and 3 cables and the group 3 cables should be routed separate from 1 and 2 insofar as possible.

The other pipe must be used for the transceiver cables of group 4 and as these cannot be interrupted, there is no need for a junction box.
Group 4 cables, however, must also be separated from each other. When this is not possible within the space limitations inside the mast, these cables must be provided with additional screening. This then allows these cables to be routed together. This screening, however, does not fit in the plugs for the equipment.

A compromise is thus, to install the additional screen only where the cables run parallel for longer lengths inside the mast and wheelhouse.
The screening can then be taken off near the connections at the ends and the original connectors can be used.

4.12 Cable routing in general

In general, cable routing, trays, deck and bulkhead penetrations must allow for separation as defined before.
When separation distances cannot be met, as in the case of a single pipe mast, alternative measures must be taken, such as the installation of an extra screen around a cable. This increases the shielding of the cable and limits the radiation to the environment.
This is applicable to all group 4 cables in this project. Additional screening has to be provided for the longer lengths and screening over the shorter lengths has to be minimal.



Cables on deck chemical tanker

1. Intrinsically safe cables
2. Control cables
3. Cable tray

18. ELECTRIC CABLING

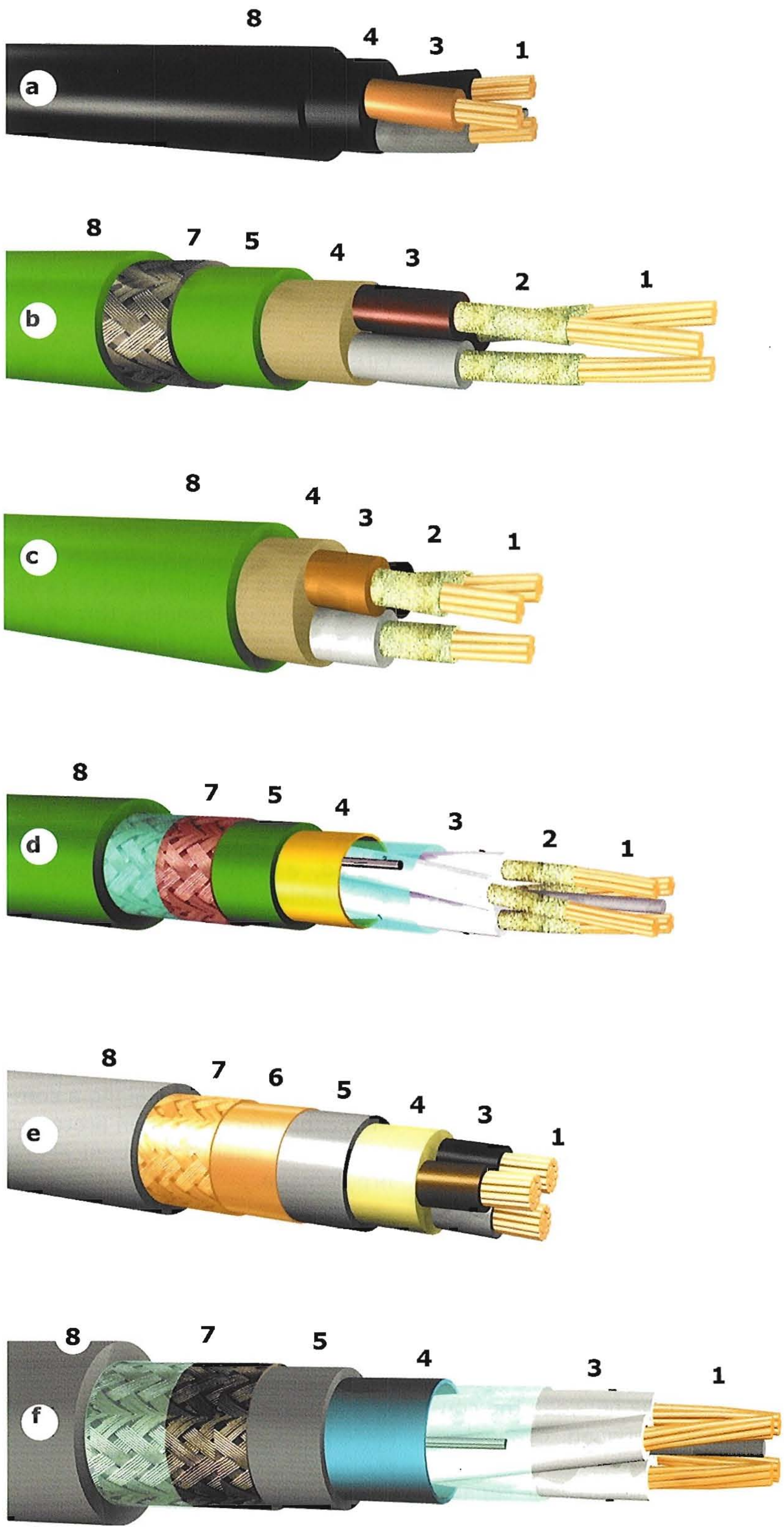
Electric Cables form the connections between the different parts of an electric installation. They are nowadays available in many varieties and quality.
The main acceptable types are:
- low smoke
- low toxic
- fire resistant.

Application of such more sophisticated cables like for instance the fire resistant variety will reduce the consequences and damage of a fire contrary to the commercially attractive PVC-insulated types.
These pvc cables generate toxic and corrosive gases during a fire, resulting in a lot more damage to the installation than the parts which are directly damaged by the fire.
A disadvantage, however, of the low smoke types of cables is that their mechanical properties, as strength against mechanical stress while being pulled, is considerably less with the possibility of damage with installation.

1 Cables

Some samples of ship's cables, from top to bottom
a. Normal three-core power cable
b. Fire resistant screened power cable
c. Fire resistant power cable
d. Fire resistant control cable
e. Double screened (EMC) power cable
f. Overall screened signal cable.

Cables for ship's installations differ from those for on-shore installation by the way the conductor is built up. Instead of a solid conductor as in most on-shore or industrial cables, a marine cable consists of a stranded conductor consisting of 7 or more wires to cope with the vibrating environment.
This does not mean that a MARINE cable is flexible enough for a non-fixed or a moving installation.
A further difference with on-shore installations is that cables in a marine environment must be fixed to the cable supports.
Flexible cables for moving installations such as cranes or telescopic supported wheelhouses are fixed to movable cable trays.



Flexible cables shall consist of flexible conductors, i.e. stranded of 19 or more wires and special flexible insulating materials, which have that capability also at lower temperatures (below zero).

1. Core of twisted copper conductors
2. Mica wrap
3. Core insulation
4. Filler
5. Inner sheath
6. Copper wrap
7. Braiding copper or galvanized steel
8. Outer sheath.

Cables with solid conductors up to 2.5 mm^2 can be used in ship's accommodations.

See for details of shipboard cables the relevant IEC standards.

Screened power cable consisting of, in addition to the above cable, 4 copper sheath, 5 and 6 galvanised steel wire braiding.

Screened single core AC power cables shall have a non-magnetic screen, because a steel braiding will heat up by the magnetic field resulting from the current in the cable.
The same is applicable when single core AC power cables pass through a steel bulkhead penetration. The sum of the currents through such a penetration shall be zero. Also gland plates for single core cables shall be of non-magnetic materials.

Screened multicore control cable consisting of laid up twisted pairs.

Fire resistant cable.
Cables which should remain functioning under fire conditions have a similar construction as other cables, but are provided with an additional layer of mineral insulation around the conductors, in this case mica tape.
It is amazing to see how this simple measure makes the cable fire resistant, not only in straight lengths but also in bent parts of the cable run.
Tests have been performed at several cable manufacturers' works where straight and bent pieces of cables have been subjected to a standard fire test up to 1000 °C for a period of one hour. These cables remain in service, with acceptable megger readings between the conductors and between conductors and earth.
The cores are found still capable to transport electrical power, which means that no wire is interrupted.
When fire resistant cables are used all other parts of the system like junction boxes involved, should also be fire resistant.

2 Application fire resistant cables

Fire resistant cables are applied when the circuits have to remain in operation under fire conditions.
This is mainly limited to safety and fire fighting circuits such as emergency lighting, fire detection, alarming circuits, communication circuits and fire safety shutdown circuits.

Fire resistant cables shall be used to ensure continuity of service in spaces adjacent to the space which could be damaged by fire.
For example emergency lighting circuits routed through an engine room supplying a steering-gear room.
The same is applicable to a public address circuit running through a fire zone servicing loudspeakers in a next fire zone.
Another example is a fire door, which requires electric power to close, has to get its supply by a fire resistant cable from a safe area.
If the door would close by itself when the power supply is interrupted, a normal cable would be acceptable.
The same is applicable to any sort of safety equipment or essential propulsion equipment.
Duplicated essential propulsion equipment shall not be powered from the same source or be powered by cables routed along a common cable run other than protected individually against mechanical and fire damage.

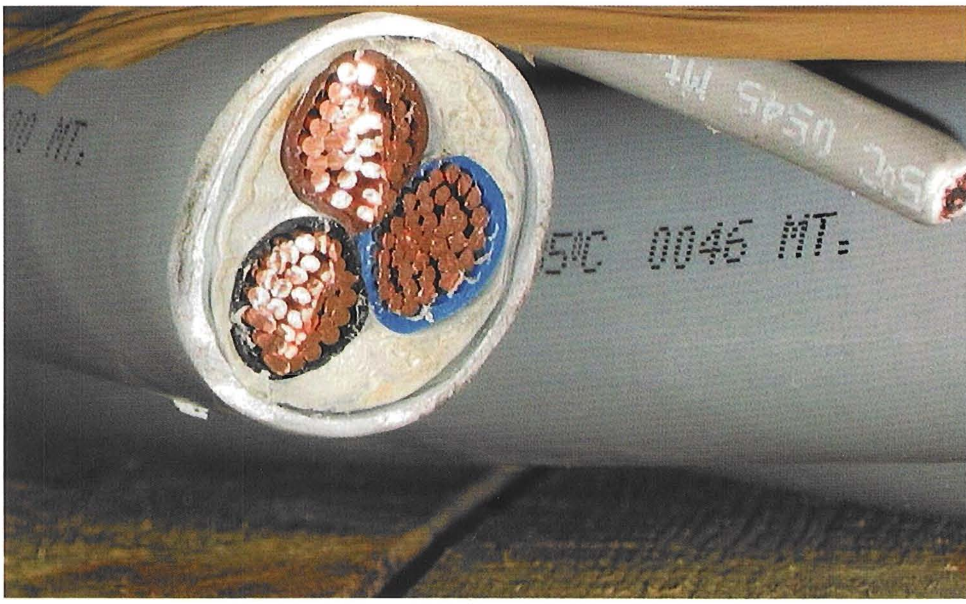
3 Cable selection tables

The table on the next page shows the cable ratings for various types of cables for an ambient temperature of 45° C.

When cables are installed in an area with a different ambient temperature, the correction factors as per table on the top of the page should be applied.

Example:
A cross linked PE cable of 3 x 4 has a current rating of 27A.
When this cable is installed in an area with an ambient temperature of 60° C a correction factor of 0.79 must be applied. The current rating then will be 0.79 x 27 = 21.33A

Note: correction factors for bunching of cables may also be applied and class rules must be consulted for the corresponding values.



To indicate the quality of the cable, codes are printed on the outside, according to the production standard.

Correction factors for cables

Insulation material	Correction factor for ambient air temperature of °C										
	35	40	45	50	55	60	65	70	75	80	85
PVC, Polyethylene	1.29	1.15	1.00	0.82	–	–	–	–	–	–	–
EPR, XLPE	1.12	1.06	1.00	0.94	0.87	0.79	0.71	0.61	0.50	–	–
Mineral, Silicon rubber	1.10	1.05	1.00	0.95	0.89	0.84	0.77	0.71	00.63	0.55	0.45

CABLE RATINGS AT AMBIENT TEMPERATURE 45°C									
Nominal cross section Q mm2 (#AWG)	Continuous r.m.s current rating, in amperes								
	THERMOPLASTIC, PVC, PE			EP RUBBER and CROSSLINKED PE			SILICON RUBBER or MINERAL		
	Single Core	2-core	3- or 4-core	Single Core	2-core	3- or 4-core	Single Core	2-core	3- or 4-core
0,75	6	5	4	13	11	9	17	14	12
1(#18)	8	7	6	16	14	11	20	17	14
1.25(#16)	10	8	7	18	15	13	23	19	16
1.5	12	10	8	20	17	14	24	20	17
2(#14)	13	11	9	25	21	17	31	26	21
2.5	17	14	12	28	24	20	32	27	22
3.5(#12)	21	18	14	35	30	24	39	33	27
4	22	19	15	38	32	27	42	36	29
5.5(#10)	27	23	19	46	39	32	52	44	36
6	29	26	20	48	41	34	55	47	39
8 (#8)	35	30	24	59	50	41	66	56	
10	40	34	28	67	57	47	75	64	53
14(#6)	49	42	34	83	71	58	94	80	66
16	54	46	38	90	77	63	100	85	70
22(#4)	66	56	46	110	93	77	124	105	87
25	71	60	50	120	102	84	135	115	95
30(#2)	80	68	56	135	115	94	151	128	106
35	87	74	61	145	123	102	165	140	116
38	92	78	64	155	132	108	175	149	122
50	105	89	74	185	153	126	200	175	140
60	123	104	86	205	174	143	233	198	163
70	135	115	95	225	191	158	255	217	179
80	147	125	103	245	208	171	278	236	195
95	165	140	116	275	234	193	310	264	217
100	169	144	118	285	242	199	320	272	224
120	190	162	133	320	272	224	360	306	252
125	194	165	134	325	280	230	368	313	258
150	220	187	154	365	310	256	410	349	287

In order to determine the necessity for fire resistant cables and the cable routing, the approved Safety Plan showing the watertight bulkheads, fire resistant bulkheads and decks, the A-60 insulation and the fire zones, is required.

Larger cross-sections are considered unsuitable for installation on ships because of their size and associated bending radius.

Parallel cables have to be routed in such a way that sufficient air can circulate for cooling.
If this is not the case, de-rating factors must be applied.

AWG in the above table refers to American Wire Gauge which is the cross section as per American standards.

When a cable is damaged due to a too high ambient temperature, and has to be replaced, the proper quality cable has to be chosen. Refitting using the same quality cable will result in the same damage, or the allowed current has to be reduced as per table above.

4 The making of a cable

4.1 Introduction

Cables come in a variety of sizes, materials and types dependent on their application.
Cables are made up of three major components:
- one of more conductors
- one or more layers insulation
- one or more protective jackets.

The construction of a cable and the materials used are determined by the following factors:
- working voltage, determining the thickness of the insulation.
- current-carrying capacity, determining the cross-sectional size of the conductor(s).
- environmental conditions such as temperature, water, chemicals or sunlight exposure.
- mechanical impact, determining the form and composition of the outer cable jacket.
  Application which determines, amongst others, the required flexibility of the cable.

Cables come in all shapes and sizes for a wide range of applications. From network cables, fibre optic cables, low voltage cables to high voltage cables and everything in between.
Larger power cables use so-called sector shaped conductors which makes these thinner than when circle-shaped conductors would be used. Non-conducting filler strands may be added to the cable assembly to maintain its shape.
For installation in ships most cables are specified to be of the low smoke, halogen free type.
This is because halogenated materials in cables will release corrosive and toxic gases if ignited in a fire. The corrosive element of these gases has the potential to damage electronics wherever the smoke travels, and the toxic element can be potentially hazardous to persons. This concern is particularly important in places where many people will be around like in the accommodation of a ship.
Most power cables nowadays are using polymers or polyethylene, including (XLPE) for insulation of the cores which allows the cables to be used with higher core temperatures than the older cable types that use PVC insulation.
Special cables are often custom-made like the cables for connection of a Remote Operated Vehicle (ROV). Those cables are more often hybrid cables that include conductors for power supplies, control signals and fibre optic fibres for data transfer and CCTV signals.

4.1.1 Medium and high volt cables

Cables for use in medium or high voltage installations, above 1000 volts, have extra conductive shields between the conductors and a conductive shield may surround each insulated conductor. This equalizes electrical stress on the cable insulation. The individual conductor shields of these cables are connected to earth / ground at the ends of the cable. To enhance safety medium and high voltage cables have a distinctive colour from other cables, mostly bright red, and are installed on separate cable supports.

4.2 Cable manufacturing

Cable manufacturing involves a number of stages, starting with raw materials such as large quantities of thick copper wires.
As an example the following is a brief description of the various stages in the manufacturing process of a larger type power cable with a steel braiding for mechanical protection.

The image at the bottom of this page shows the various layers of the power cable which will be described with the following components:
1. Stranded copper cores
2. Individual core insulation
3. Filler compound between cores
4. Insulation material over cores.
5. Steel braiding
6. Insulation material over steel braiding.

The manufacturing process will be as follows, where the numbers in brackets refer to the part of the cable as listed above.
To get a particular size of copper wire for a type of cable the raw copper wires are pulled through drawing dies, set to the correct size, by friction wheels. (Image 1)

The individual cores are twisted into stranded conductors (1). (Image 2)

The individual cores are covered with an insulating material like cross-linked polyethylene (XLPE) with a specific colour to identify the use of the conductor. For power cables this will be phase, neutral or ground when included(2).

The individual isolated conductors are twisted together (Image 3) and a filler compound is added between the wires (3).

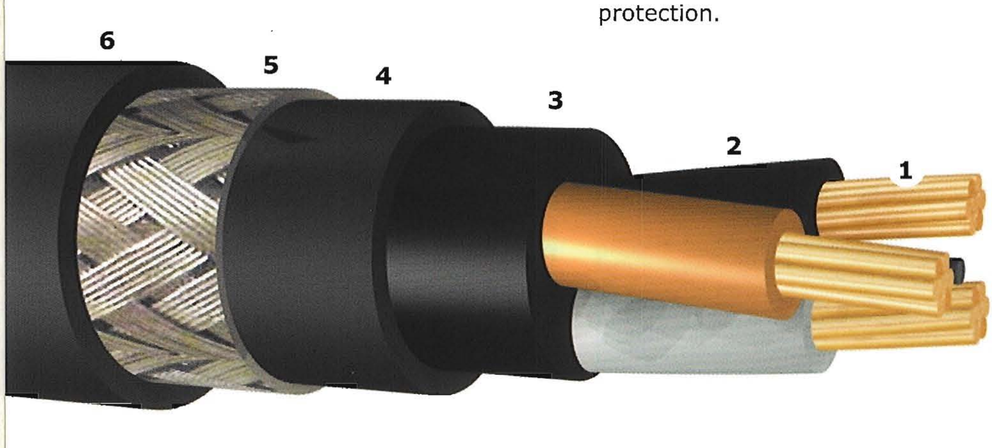
An inner insulation layer is applied over the twisted cores and filler compound (4).

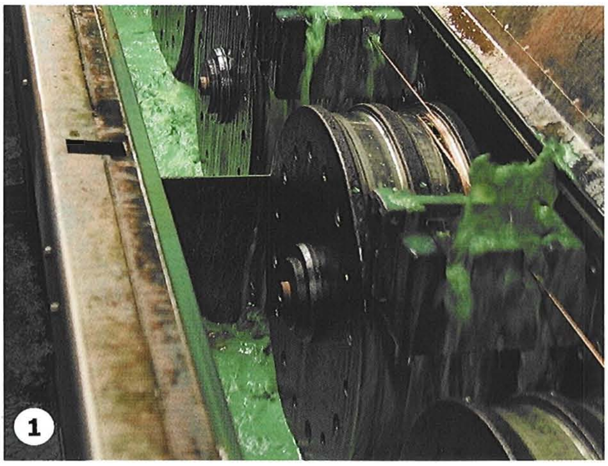
A layer of steel wires is spun around the inner isolation layer forming the steel braiding (5) (Image 4).

An insulation layer is applied over the steel braiding (6) (Image 5).

A cross section of a power cable is shown as an example of the structure. (Image 6) This cross section is from a cable without the inner isolating layer but with the filling compound. Each phase is built from 39 sub cores with each about 40 wires, so in this example each phase will have close to 1600 smaller individual copper wires.

When the manufacturing process is completed the cable is ready for the manufacturer's tests and after that ready for delivery (Image 7).

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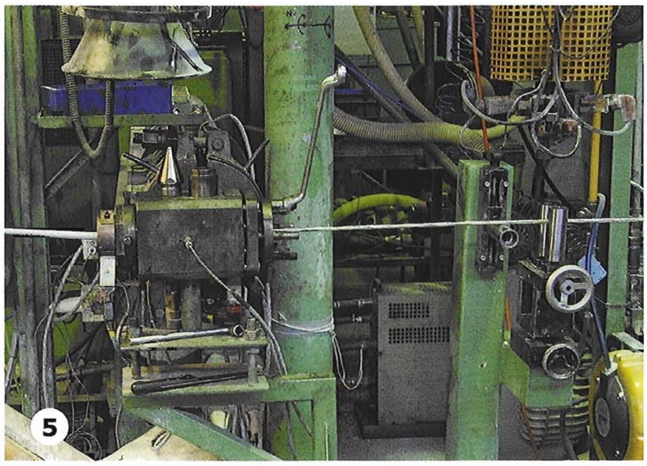
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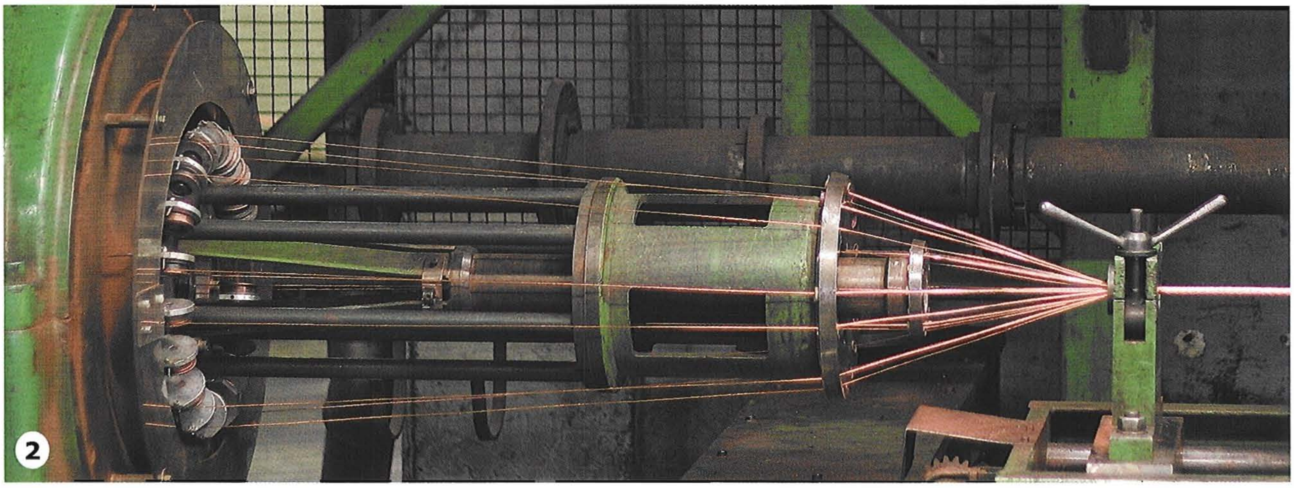
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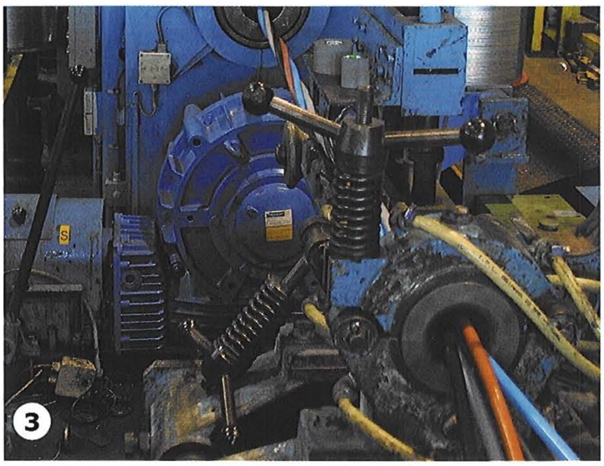
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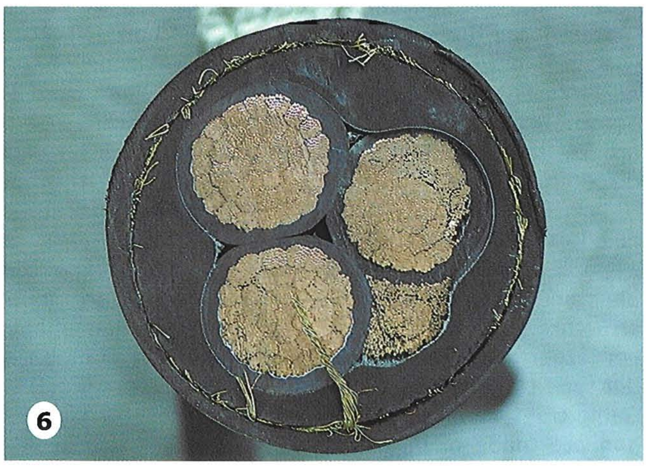
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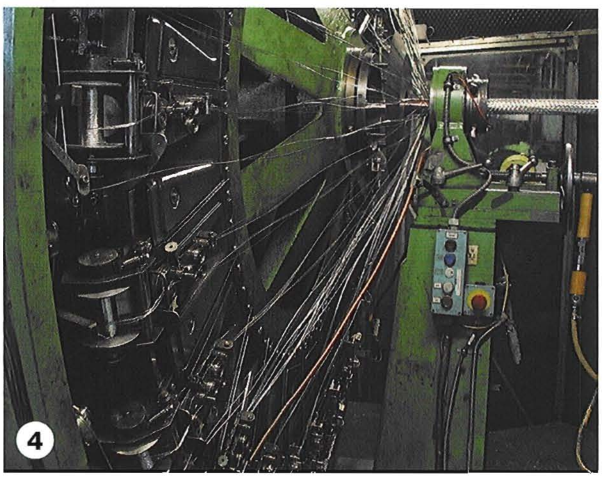
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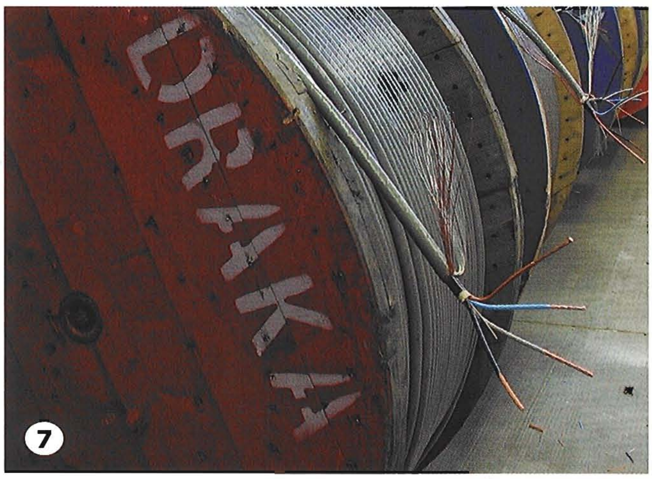
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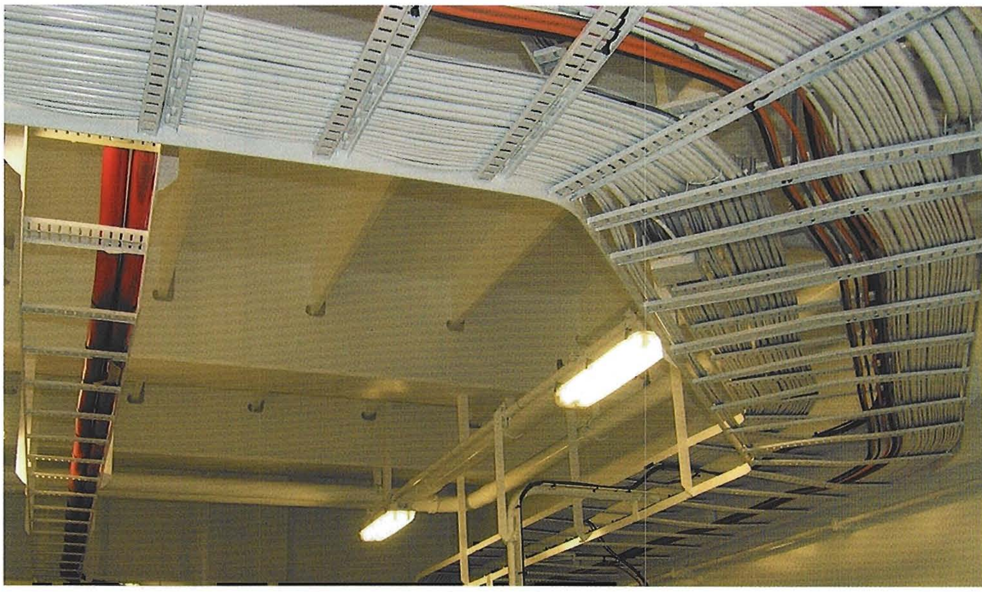
5 Cable trays and cable fixing

For minimum internal radia of bends for low voltage cables, an average figure of 6 times the overall diametre is a reasonable rule of thumb.
Above 1000 V, i.e. high voltage cables, the figure lies between 15 times the overall diametre for multi-core cables and 20 times for single-core cables.
Also, the environmental temperature during installation must be taken into account; at temperatures lower than plus 5° centigrade, pulling of cables must be stopped, as the outside screens and core insulation are likely to be damaged.

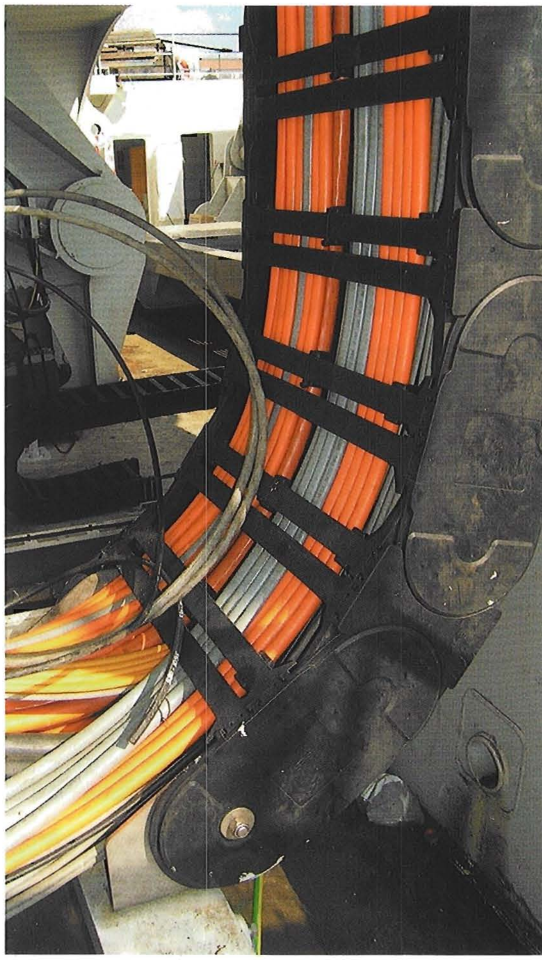
High voltage cables must be segregated from low voltage cables.
Cables have to be type-tested, or in case no type approval is available, tested by the manufacturer and certified by the classification society.
These tests must include:
- measurement of electrical resistance of conductors
- high voltage test
- insulation resistance measurement
- for high voltage cables, partial discharge tests

All tests have to be carried out in accordance with a relevant standard by the manufacturer prior to dispatch.

Fixed cable supports for a single or a small amount of cables are simple steel strips welded to the ship's structure.
For larger quantities of cables, ladder type trays are used.
Cable trays come in different sizes and are made of different materials. The simplest are the cable trays made from ordinary steel which are painted before the cables are pulled.
Outside cable trays are hot dipped galvanized or made of stainless steel.
When stainless steel is used care must be taken to isolate those cable trays from ordinary steel supports to avoid galvanic corrosion. When weight is an issue, aluminium type cable trays are used. In that case a seawater-proof type must be selected to avoid excessive corrosion.



Examples of fixed and flexible cable trays.



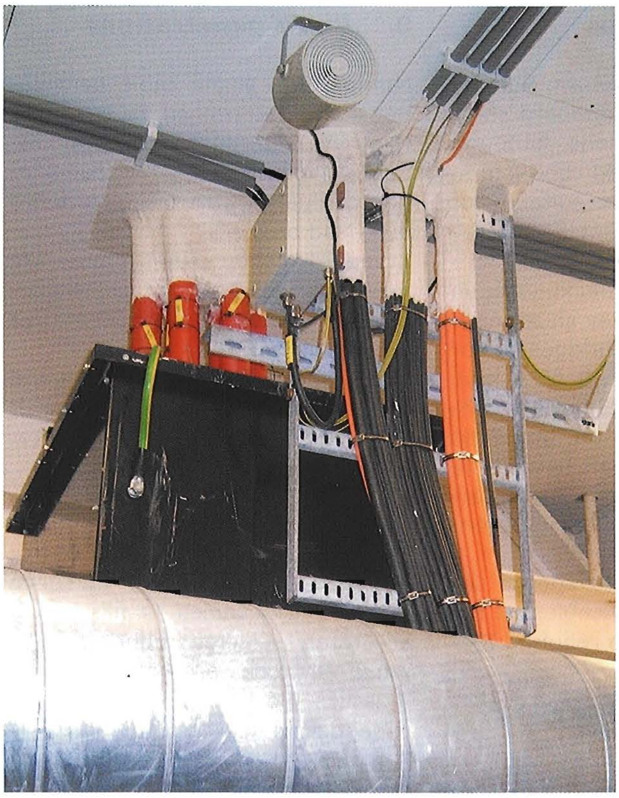
In any case, all cable tray types other than the ordinary steel types will be more expensive both for material and installation cost. When weight is an issue light weight cable trays made of a glass fibre reinforced composite material can be used. These types of cable trays are identified with FRP or GRP.

Cables are normally fixed with plastic bands, so-called Ty-raps, which should be of UV restinstant material when used outside. Steel cable bands are used when cables are mounted on vertical cable trays or when on the bottom side of overhead horizontal cable trays.

When single core or high voltage cables are involved special consideration should be given to the choice of materials. (non-magnetic, stainless steel)

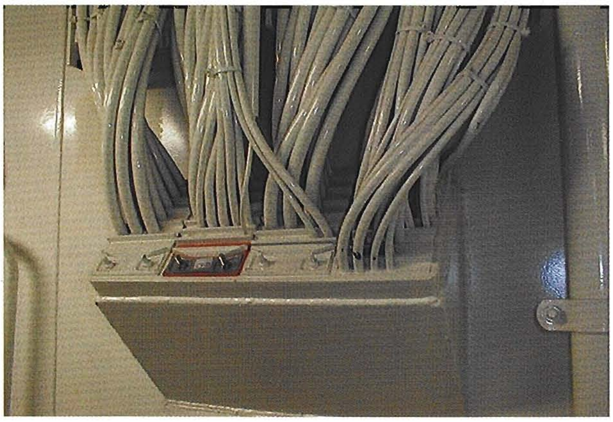
Maxium distances cable supports

External diametre of cable exceeding	not exceeding	Non-armoured cables	Armoured cables
mm	mm	mm	mm
–	8	200	250
8	13	250	300
13	20	300	350
20	30	350	400
30	–	400	450

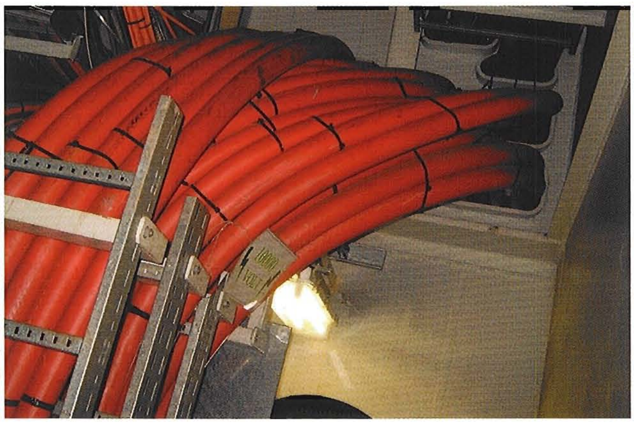


Additional fire protection by application of fire resistant coating (white covers at the top) around cables, passing through a fire-insulated deck.

Pipe and cable tunnel in a ship for heavy cargo



Watertight cable penetration (MCT, Multi cable transit)



High voltage cables

Minimum bending radia for fixed cables

Cable construction		Overall diametre of cable	Minimum internal radius of bend (times overall diametre of cable)
Insulation	Outer covering		
Thermoplastic and elastomeric 600/1000 V and below	Metal sheathed Armoured and braided	Any	6*D*
	Other finishes	≤ 25 mm > 25 mm	4*D* 6*D*
Mineral	Hard metal sheathed	Any	6*D*
Thermoplastic and elastomeric above 600/1000 V			
– single core	Any	Any	20*D*
– multicore	Any	Any	15*D*

6 High voltage cables

High voltage cables are slightly different, from a construction point of view.
Above 3kV HV cables have a radial field construction with an earthing screen between the cores and the outside insulation.
A radial distribution of field strength is obtained by making the transfer of field strength radially from the conductor to the insulation and from the insulation to the screens, by means of semiconductive layers and special installation parts. Radial means homogeneous field strength resulting in minimum electrical stresses.
High voltage cable must be tested after installation and on completion of termination.

The special installation parts consist of a shrink-on 3-pole sleeve that connects the cable lug on the core to the core semiconductive layer and the core shield to the semiconductive layer around the core insulation.

1. Round copper conductor
2. Semiconductive XLPE with semiconductive tape
3. XLPE core insulation
4. Semiconductive XLPE with semi conductive tape
5. Core shield with copper tape and copper round braiding
6. XLPE inner sheath
7. Galvanized steel wire braiding
8. Outer screen MBZH red.

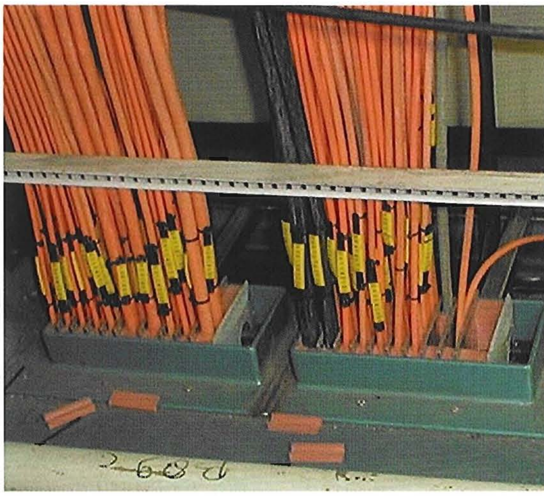
7 Flexible cables

Marine standard cables are suitable for fixed installation onboard ships and offshore installations. Although provided with stranded conductors, these cables are only suitable for fixed limited movement and at favourable temperatures.
A vertically moving deckhouse, in use on inland waterway ships, enabling passing under bridges or for proper lookout in case of a high cargo, requires special flexible conductors. The insulation materials and sheathing materials need to be of a more flexible type, in connection with the expected environmental conditions such as frost.
Additional attention to special cables, such as coaxial cables, is required to achieve the required lifetime.

Telescopic supported wheelhouse

8 Cable penetrations

Multiple and single cable penetrations are determined in a similar way. A watertight bulkhead requires a different type of penetration compared with those for a fire bulkhead or -deck.
Standard cable penetrations are A-60 fire resistant and are watertight up to a pressure of 50 metres water column.
They are readily available in several types, such as cast types, sealed with a suitable compound after completion of the installation.
Multicable transits (MCT's) use a steel frame that is welded or bolted in a deck or bulkhead. The cables pass this steel frame and the space between the cables is filled with accurately selected rubber blocks. When all blocks are fitted a larger pressure block is inserted that is expanded to seal the MCT.
This system allows opening of the cable transit and adding more cables at a later date.



Multiple glands with rubber sealing blocks

Radial field cable

Design Appraisal Document (or Certificate, depending on the Classification Society) is a statement that the Class has examined drawings or prescriptions of equipment (or an alteration) and that that has been approved for the intended use.

In this case it handles electric cables, intended to be used on board ships.

It declares that the cables are fabricated in accordance with the Rules for Steel Vessels (ships) and in accordance with the MODU Code, the Rules for Mobile Offshore and Drilling Units.

Also when a conversion to an existing, classed ship or offshore unit has to be carried out, which is subject to Class approval, such a statement has to be issued after examination and approval of the drawings which in such a case have to be submitted for approval.

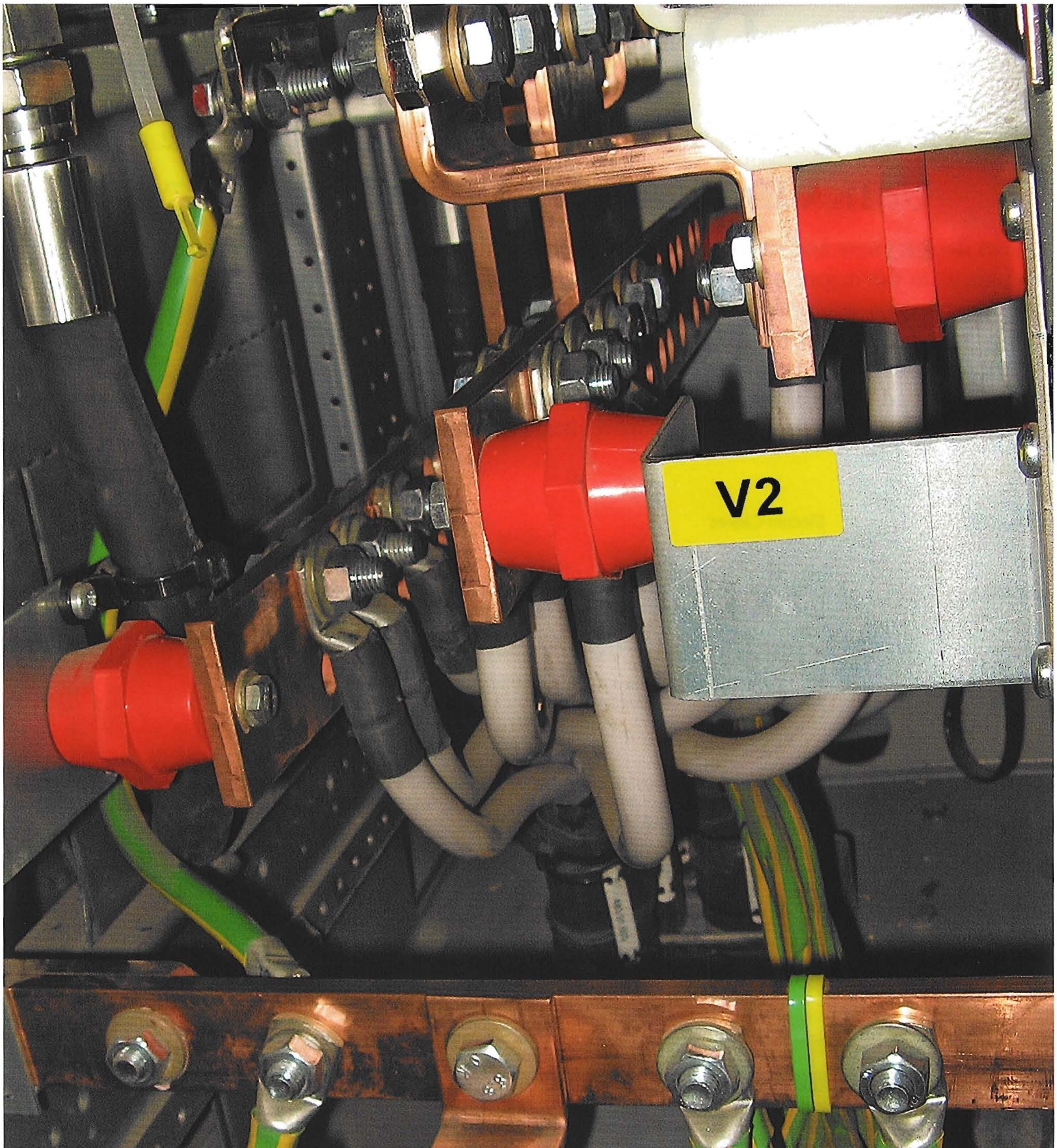
Subject to, approval are changes to the ships construction or to all equipment which is part of power generation, propulsion, watertight integrity, as far as this is described in the Classification Rules and Regulations or by SOLAS.

SOLAS is in principle a Flagstate matter, but is by many countries delegated to Class.

Often the relevant drawings are provided with comments, which the local surveyor, during approval at the location of the conversion has to check.

These comments are in such case written on the DAD.

The local surveyor refers to the particular DAD in his report on completion of the work.



ABS

CERTIFICATE NUMBER

07-PR286193-PDA

DATE

02 November 2007

ABS TECHNICAL OFFICE

Piraeus Engineering Services

CERTIFICATE OF
Design Assessment

This is to Certify that a representative of this Bureau did, at the request of

UNIKA UNIVERSAL KABLO SAN. VE TIC A.S.

assess design plans and data for the below listed product. This assessment is a representation by the Bureau as to the degree of compliance the design exhibits with applicable sections of the Rules. This assessment does not waive unit certification or classification procedures required by ABS Rules for products to be installed in ABS classed vessels or facilities. This certificate, by itself, does not reflect that the product is Type Approved. The scope and limitations of this assessment are detailed on the pages attached to this certificate. It will remain valid as noted below or until the Rules or specifications used in the assessment are revised (whichever occurs first).

PRODUCT: Electric Cables

MODEL: U-HF m, U-HFA m, U-HFA m EMC, U-HFFR m, U-HFFRA m, U-HFAT m, U-HFAT m (I), U-HFAT m (C), U-HFAT m (I+C), U-HFFRAT m, U-HFFRAT m (I), U-HFFRAT m (C), U-HFFRAT m (I+C).

ABS RULE: 2007 Steel Vessels Rules 1-1-4/7.7, 4-8-3/9.1, 9.3, 9.5, 9.9.
2006 MODU Rules 4-3-4/13.1.

OTHER STANDARD: IEC 60092-353 (1995-01 as amended by Amendment 1 of 2001-04), 60092-375 (1977-01), 60092-376 (2003-05), 60228 (2004-11), 60092-350 (2001-06), 60092-351 (2004-04), 60092-359 (1999-08), 60331-21, 60331-31, 60332-3, 60811.;

AMERICAN BUREAU OF SHIPPING

Ion G. Koumbarelis
Engineering Type Approval Co-ordinator

AMERICAN BUREAU OF SHIPPING
PIRAEUS OFFICE

AB258(07/03)

NOTE: This certificate evidences compliance with one or more of the Rules, Guides, standards or other criteria of American Bureau of Shipping or a statutory, industrial or manufacturer's standard and is issued solely for the use of the Bureau, its committees, its clients or other authorized entities. Any significant changes to the aforementioned product without ABS approval will result in this certificate becoming null and void. This certificate is governed by the terms and conditions on the reverse side hereof.

9 Cable connections

A vital part of the electrical installation are the cable connections as these make the real connections between the various parts of the systems.

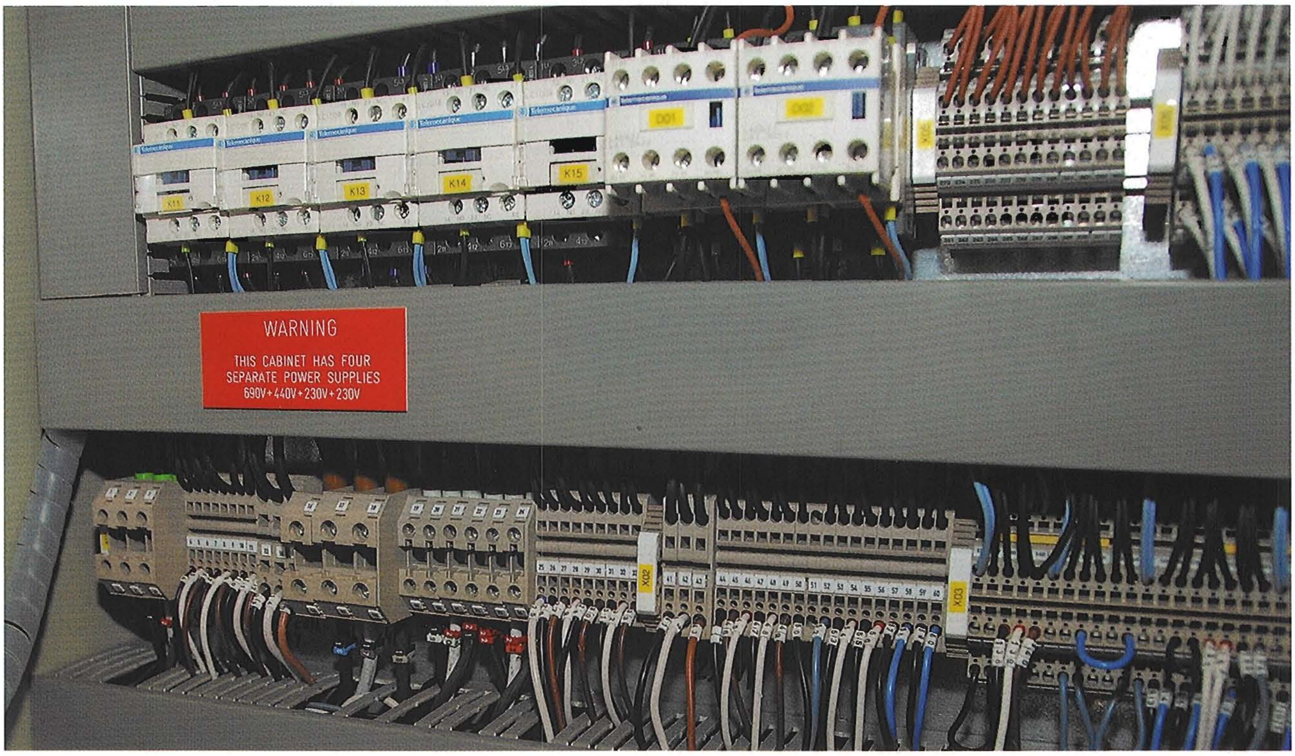
Cable connections come in all shapes and sizes to suit every possible type of connection like for example:
- High voltage power cables
- Low voltage power cables
- Multicore cables
- Coaxial cables
- Fibre optic cables
- Network cables

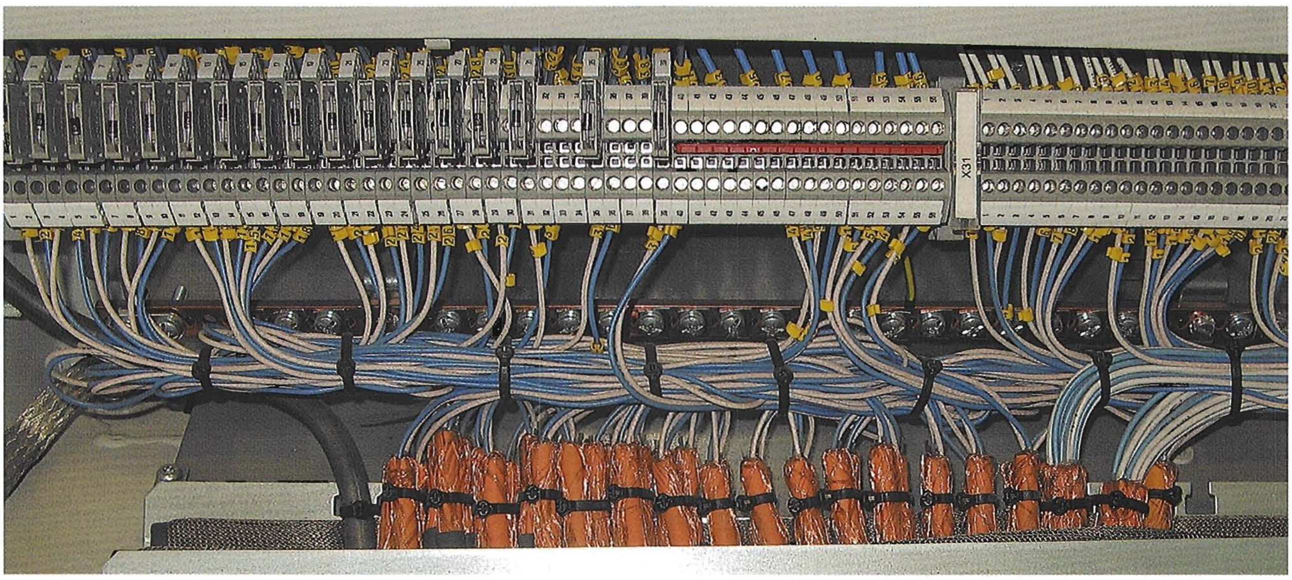
Every type of connection has its own specific requirement and there are large specialist companies, who have developed and produced a whole range of cable connections. One development is the push-in terminal (PIT) for control cables which does away with the screws and saves connection time.

Power connections, both for high and low voltage, are most critical especially when these are for large currents.

When these connections are not made with the correct cable lugs for the wire-cross section and crimped with the right tool the connection may be loose.
A loose connection has a higher resistance which generates heat which eventually can lead to a fire.

This also applies to the bus bars in switchboards.
The nuts and bolts that secure the bus bars must be tightened with a torque wrench set at the correct threshold.

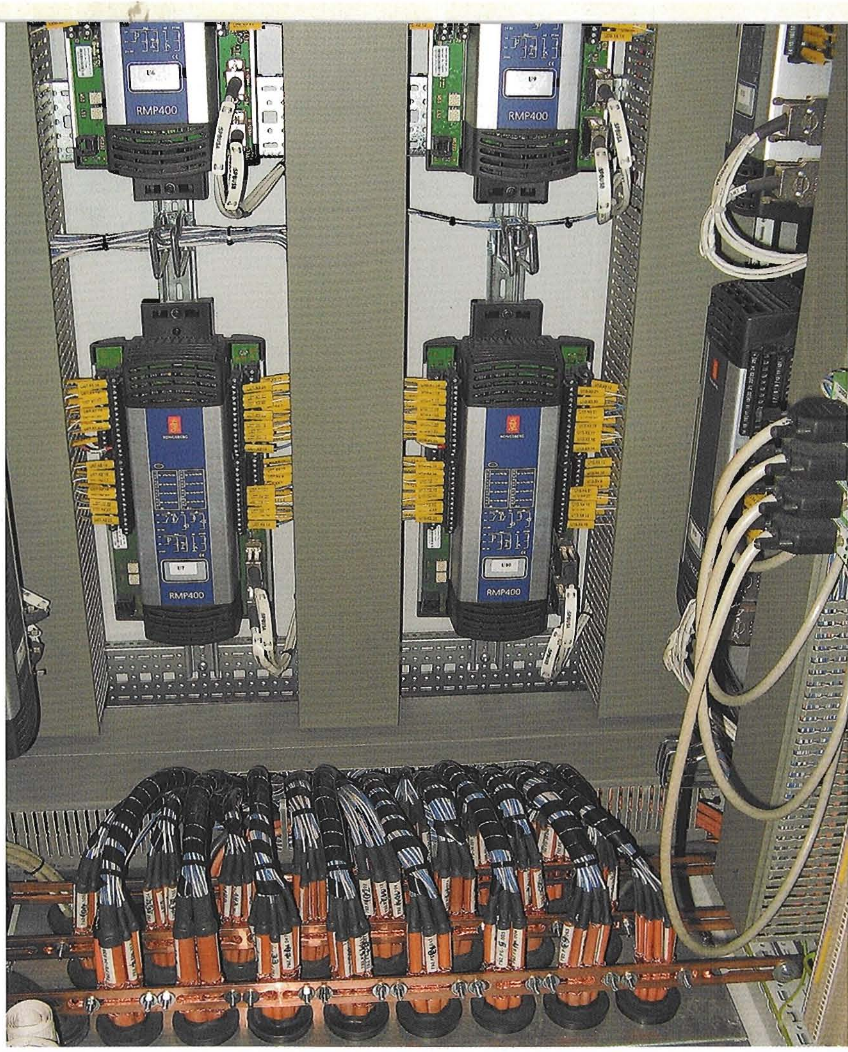




19. AUTOMATIC CONTROL SYSTEMS

Automation helps the crew to operate the systems on board easier and safer.
It will execute actions which are too complicated for the crew to handle in a given time.

Automation allows automatic observation of systems, registration of failures, registration of service time and planned maintenance.
Detailed requirements for Automatic Control Systems on board of ships are described in IEC publication 60092-504 Control and instrumentation.



Field I/O panel of a distributed automation and control system.

1 Automation

The level of automation depends on a number of factors:
- requirements of the owner
- function of the ship
- cost
- complexity of the installation
- rules and regulations of the classification society and the Flag State (registry)

First of all a cost/availability analysis has to be made before planning automation.

Integration of systems and the introduction of distributed control systems is an ongoing process.
It reduces cost of cabling and manning.
The only problem is that the rules and regulations of both the classification societies and those of the national authorities cannot keep up with this everchanging process.
Such a control system can consist of programmable logic controllers with remote input and output modules, connected through a two wire bus system and operated/supervised from a PC type workstation through an operator-friendly SCADA software package.
Redundancy both in hardware and software is a logical requirement for automatic systems.

Software must be well-structured and tested as per class standards.

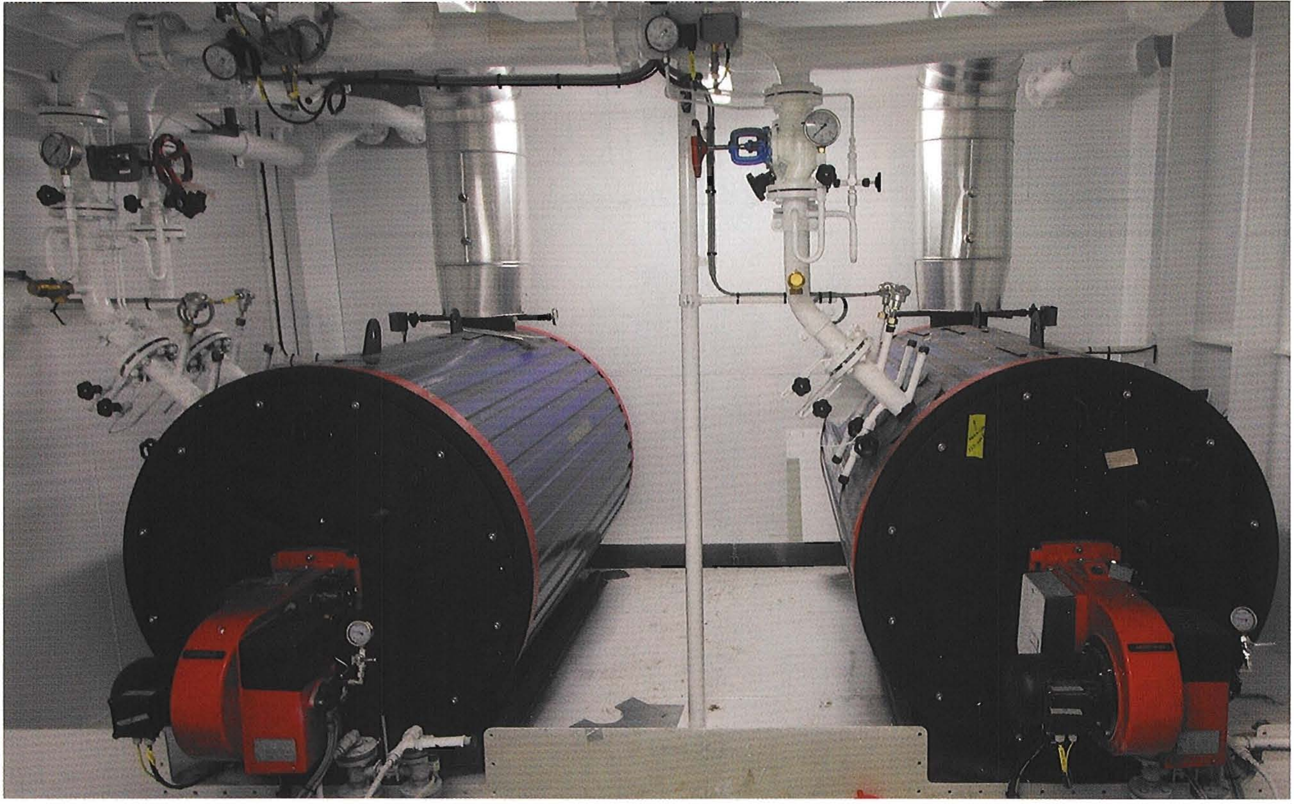
Essential systems required for sailing and comfort of the crew must have sufficient back-up or emergency controls.

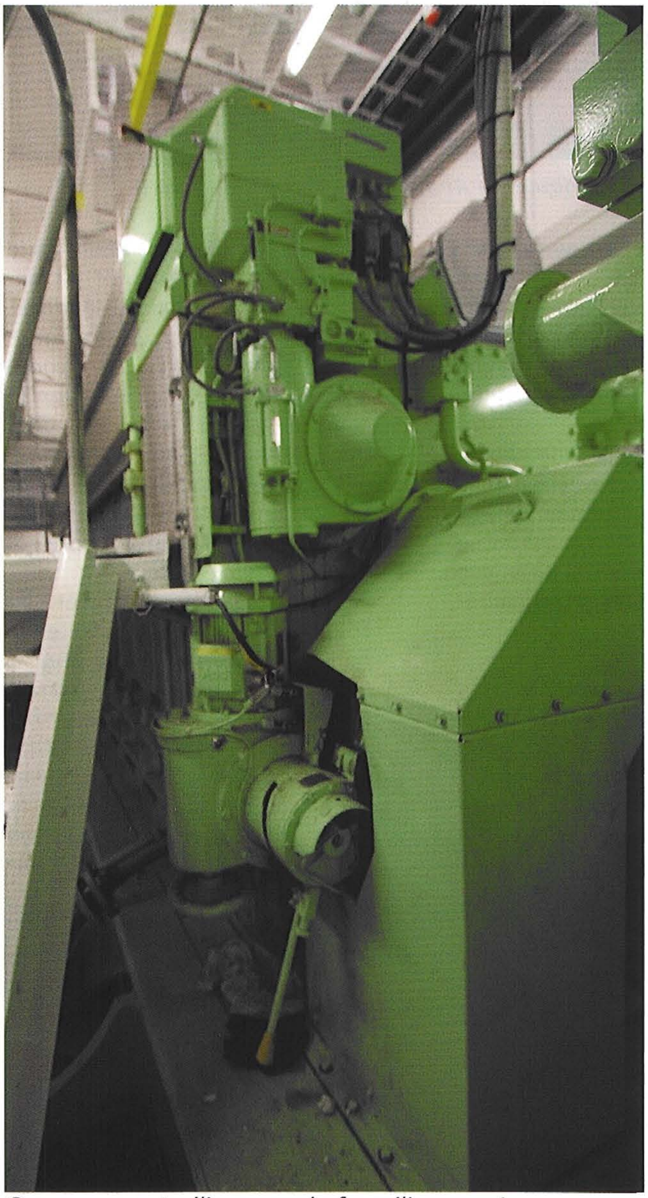
1.1 More advanced systems

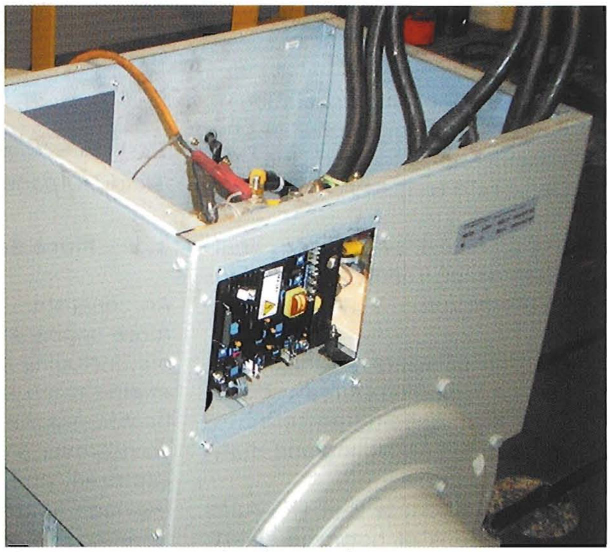
An operator workstation makes more sophisticated systems possible, including control and display of engine room systems with sophisticated graphics.
Trends over a period of time can be captured. Analyses of relationships between figures can be calculated.
Running hours and the required automatic logging of all figures can be stored, along with many other statistics.

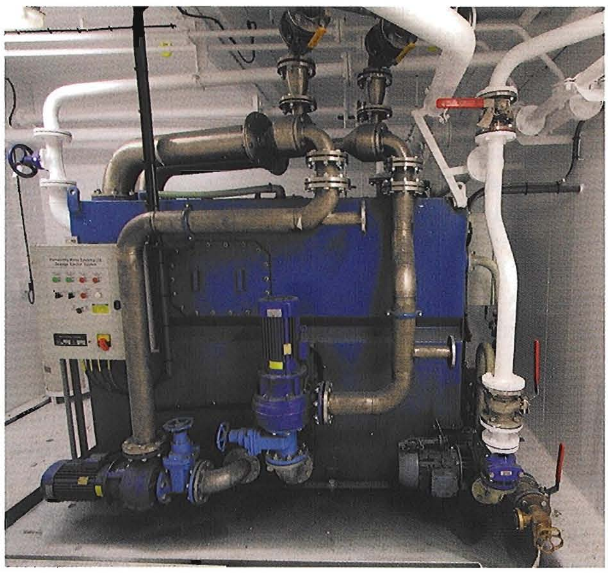
Some examples of systems that can be part of an automatic control system are:
- **Tank gauging system**
  From the simple, such as providing liquid heights to the more sophisticated, giving tank contents in m^3 or even in tons.
- **Reefer monitoring system**
  From failure alarms to complete data logs of the reefer's temperature and CO_2 content throughout the voyage, which can prove that cargo is not damaged due to transport.
- **Generator control and power management system**
  From minimum automatic starting of a standby generator in case of generator failure and sequential restarting of all essentials to a complete load-dependent start-stop of the generator plant. In this case, there is automatic power reduction in case of generator failure, until the standby generator is started, has been synchronised, put on-line and has taken the load.
- **Propulsion remote control system**
  From straight forward remote control systems where each handle controls a single engine or propeller to state-of-the-art systems which can make a ship move 25 metres to port, rotate with the stern as rotating point over 90° to port, follow track or a link in location, adjust speed in accordance with available water depth.

In automation there are no technical limits and therefore, a balance between expected results and cost has to be found.
Essential automation systems must be composed of type-approved equipment and are subject to an acceptance test at the manufacturer's under conditions as real as possible.


Two automatic boilers


Governor controlling speed of auxiliary engine


Generator connection box with automatic voltage regulator cover open


Automatic sewage plant

2 Local control systems

Some equipment has a dedicated local control system which is separated from the central automation system.
Most of the time these local control systems exchange some parameters with the central automation system. Examples are:

- Basic engine room alarm and monitoring system, consisting of simple displays giving status and analogue values of essential parameters as required by class.
- Local self-contained small automatic systems controlling lubricating oil temperatures and high and low water temperatures of propulsion and auxiliary diesel engines.
- Local automatic voltage regulators for generators, controlling the voltage.
- Local governors on engines, controlling engine speed.
- Local standby starters for duplicated essential auxiliaries.
- Local automatic boilers
- Local automatic sewage plant.

3 Essential services

Essential services are those services required for sailing and keeping the ship in a habitable condition.

Electric power required for propulsion can be supplied by a single generator set or by more sets in parallel. When supplied by a single generator, failure of this generator set should start a second generator. This generator should automatically be connected to the switchboard followed by automatic restart of all essential auxiliaries.
A sequential start system may be required to limit the step load to the diesel engine.

Essential services include:

- Main and emergency lighting
- Propulsion engine lubricating oil pumps (if not engine driven)
- Propulsion engine freshwater pumps (if not engine driven)
- Propulsion engines seawater pumps (if not engine driven)
- Fuel oil booster pumps
- Gearbox lubricating oil pumps
- Controllable pitch propeller hydraulic pumps
- Steering gear hydraulic pumps
- Start air compressors
- Engine room fans

On ships sailing on heavy fuel oil, fuel oil circulating pumps, thermal oil circulating pumps and a thermal oil boiler are essential and must automatically restart.

When the electric power required for propulsion is supplied by more generators in parallel, an automatic load shedding system must be fitted.
This system reduces the load immediately to the capacity of the remaining generator(s) after failure of one generator.

When large motors with frequency drives are installed the control system can be programmed to reduce the speed of the motors when the generators are close to be overloaded.
A complete shutdown of these motors is then not required and when enough power is available again the motors can be set to the original speed.

Sequential restart timing priority:

- Instantaneous main and emergency lighting
- After 5 seconds, lubricating oil pumps, engines and gearboxes and fuel oil pumps and thermal oil system and pumps
- Steering gear pumps and controllable pitch propeller pumps
- Freshwater pumps and air compressors
- Seawater pumps
- In about 30 seconds, all auxiliaries are back in service and propulsion engines can be restarted

When auxiliaries are engine driven and the engines can be started without lubricating oil pressure, this process is simpler.

4 Failure mode and effect analysis

The Failure Mode and Effect Analysis is an appraisal of the result of a failure of equipment on the operation of a ship (or any other type of equipment).
This study is compulsory for units which have to fulfill the requirements of the MODU Code.
The MODU Code is one of the IMO Codes, especially drawn up for offshore equipment. MODU stands for Mobile Offshore Drilling Unit.
Originally for drilling equipment only, but later made a requirement for offshore equipment in general.
FMEA is not limited to the automation of electrical systems but covers all systems required for propulsion of a ship and all components.
The following example of an FMEA covers the layout, the auxiliary systems and the electrical installation of a large pipe lay vessel with the following main characteristics:

- 6 main generators each 3360kW
- Thrusters forward, two retractable azimuth thrusters each 2400kW, one tunnel thruster 2200kW
- Three azimuth thrusters each 2900kW aft
- Class notation Lloyd's Register +100A1, +LMC, UMS, DP(AA) equal to class 2.

The class notation DP(AA) or class 2, requires that a single failure does not result in loss of position of the vessel. Flooding or fire of a space is not considered in this notation.
The ship is designed for dual fuel but marine gas oil is used during DP operation with heavy fuel only for long passages or between jobs.

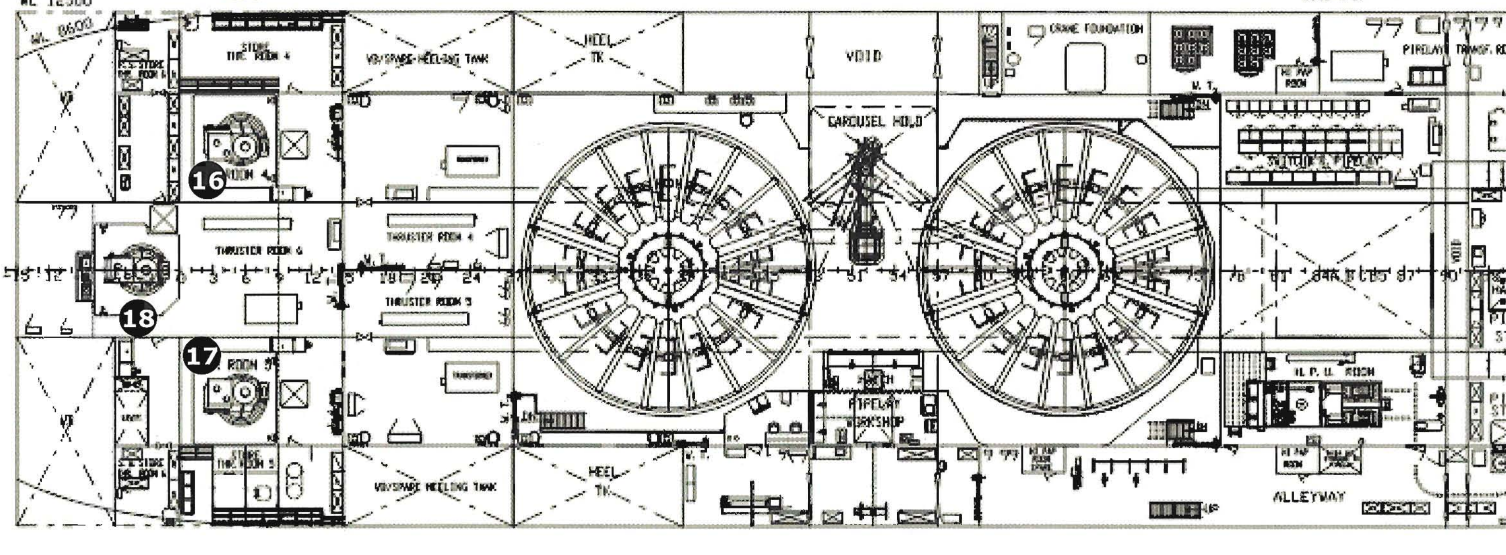
An FMEA addresses the items:

1. Layout of the vessel, location of main components, such as diesel generators, switchboards, transformers, converters and thrusters.
2. Compressed air systems
3. Cooling water systems
4. Fuel oil systems
5. Freshwater system
6. Seawater system
7. Thruster control system
8. Electric main distribution system

On the following pages the general layout and the various systems are depicted.

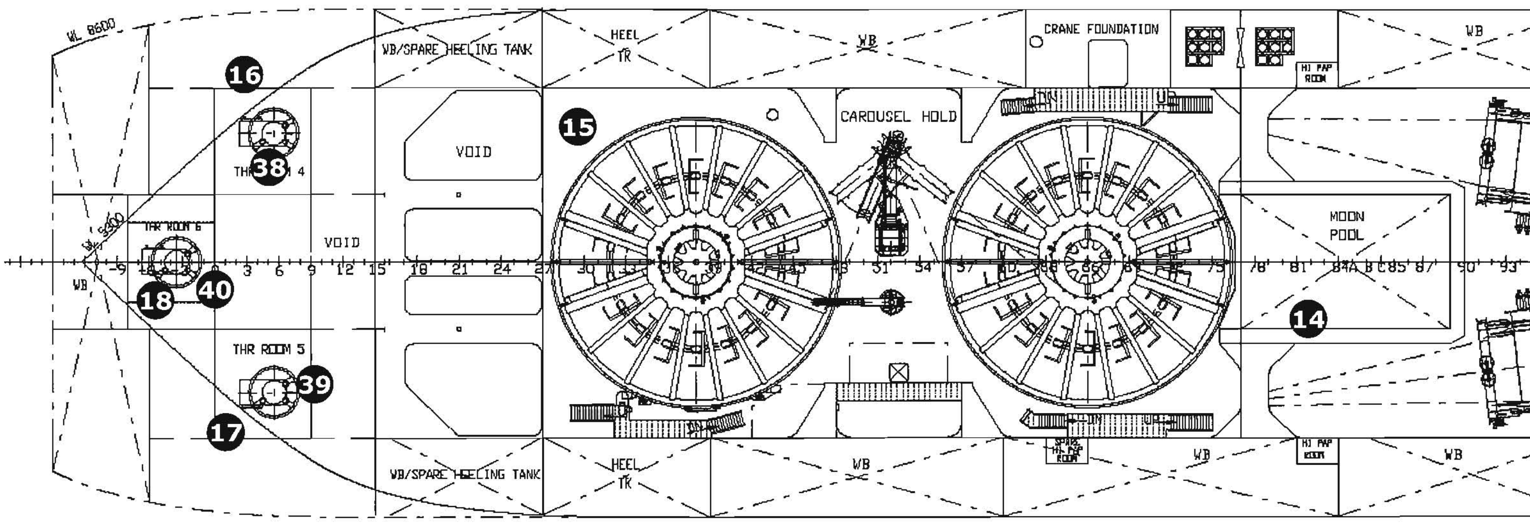
DECK 3 (UPPER TWEENDECK

8600 A. B.



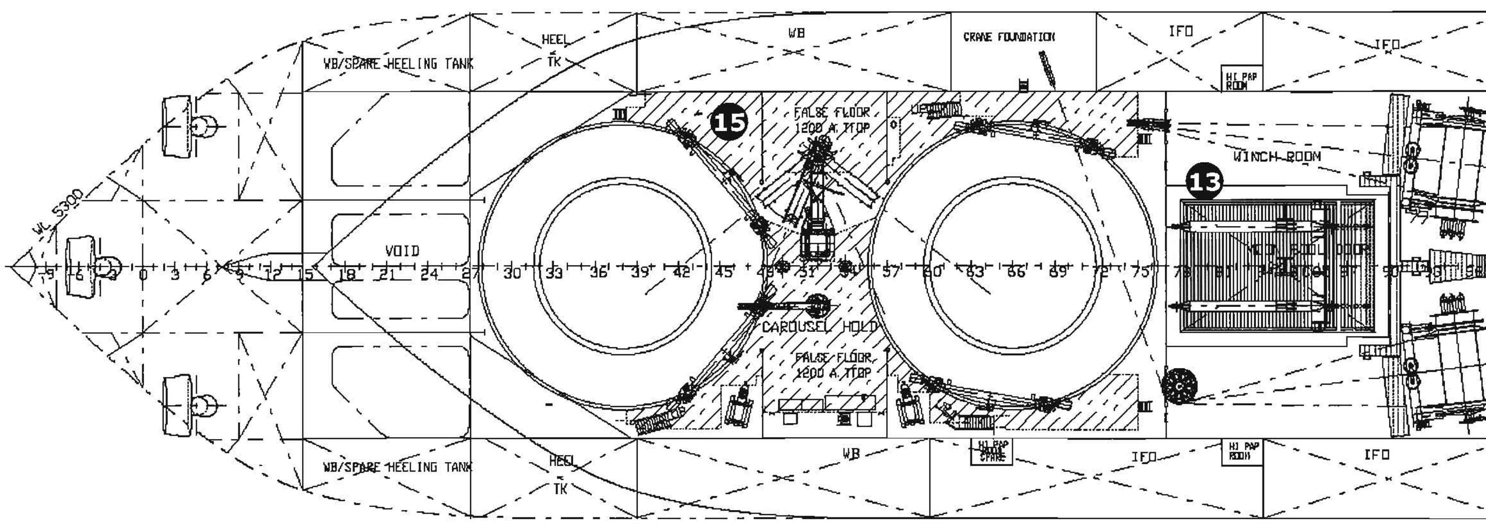
DECK 2 (LOWER TWEENDECK)

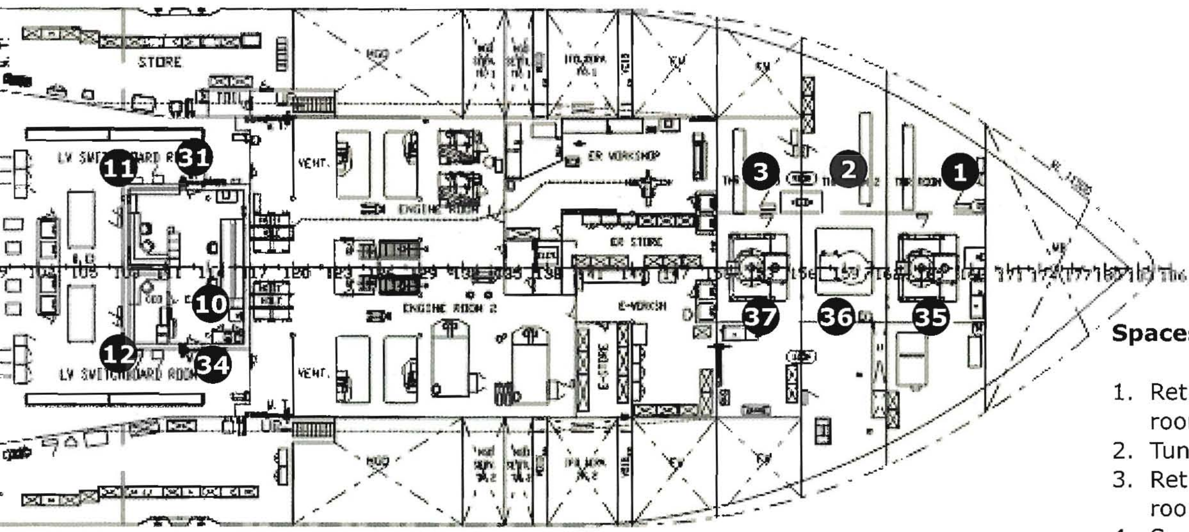
5300 A. B.

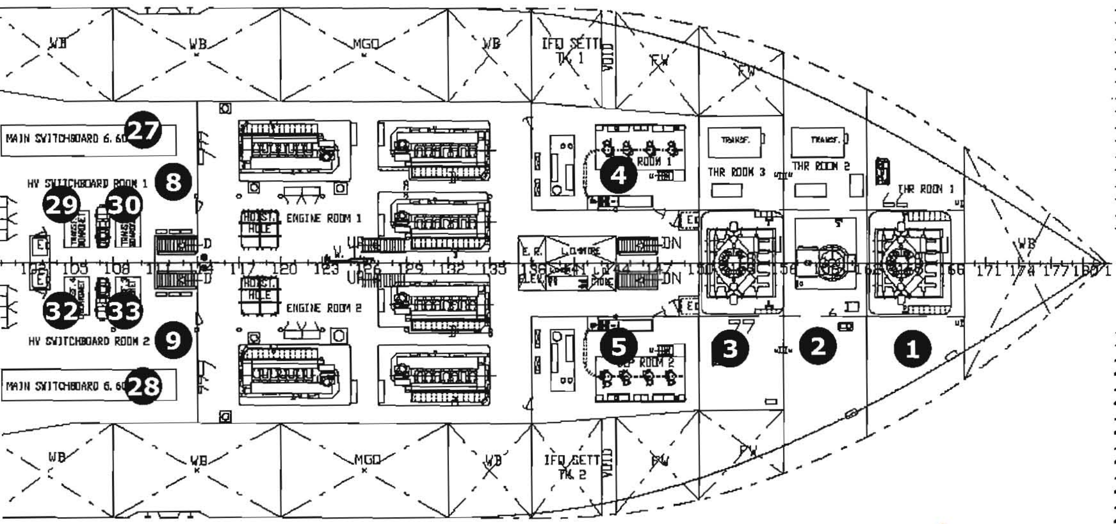


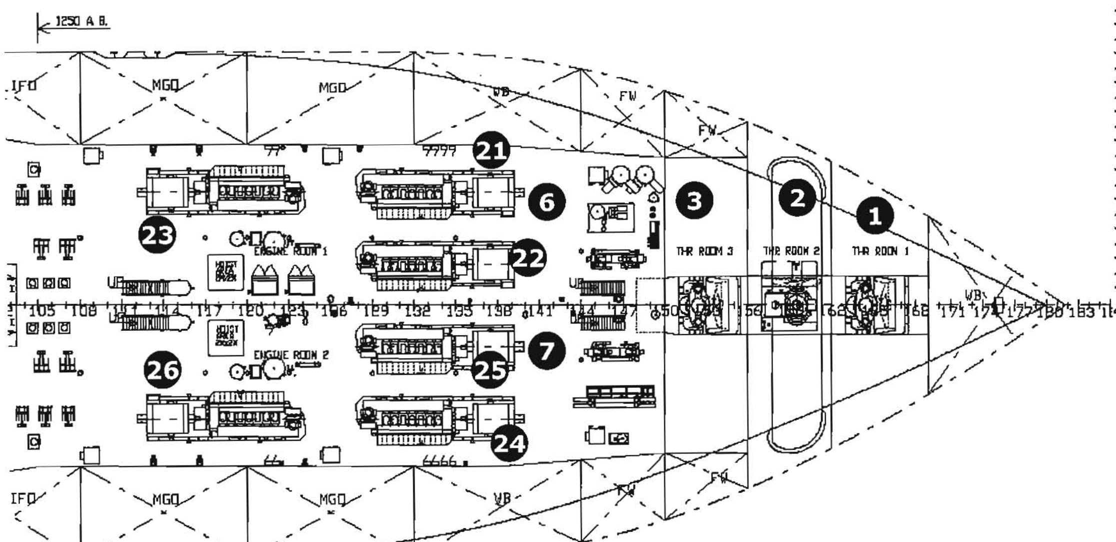
DECK 1 (TANKTOP)

1250 / 1475 A. B.



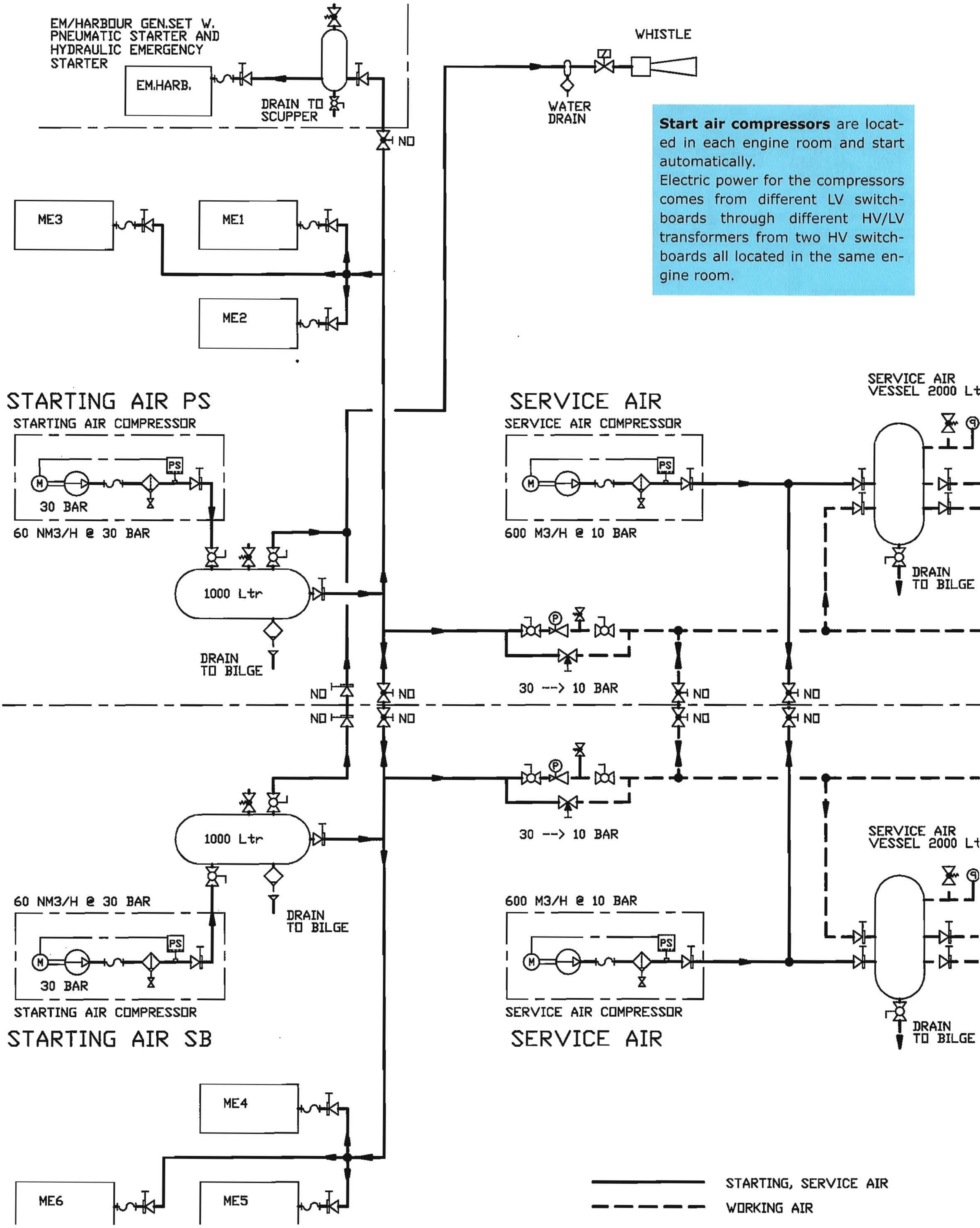






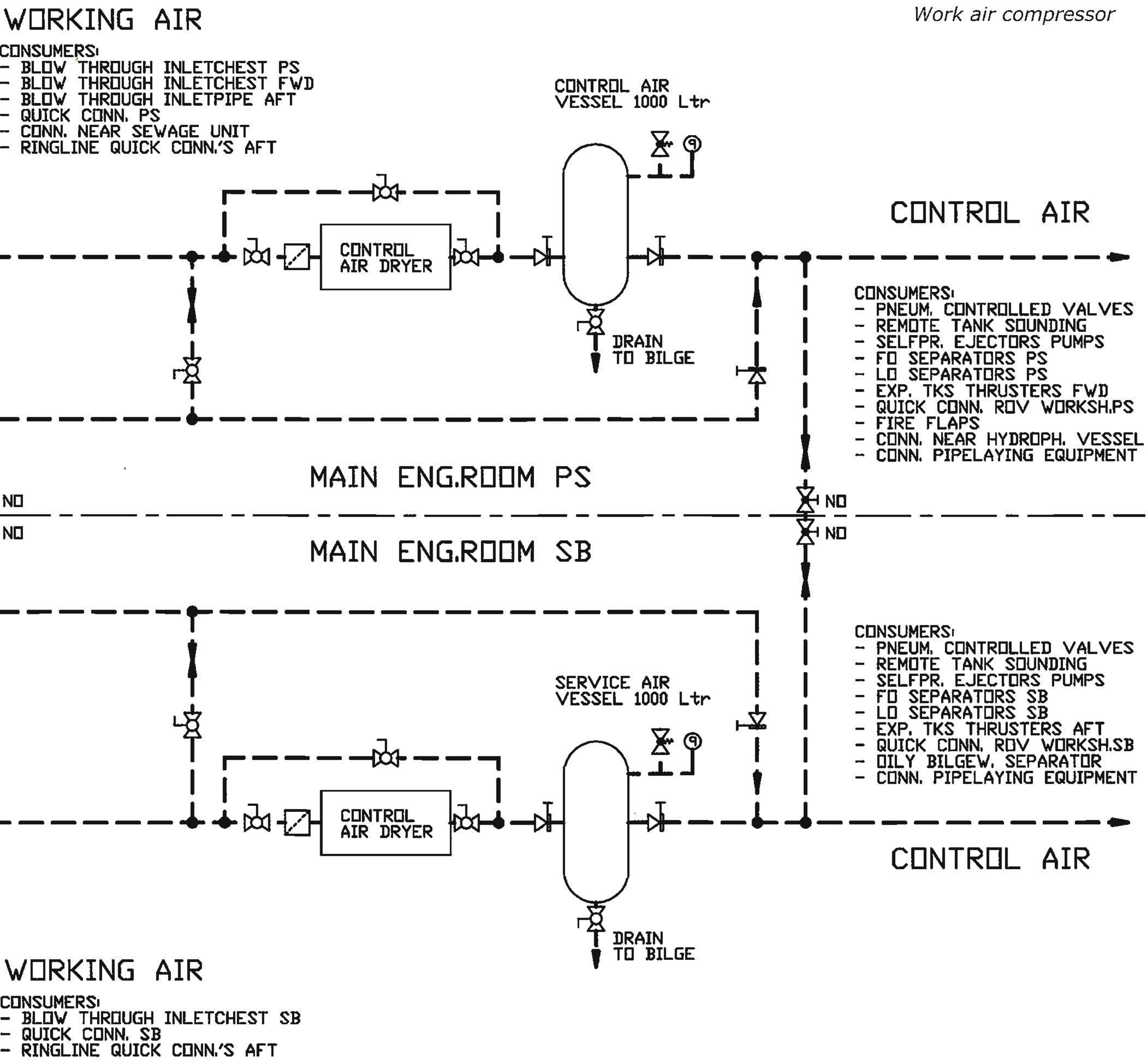
Spaces / equipment

1. Retractable azimuth thruster room 1
2. Tunnel thruster room 2
3. Retractable azimuth thruster room 3
4. Separator room 1
5. Separator room 2
6. Engine room PS 1
7. Engine room SB 2
8. HV Switchboard room 1 (PS)
9. HV Switchboard room 2 (SB)
10. Engine control room
11. LV switchboard room 1 (PS)
12. LV Switchboard room 2 (SB)
13. Winch room
14. Moonpool
15. Caroussel hold
16. Azimuth thruster room 4 (PS)
17. Azimuth thruster room 5 (SB)
18. Azimuth thruster room 6 (CL)
19. Not used
20. Not used
21. Diesel generator 1
22. Diesel generator 2
23. Diesel generator 3
24. Diesel generator 4
25. Diesel generator 5
26. Diesel generator 6
27. HV switchboard 1 (PS)
28. HV switchboard 2 (SB)
29. HV/LV transformer 1 (PS)
30. HV/LV transformer 2 (PS)
31. LV switchboard 1 (PS)
32. HV/LV transformer 3 (SB)
33. HV/LV transformer 4 (SB)
34. LV switchboard 2 (SB)
35. Azimuth thruster 1
36. Tunnel thruster 2
37. Azimuth thruster 3
38. Azimuth thruster 4 (PS)
39. Azimuth thruster 5 (SB)
40. Azimuth thruster 6 (CL)

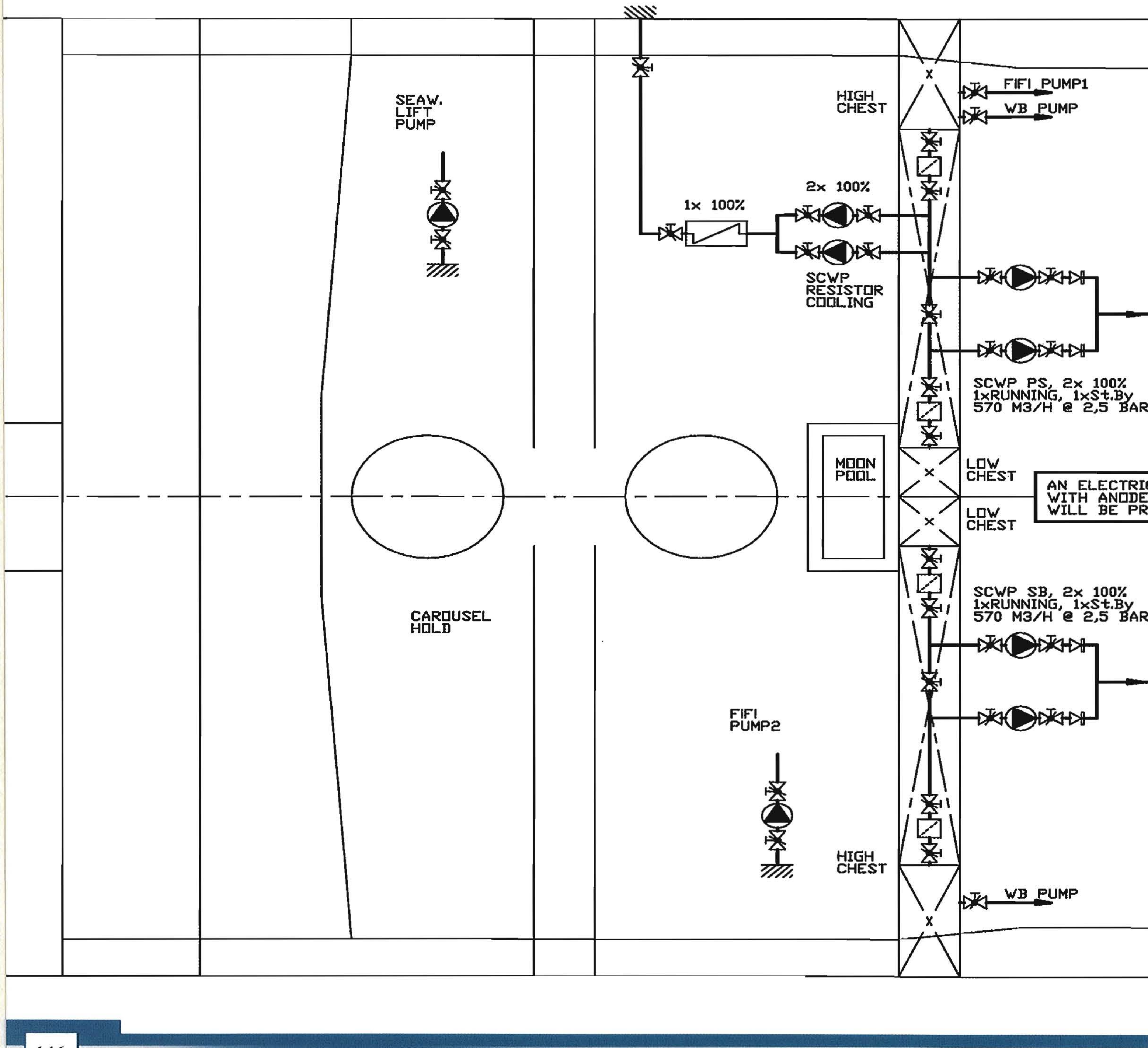


Start air compressors are located in each engine room and start automatically.
Electric power for the compressors comes from different LV switchboards through different HV/LV transformers from two HV switchboards all located in the same engine room.

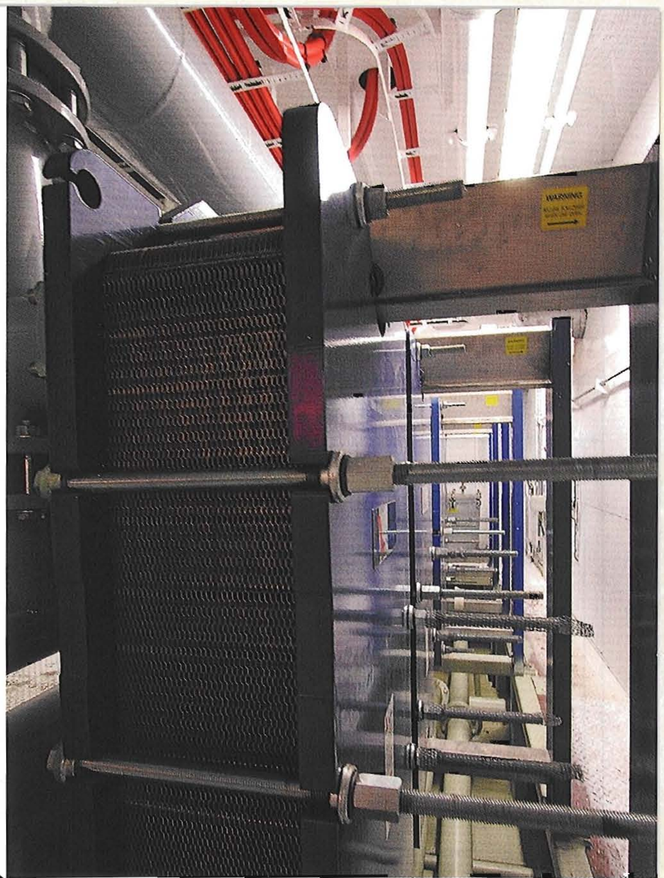
Work air compressor



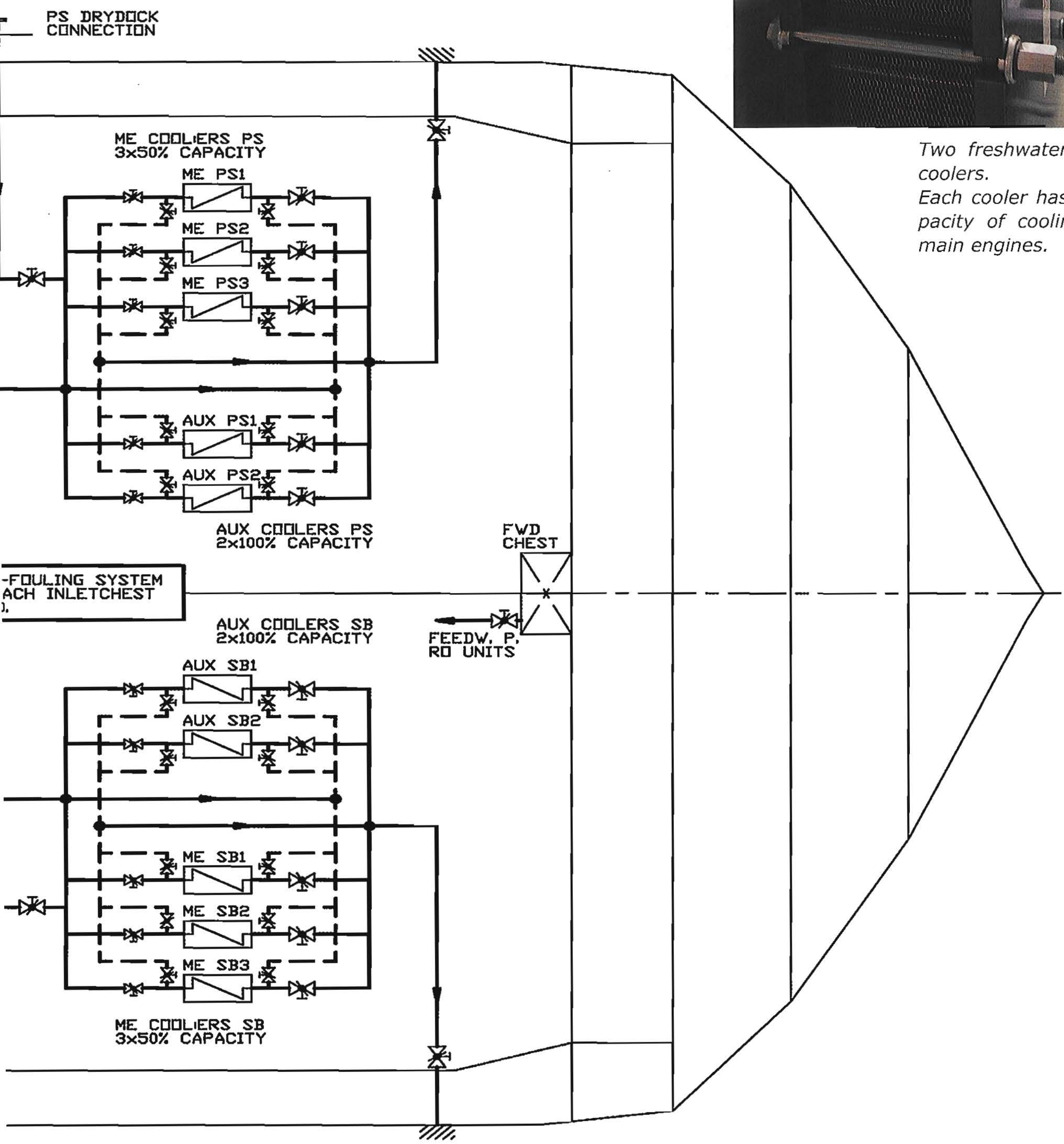
Two sea water cooling pumps.

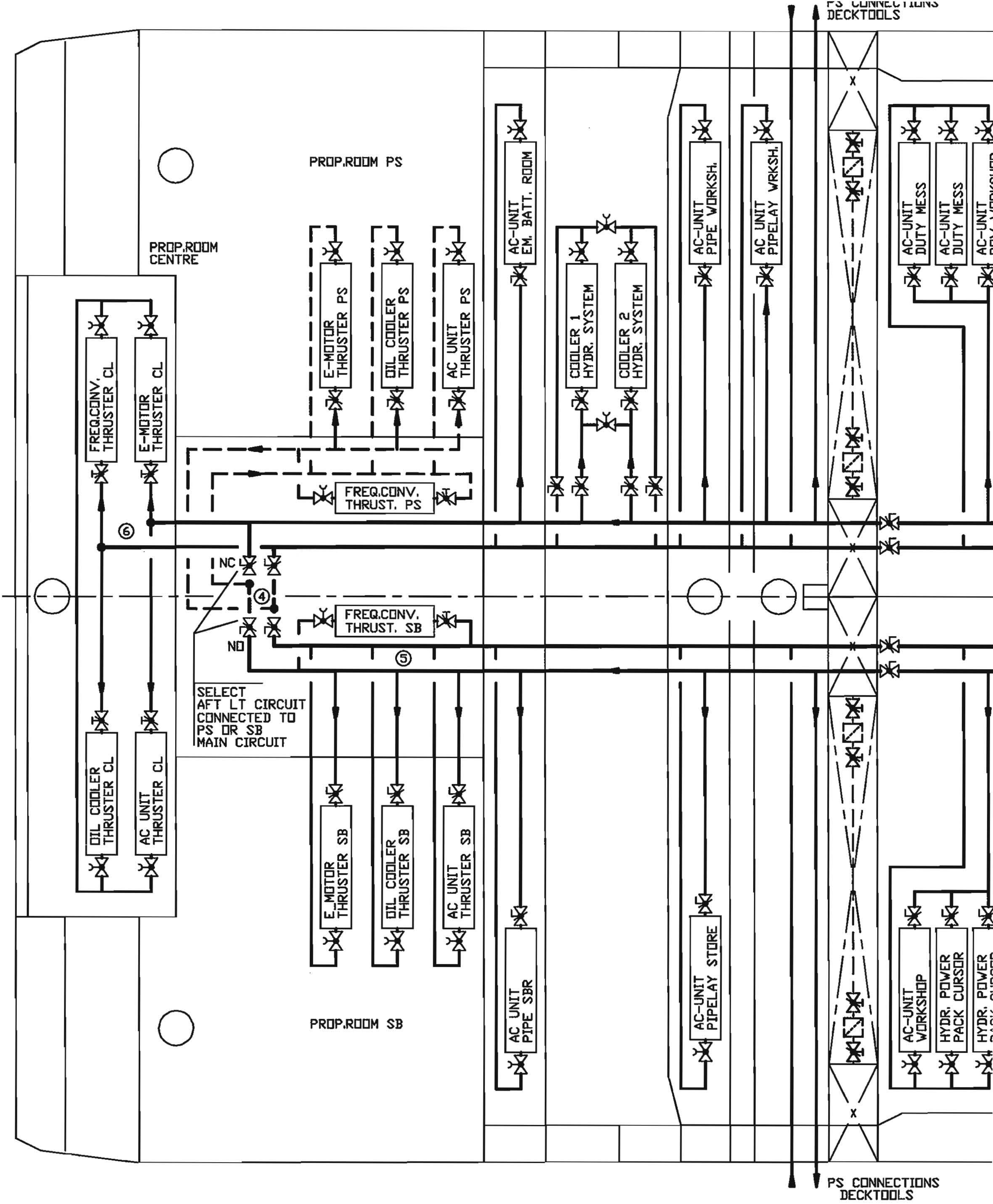


The seawater system consists of two pumps provided with an automatic standby starting system. Failure of a running pump will cause automatic starting of the standby pump.
Each seawater system supplies cooling water to the individual heat exchangers of the main generator sets in that engine room as well as cooling water to the two heat exchangers serving the freshwater system.



Two freshwater cooling coolers. Each cooler has the capacity of cooling three main engines.

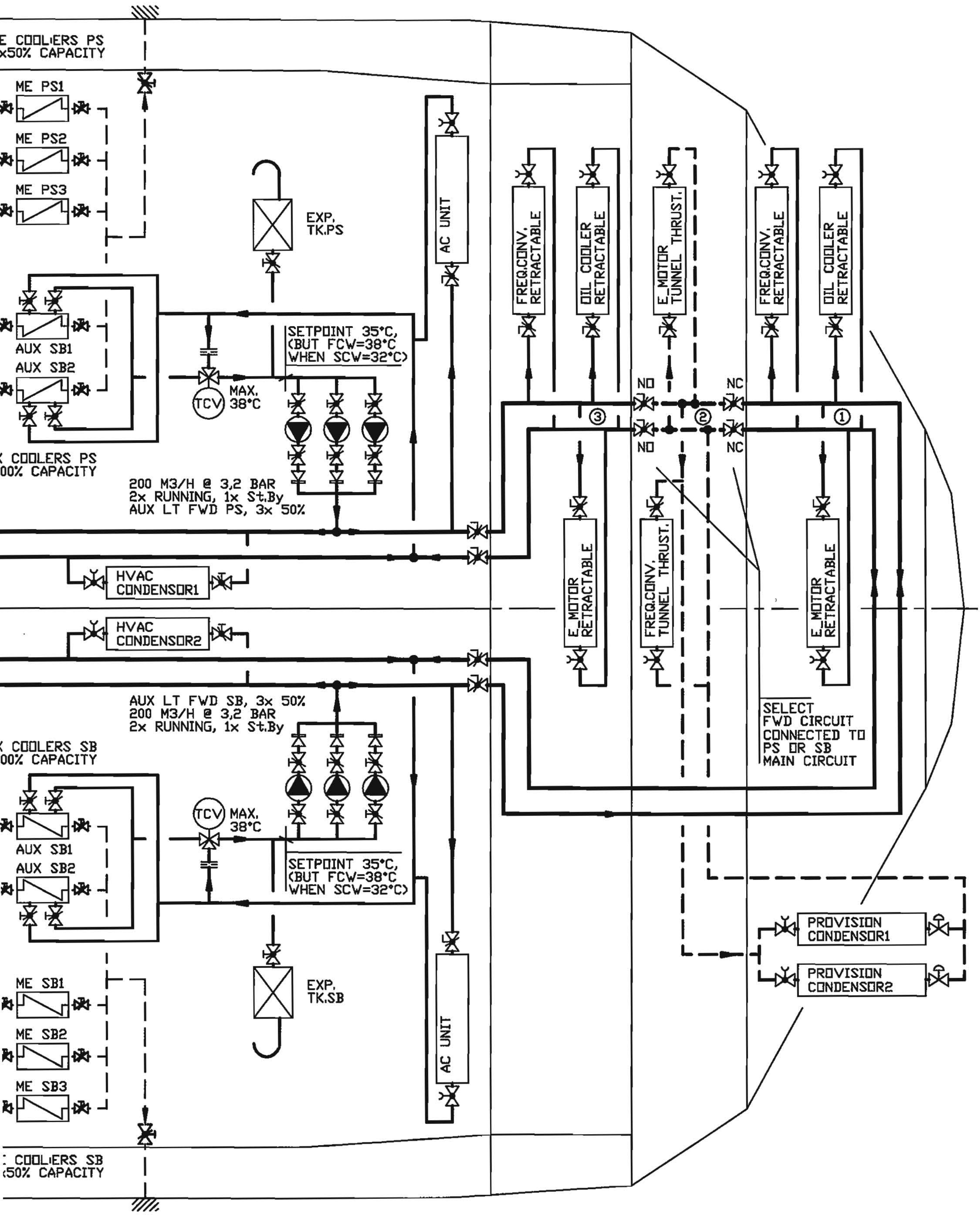




PS OR SB MAIN LOOP

SWITCHABLE TO PS OR SB

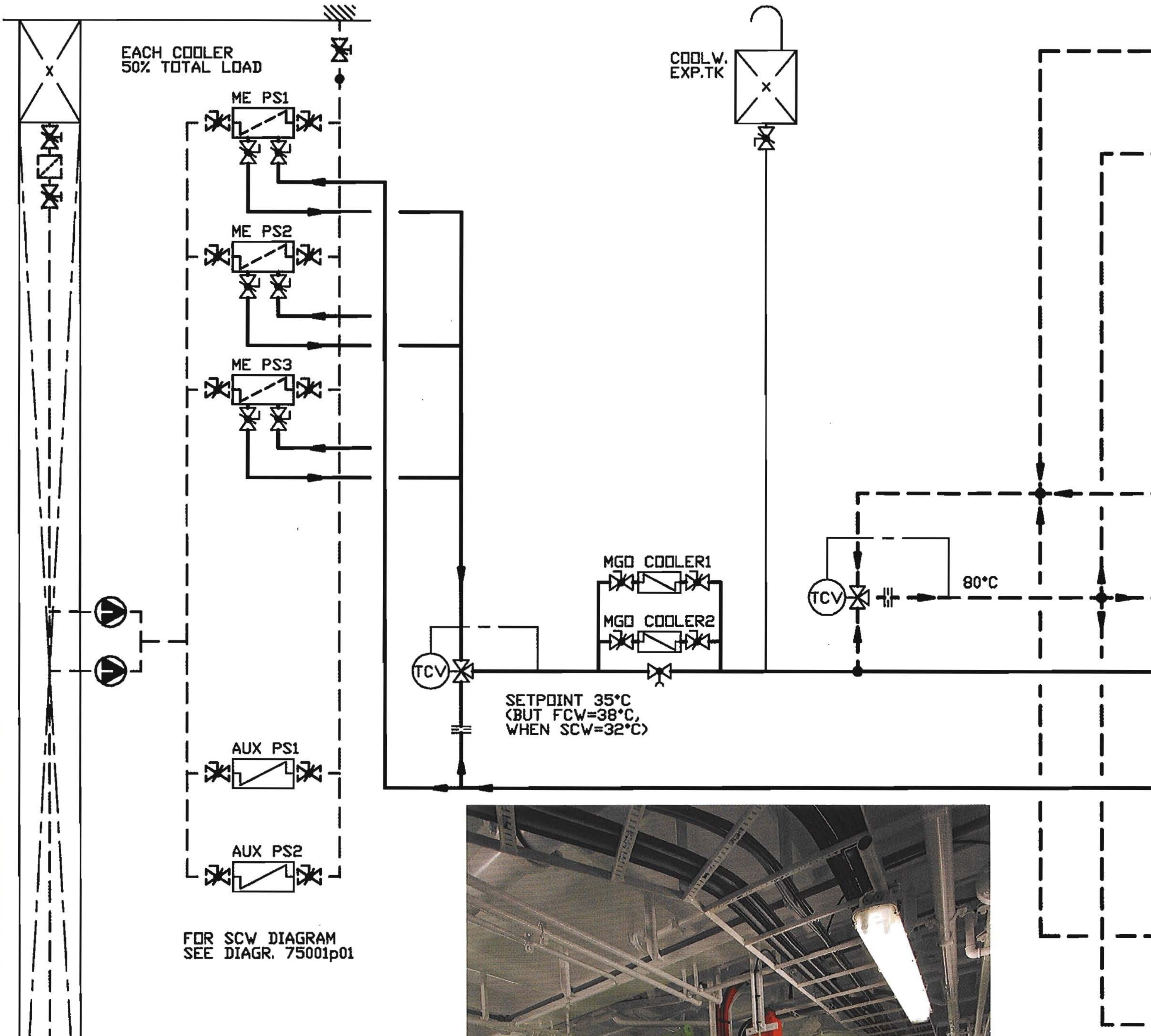
NOTE: THE DIVISION OF THE MAIN PS CIRCUIT, MAIN SB CIRCUIT, AFT CIRCUIT AND FWD CIRCUIT IS ALSO DETERMINED BY THE DIVISIONS OF THE ELECTRICAL POWER DISTRIBUTION SYSTEM.

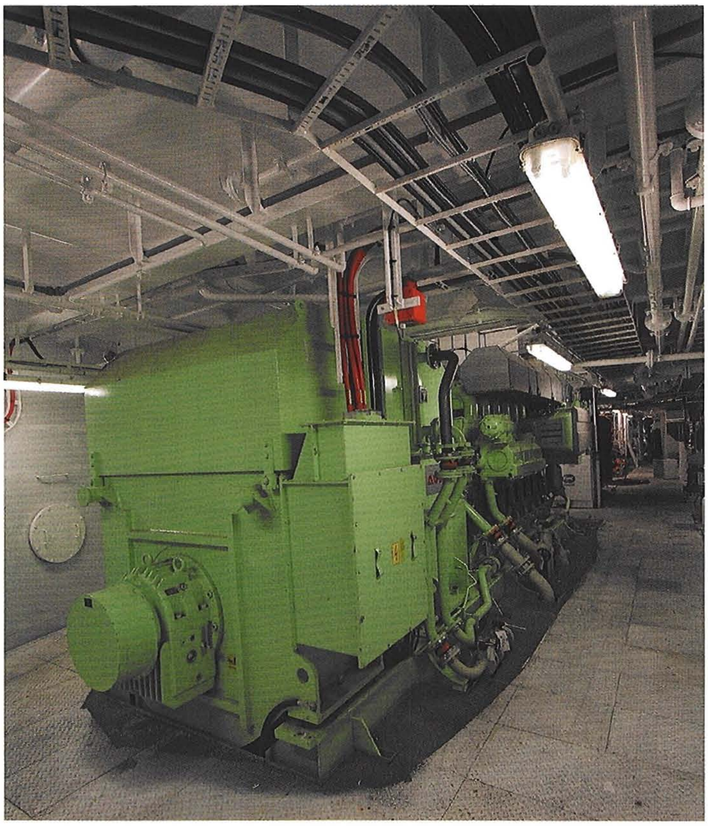


The freshwater service system is executed per engine room each with 3 50% pumps supplied from switchboards. The pumps are provided with an automatic standby starting system that starts the third pump when one of the two running pumps fails. The freshwater service system is also used for the thruster cooling systems.

The thruster cooling circuits are arranged in the same way as the electric power circuits for the thruster motors. Thus, thruster 4 which is powered by the SB switchboard has freshwater cooling from the SB engine room.

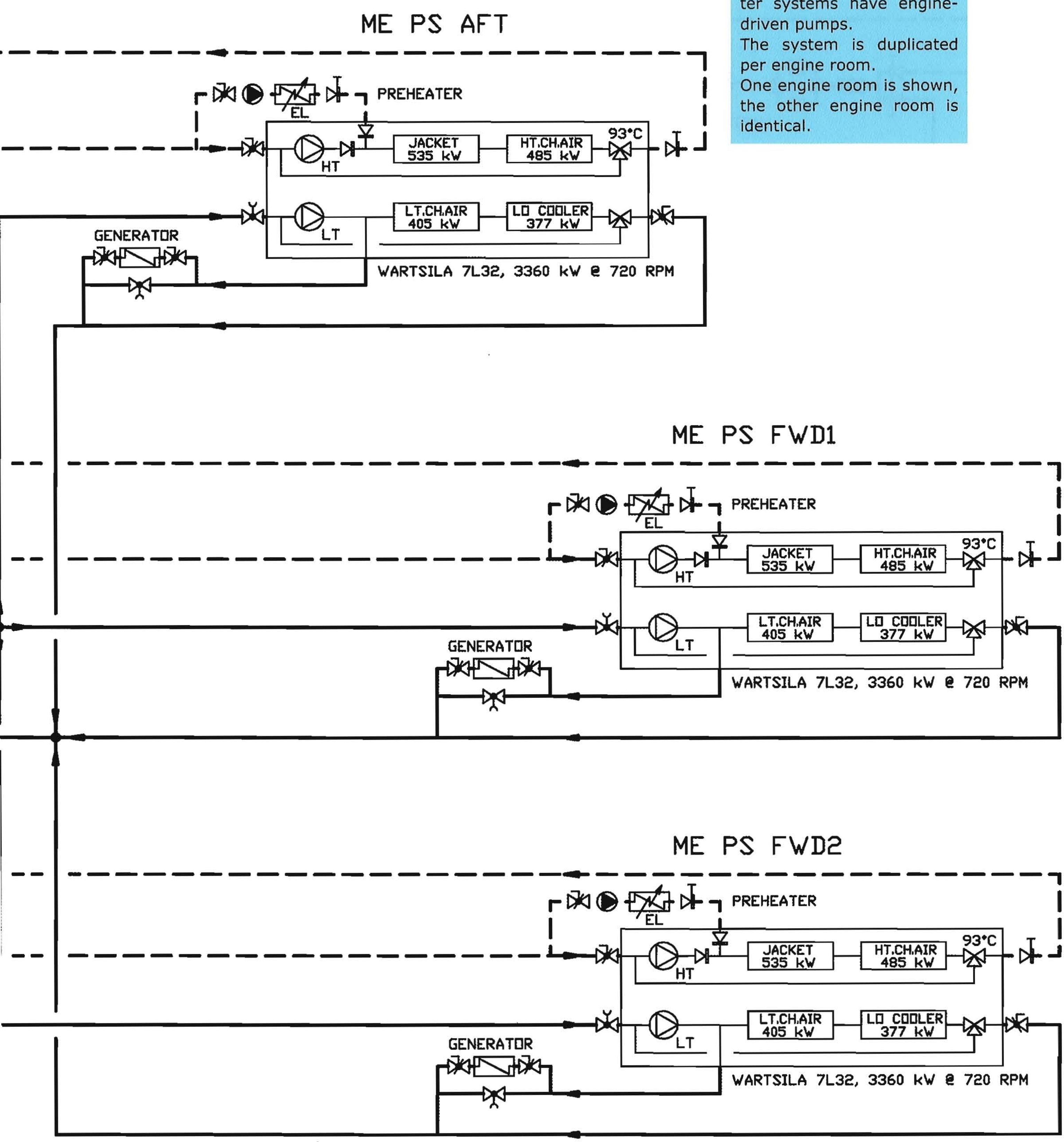
Thruster 5 also from SB and thruster 6 from PS. Consequently, a failure in an engine room freshwater cooling system can cause failure only of the cooling of the thrusters supplied from that engine room.



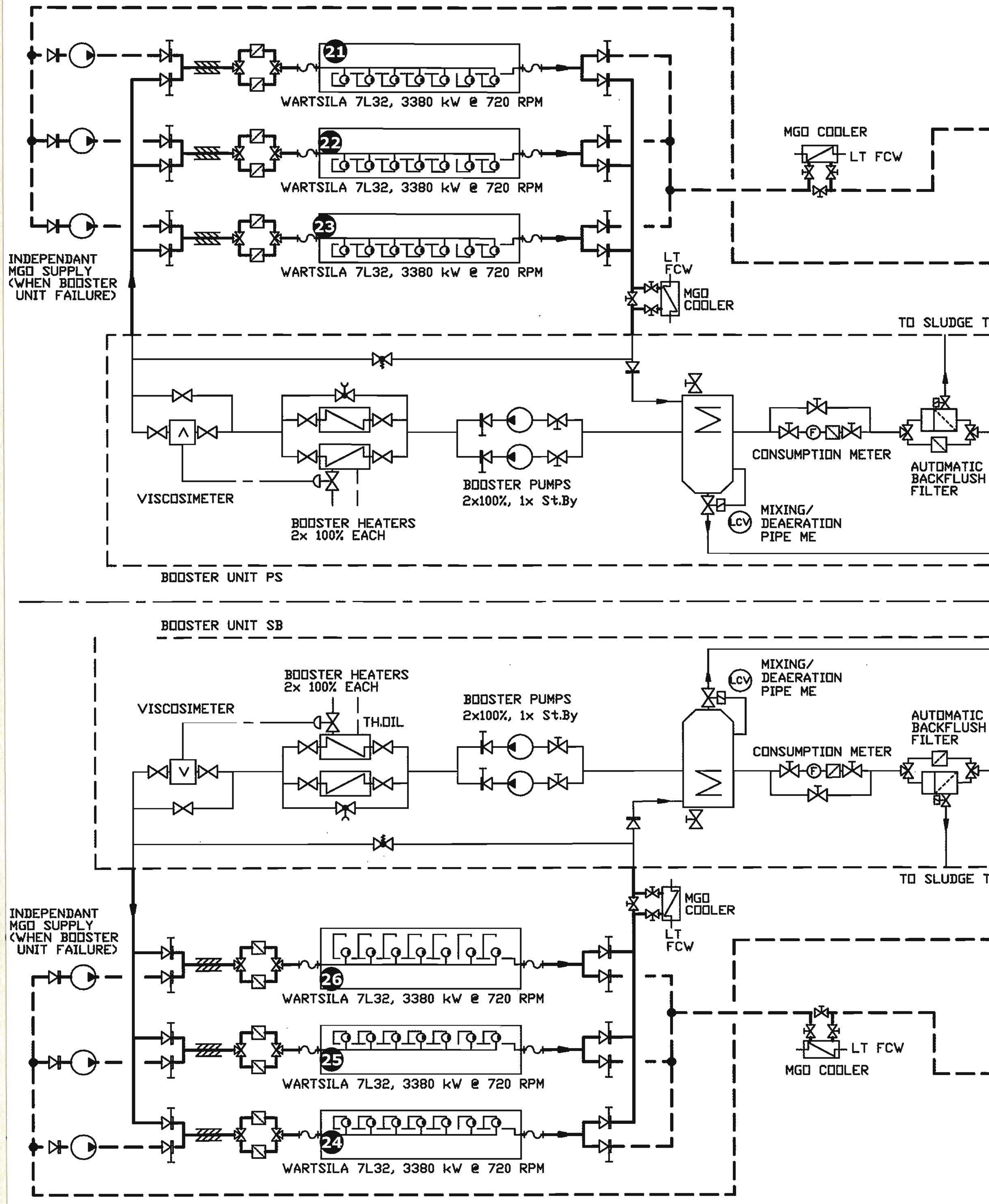


Engine room PS

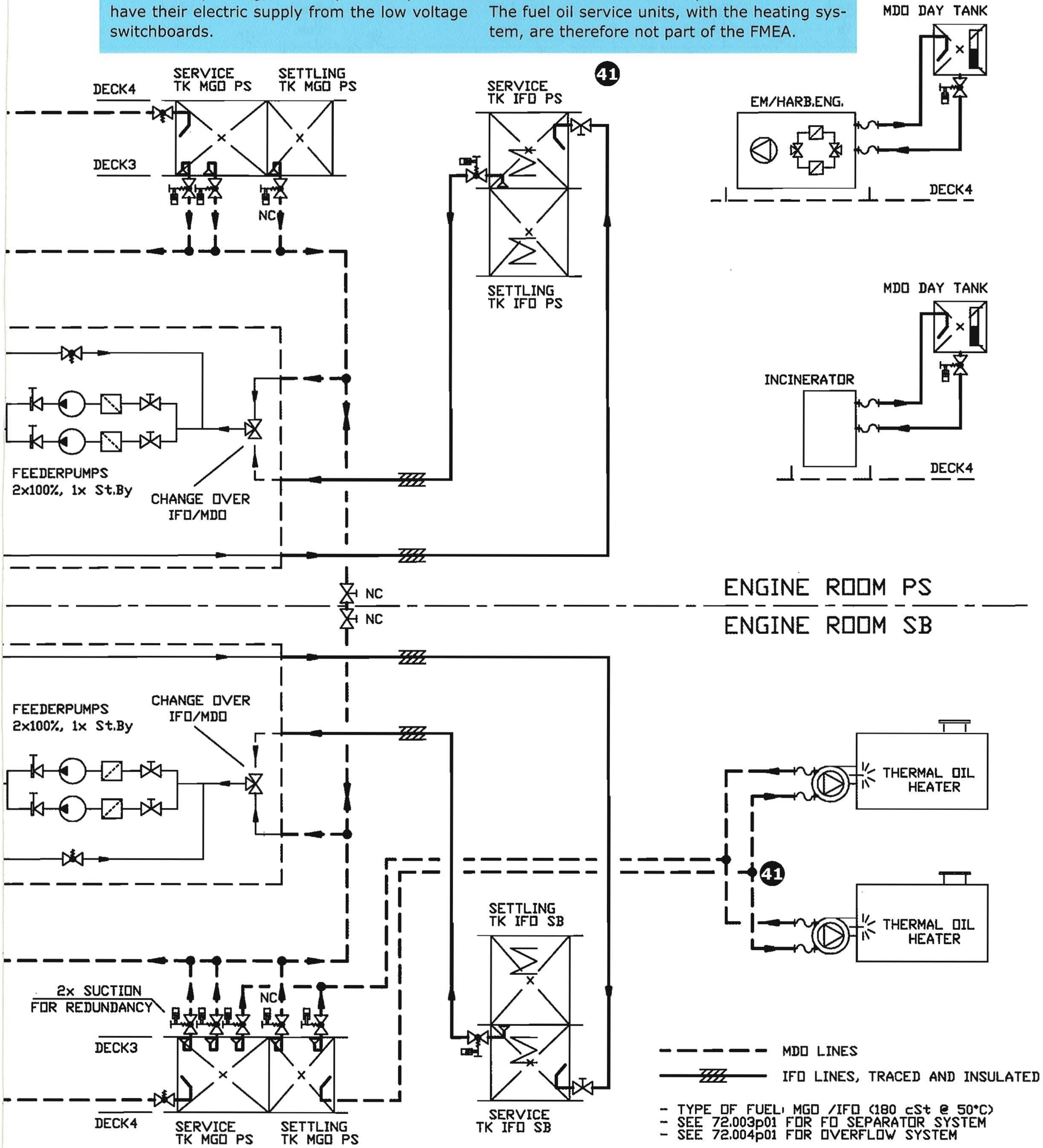
The main engine freshwater systems have engine-driven pumps.
The system is duplicated per engine room.
One engine room is shown, the other engine room is identical.

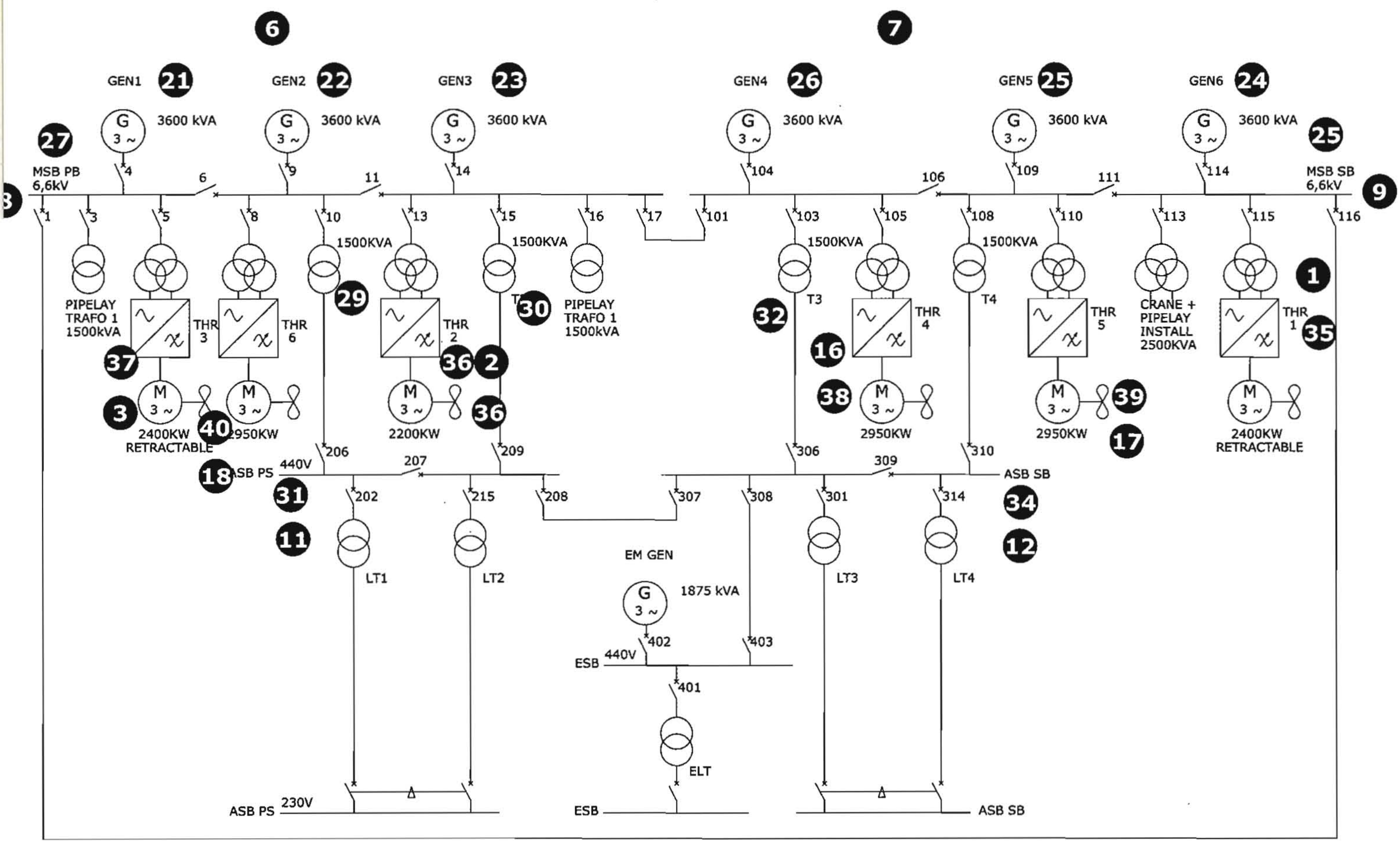


PS Engine room


WARTSILA 7L32, 3380 kW @ 720 RPM
WARTSILA 7L32, 3380 kW @ 720 RPM
WARTSILA 7L32, 3380 kW @ 720 RPM
MGO COOLER
LT FCW
INDEPENDANT MGO SUPPLY (WHEN BOOSTER UNIT FAILURE)
LT FCW
MGO COOLER
TO SLUDGE T
VISCOSIMETER
BOOSTER HEATERS 2x 100% EACH
BOOSTER PUMPS 2x100%, 1x St.By
CONSUMPTION METER
AUTOMATIC BACKFLUSH FILTER
LCV
MIXING/ DEAERATION PIPE ME
BOOSTER UNIT PS
BOOSTER UNIT SB
BOOSTER HEATERS 2x 100% EACH
VISCOSIMETER
TH.OIL
BOOSTER PUMPS 2x100%, 1x St.By
LCV
MIXING/ DEAERATION PIPE ME
AUTOMATIC BACKFLUSH FILTER
CONSUMPTION METER
TO SLUDGE T
MGO COOLER
LT FCW
INDEPENDANT MGO SUPPLY (WHEN BOOSTER UNIT FAILURE)
WARTSILA 7L32, 3380 kW @ 720 RPM
LT FCW
MGO COOLER
WARTSILA 7L32, 3380 kW @ 720 RPM
WARTSILA 7L32, 3380 kW @ 720 RPM

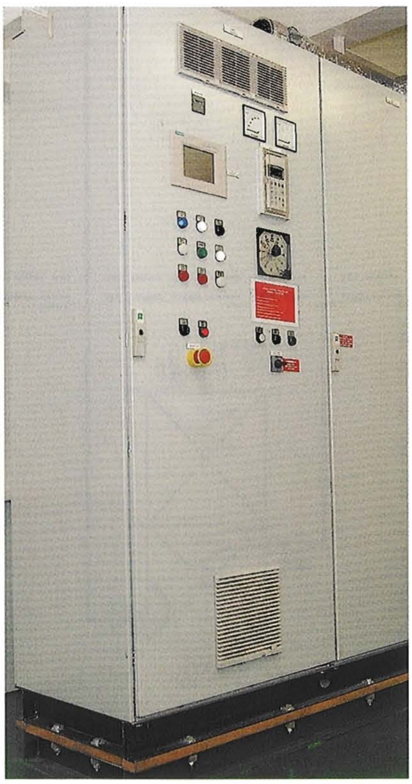
Fuel oil is supplied to the diesel engines out of tanks in the engine room, via fuel oil service units (heating, viscosity control) which have their electric supply from the low voltage switchboards. However, when the ship is operating on DP, the diesels are running on gasoil, and not on heavy fuel. The FMEA is drawn op for the DP mode. The fuel oil service units, with the heating system, are therefore not part of the FMEA.





1. Retractable azimuth thruster room 1
2. Tunnel thruster room 2
3. Retractable azimuth thruster room 3
4. Not used
5. Not used
6. Engine room PS 1
7. Engine room SB 2
8. HV Switchboard room 1 (PS)
9. HV Switchboard room 2 (SB)
10. Not used
11. LV switchboard room 1 (PS)
12. LV Switchboard room 2 (SB)
13. Not used
14. Not used
15. Not used
16. Azimuth thruster room 4 (PS)
17. Azimuth thruster room 5 (SB)
18. Azimuth thruster room 6 (CL)
19. Not used
20. Not used
21. Diesel generator 1
22. Diesel generator 2
23. Diesel generator 3
24. Diesel generator 4
25. Diesel generator 5
26. Diesel generator 6
27. HV switchboard 1 (PS)
28. HV switchboard 2 (SB)
29. HV/LV transformer 1 (PS)
30. HV/LV transformer 2 (PS)
31. LV switchboard 1 (PS)
32. HV/LV transformer 3 (SB)
33. HV/LV transformer 4 (SB)
34. LV switchboard 2 (SB)
35. Azimuth thruster 1
36. Tunnel thruster 2
37. Azimuth thruster 3
38. Azimuth thruster 4 (PS)
39. Azimuth thruster 5 (SB)
40. Azimuth thruster 6 (CL)

See layouts on previous pages for location of equipment.



Frequency converter

The one-line diagram above shows the main electrical power arrangement of the subject vessel.
The bus tie breakers in the main switchboards (8) and (9) can be open/closed to connect the generators two by two to different switchboards in three engine rooms.
A single failure would then result in a 33 per cent loss of capacity and the vessel would be able to continue to operate.

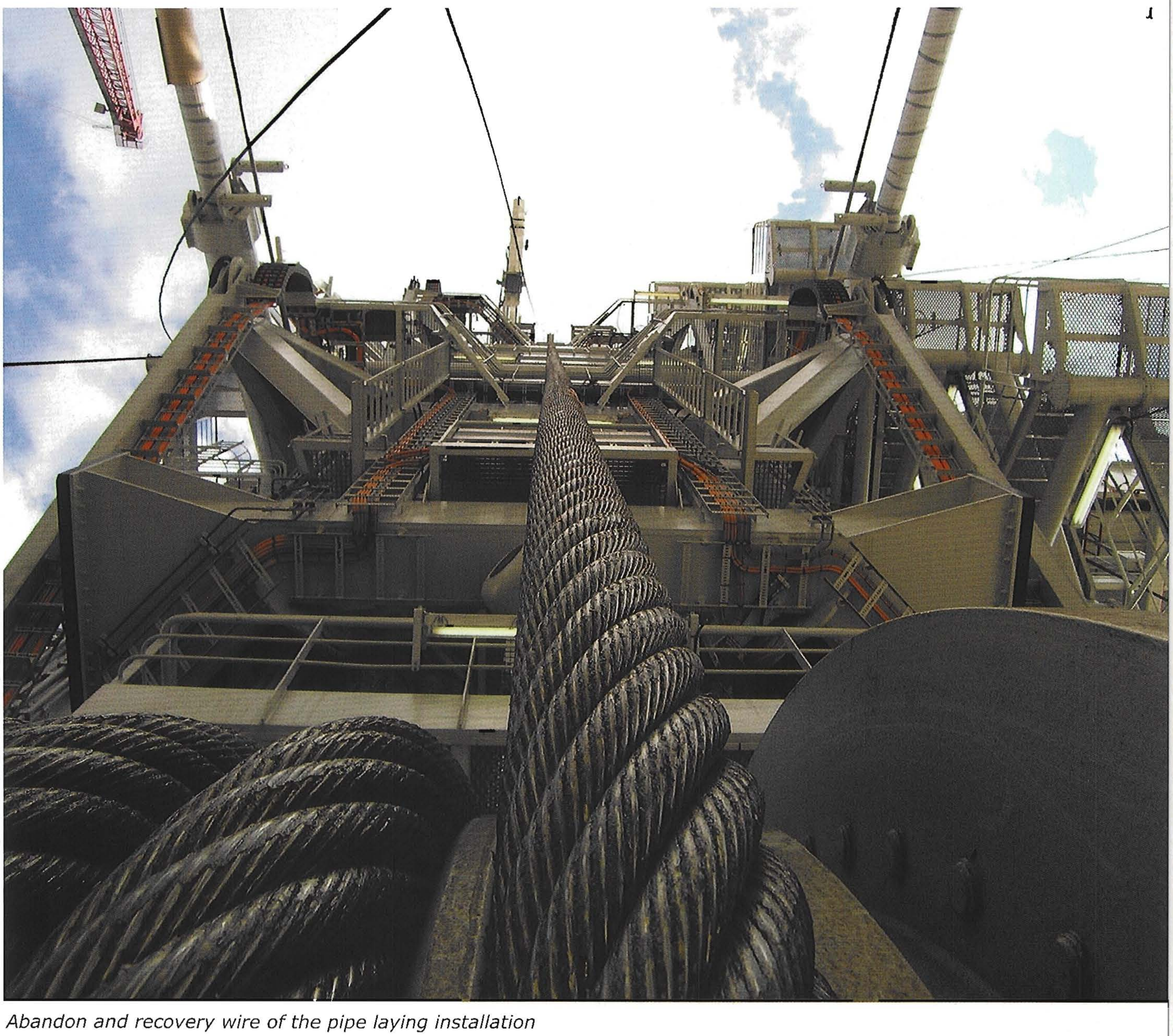
L-Drive aft thruster

All supporting systems for the diesel engines and thrusters should be carefully assessed to ensure these are available with the primary supplies.
The two 24 DC supplies have to be from different sources and a common failure must not cause failure of more than one engine.

Most HV switchgear requires an external power supply to close and open the circuit breakers.
This is essentially different from LV switchgear where no-volt coils in the circuit breakers arrange for time delayed tripping at under-voltage.
These circuits have to be included in the FMEA.

It is helpful to predetermine the location of the auxiliaries, the power for lubrication, pitch and direction hydraulics and all the control voltages.
It is useless to design a completely redundant power supply system for thrusters operated by a single powered control circuit.
It is not allowed to get the main power from one engine room and the control power from the other, as failure of either engine room would stop operation.
In this layout there are two engine rooms, with individual air, fuel, freshwater and seawater systems with fewer LV switchgear sections than in the HV systems.

The most disastrous result of a single failure is the failure of a complete HV switchboard and the associated LV switchboards resulting in a 50% reduction of propulsion capacity.
When keeping the position of the vessel is essential, such as during operations in the vicinity of offshore platforms, the operator may not use more than 50% of the available power.
If environmental conditions require more, the work must be stopped and the position abandoned.



Abandon and recovery wire of the pipe laying installation

20. ALARM AND MONITORING SYSTEMS

Alarm and monitoring systems are intended to monitor and register automatically all the essential parameters of the installation and display any abnormalities that have occurred. It saves time-consuming watch-keeping rounds, registers more information accurately, but is certainly no substitute for an engineer who, on his inspection round in the engine room, may find a small leak in a flange that can turn into a larger problem.

1 Inland waterway ships

The requirements for alarm and monitoring systems vary with the service of the vessel and associated notation, from inland waterway service with manned engine room notation or coastal service, to unrestricted service with larger engine ratings and UMS notation.

1. Alarm and monitoring display
2. VHF
3. Propulsion control handle
4. Closed circuit TV
5. Cargo tank level display
6. Rudder controls
7. Bow thruster control
8. Radar display (2)
9. Miscellaneous navigation instruments such as: Gyrocompass, Rate of turn indicator, etc.
10. Mouse for radars and electronic charts
11. Engine monitoring display

ALARMS PROPULSION SYSTEM IWW TANKER			
MAIN ENGINE	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW	ALARM
	LUBR OIL PRESS	LOW/LOW	STOP
	COOLW OUTLET TEMP	HIGH	ALARM
	COOLW OUTLET TEMP	HI/HIGH	STOP
	FUEL LINES LEAKAGE	LEAK	ALARM
	START AIR PRESS	LOW	ALARM
GEARBOX	LUBR OIL PRESS	LOW	ALARM
	HYDR OIL PRESS	LOW	ALARM
PROPELLER CONTROL	HYDR OIL PRESS	LOW	ALARM
	CONTROL AIR PR	LOW	
	ELECTRIC	FAIL	ALARM
AUXILIARY ENGINE	LUBR OIL PRESS	LOW	ALARM
	COOLW OUTLET TEMP	HIGH	ALARM
	FUEL LINES LEAKAGE	LEAK	ALARM
BOILERS	WATER LEVEL	LOW	ALARM
	WATER LEVEL	LOW/LOW	STOP
	WATER TEMPERATURE	HIGH/HIGH	STOP
STEERING GEAR	ELECTRIC POWER	FAIL	ALARM
	CONTROL POWER FAIL	FAIL	ALARM
HYDRAULIC SYSTEM	HYDRAULIC TANK	LEVEL LOW	ALARM

List of alarms for an inland waterway tanker.

Steering Console Inland Waterway tanker

2 Seagoing ships

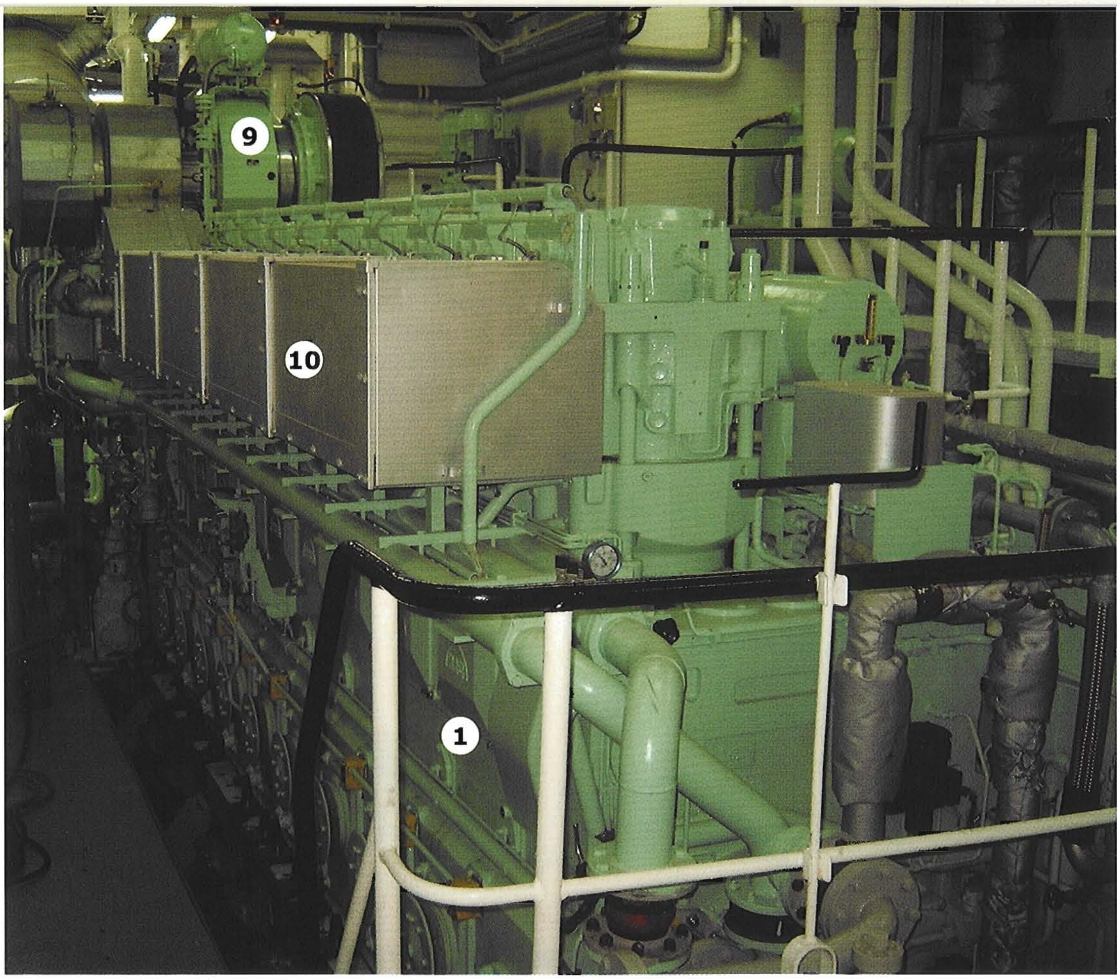
Alarm and monitoring systems are available in all sorts and sizes, starting from a small self-contained unit for 10 digital alarms with a common output for a group alarm and an audible alarm with accept and reset facilities.

Depending on the size and whether it is "manned" or "unmanned", larger systems are often composed of distributed input units linked together by a redundant network These can also send group alarms to the bridge instructing the bridge crew to reduce power or warning them of an automatic shutdown of the propulsion system.
Usually, more complex systems have a graphic display with all kinds of software to analyze retrieved data.
The engineer's logbook can be automatically generated, ready to be signed.

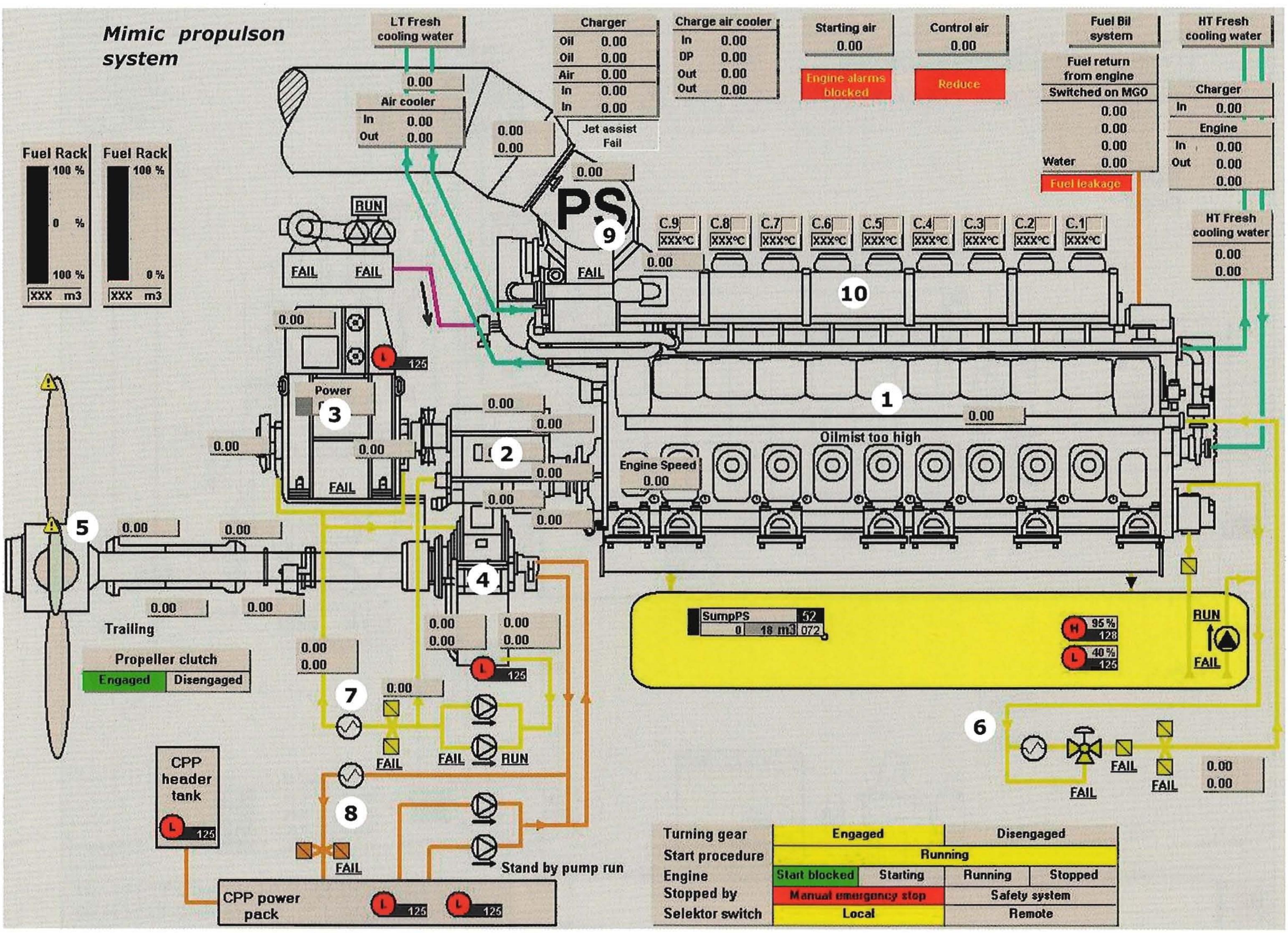
The engine room alarm and monitoring system includes the duty engineer's selection system with units in the engineers' cabins and the engineer's safety patrol system. This is a sort of egg-boiling clock, counting 27 minutes after the engineer enters the engine room or touches any button.
It initiates an alarm in the engine room and engine control room, which must be cancelled by the engineer within 3 minutes.
Otherwise, the system concludes that the engineer has a problem and initiates a general engineer's call.

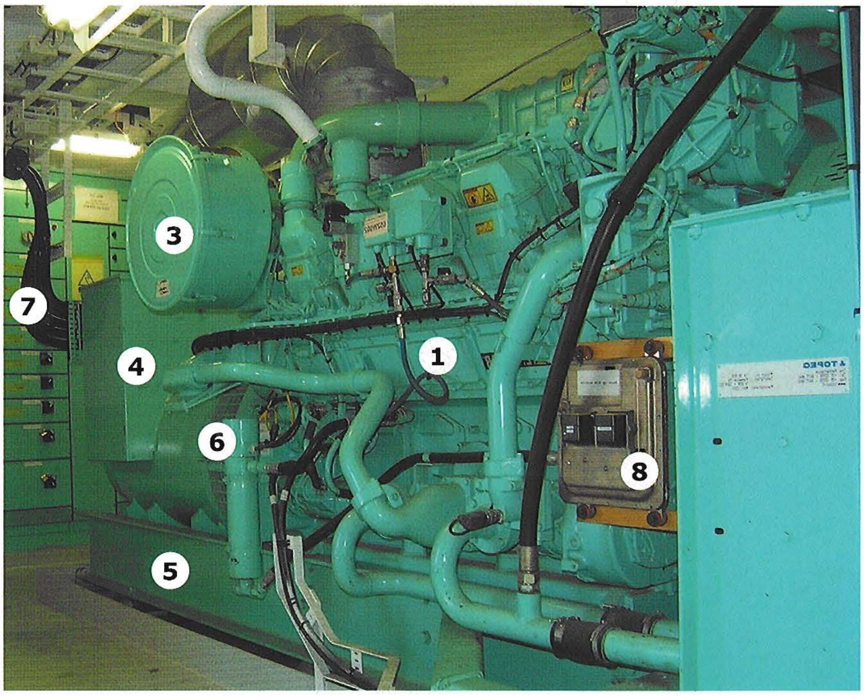
On the right is an example of minimum lists of alarms

PROPULSION SYSTEM		TESTED							
MAIN ENGINES>1500KW	SYSTEM	STATUS	RESULT	YARD	DATE	OWNER	DATE	CLASS
	LUBR OIL SUMP LEVEL	LOW	ALARM					
	LUBR OIL PRESS	LOW	ALARM					
	LUBR OIL PRESS	LOW/LOW	STOP					
	LUBR OIL TEMPERATURE	HIGH	ALARM					
	LUBR OIL FILTER DIFF	HIGH	ALARM					
	OIL MIST CONCENTRAT	HIGH	STOP					
MAIN BEARING 1	TEMPERATURE	HIGH	STOP					
MAIN BEARING 2	TEMPERATURE	HIGH	STOP					
MAIN BEARING 3	TEMPERATURE	HIGH	STOP					
MAIN BEARING 4	TEMPERATURE	HIGH	STOP					
MAIN BEARING 5	TEMPERATURE	HIGH	STOP					
THRUST BEARING	TEMPERATURE	HIGH	STOP					
HT COOLWATER	HT CW OUTLET TEMP	HIGH	ALARM					
	HT CW OUTLET TEMP	HI/HIGH	STOP					
	HT CW INLET PRESS	LOW	SLOW					
	HT CW EXP TANK LEVEL	LOW	ALARM					
LT COLWATER	LT CW OUTLET TEMP	HIGH	ALARM					
	LT CW OUTLET TEMP	HI/HIGH	SLOW					
	LT CW INLET PRESS	LOW	ALARM					
FUEL OIL	FUEL OIL PRESSURE	LOW	ALARM					
	FUEL OIL TEMPERATURE	HIGH+LOW	ALARM					
	FUEL LINES LEAKAGE	LEAK	ALARM					
START AIR	START AIR PRESS	LOW	ALARM					
CONTROL AIR	PRESSURE	LOW	ALARM					
ENGINE SPEED	OVERSPEED	HIGH	STOP					
CYLINDER 1	EXH GAS TEMPERATURE	HIGH	ALARM					
CYLINDER 1	EXH GAS TEMPERATURE	DEVIATION	ALARM					
CYLINDER2	EXH GAS TEMPERATURE	HIGH	ALARM					
CYLINDER2	EXH GAS TEMPERATURE	DEVIATION	ALARM					
CYLINDER3	EXH GAS TEMPERATURE	HIGH	ALARM					
CYLINDER3	EXH GAS TEMPERATURE	DEVIATION	ALARM					
CYLINDER4	EXH GAS TEMPERATURE	HIGH	ALARM					
CYLINDER4	EXH GAS TEMPERATURE	DEVIATION	ALARM					
CYLINDER5	EXH GAS TEMPERATURE	HIGH	ALARM					
CYLINDER5	EXH GAS TEMPERATURE	DEVIATION	ALARM					
CYLINDER6	EXH GAS TEMPERATURE	HIGH	ALARM					
CYLINDER6	EXH GAS TEMPERATURE	DEVIATION	ALARM					
TURBO BLOWER	EXH GAS BEFORE TURBO	HIGH	ALARM					
TURBO BLOWER	EXH GAS AFTER TURBO	HIGH	ALARM					
TURBO BLOWER	LUBR OIL INL PRESS	LOW	ALARM					
TURBO BLOWER	LUBR OIL OUTL TEMP	HIGH	ALARM					
ENGINE OUTPUT	OVERLOAD	HIGH	ALARM					
GEARBOX	LUBR OIL PRESS	LOW	ALARM					
	LUBR OIL PRESS	LOW/LOW	STOP					
	LUBR OIL TEMPERATURE	HIGH	ALARM					
	LUBR OIL SUMP LEVEL	LOW	ALARM					
	HYDR OIL PRESS	LOW	ALARM					
PROPELLER CONTROL	HYDR OIL PRESS	LOW	ALARM					
	CONTROL AIR PR	LOW	AA					
	ELECTRIC	FAIL	ALARM					
AUXILIARY ENGINE	LUBR OIL PRESS	LOW	ALARM					
	LUBR OIL PRESS	LOW/LOW	STOP					
	LUBR OIL TEMPERATURE	HIGH	ALARM					
	COOLW OUTLET TEMP	HIGH	ALARM					
	COOLW OUTLET TEMP	HIGH/HIGH	STOP					
	COOLW INLET PRESS	LOW	ALARM					
	FUEL LINES LEAKAGE	LEAK	ALARM					
	OVERSPEED	HIGH	STOP					
	EXH GAS BEFORE TURBO	HIGH	ALARM					
	EXH GAS AFTER TURBO	HIGH	ALARM					
BOILERS	WATER LEVEL	LOW	ALARM					
	WATER LEVEL	LOW/LOW	STOP					
	WATERTEMPERATURE	HIGH/HIGH	STOP					
STEERINGGEAR	ELECTRIC POWER	FAIL	ALARM					
	CONTROL POWER FAIL	FAIL	ALARM					
	HYDRAULIC TANK	LEVEL LOW	ALARM					
	OVERLOAD MOTOR		ALARM					
	PHASE FAIL		ALARM					
	HYDRAUKIC LOCK		ALARM					
ELECTRIC SYSTEM								
Bus-bar VOLTAGE	VOLTAGE	HIGH+LOW	ALARM					
Bus-bar FREQUENCY	FREQUENCY	HIGH+LOW	ALARM					
OVERLOAD	NON ESSENTIALS	TRIP	ALARM					
Bus-bar INSULATION	MEGOHM	LOW	ALARM					



1. Main engine
2. Gearbox
3. PTO generator
4. Oil distribution box
5. Controllable pitch propeller
6. Main engine lubricating pumps
7. Gearbox lubricating pumps
8. Propeller hydraulic pump
9. Turbo blower
10. Casing over fuel system (fire prevention

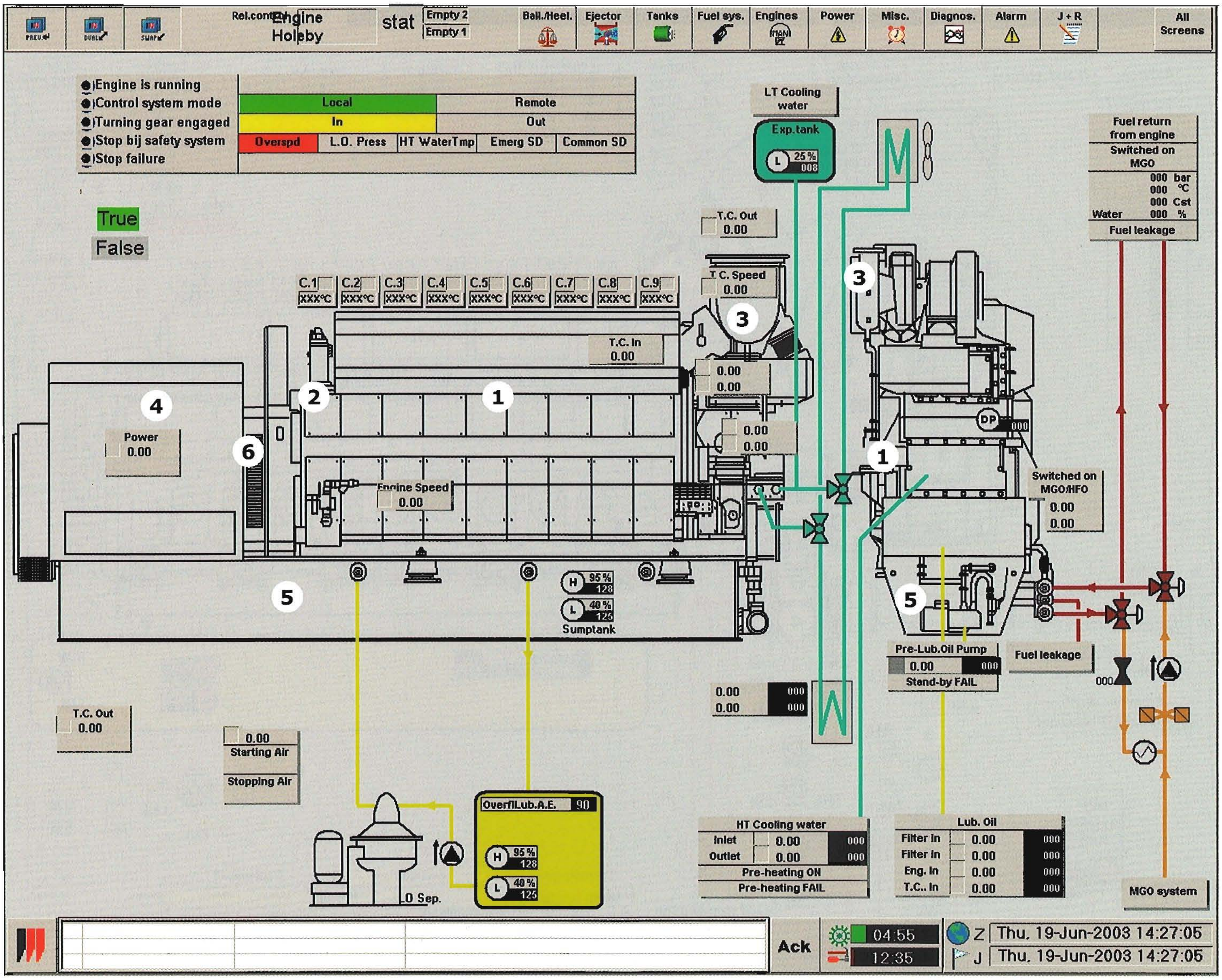


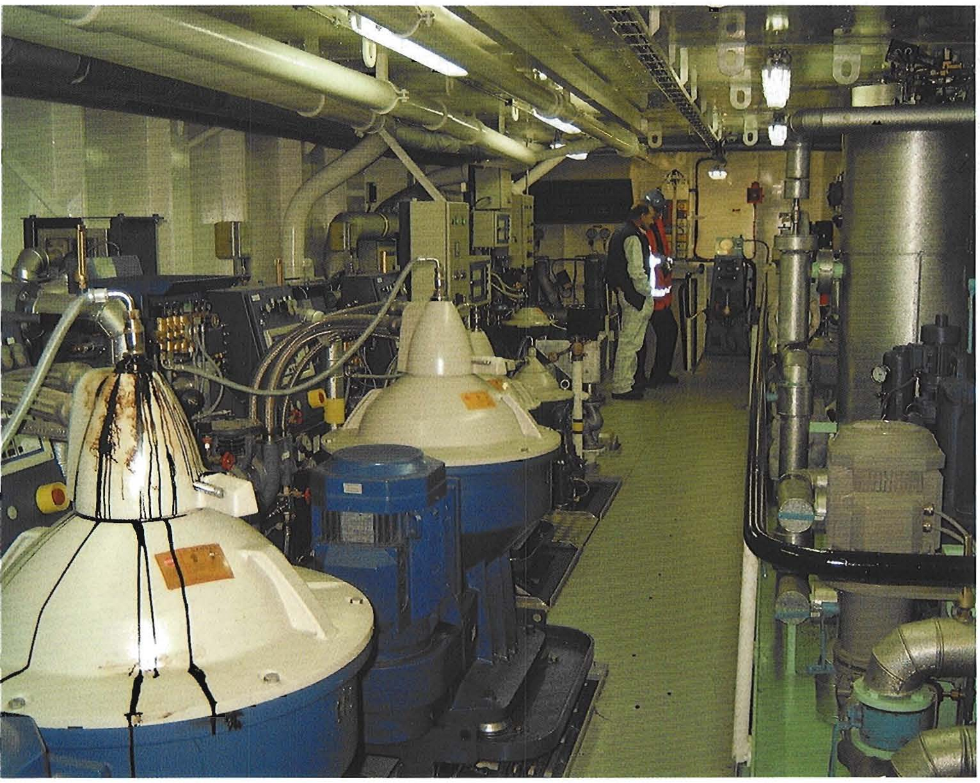


1. Diesel engine
2. Governor
3. Turbo charger
4. Generator
5. Sump tank
6. Ventilator for generator cooling
7. Output power cables
8. Control panel

SCADA: Supervisory Control And Data Acquisition.

Auxiliary engine (generator set) and SCADA display of same engine.



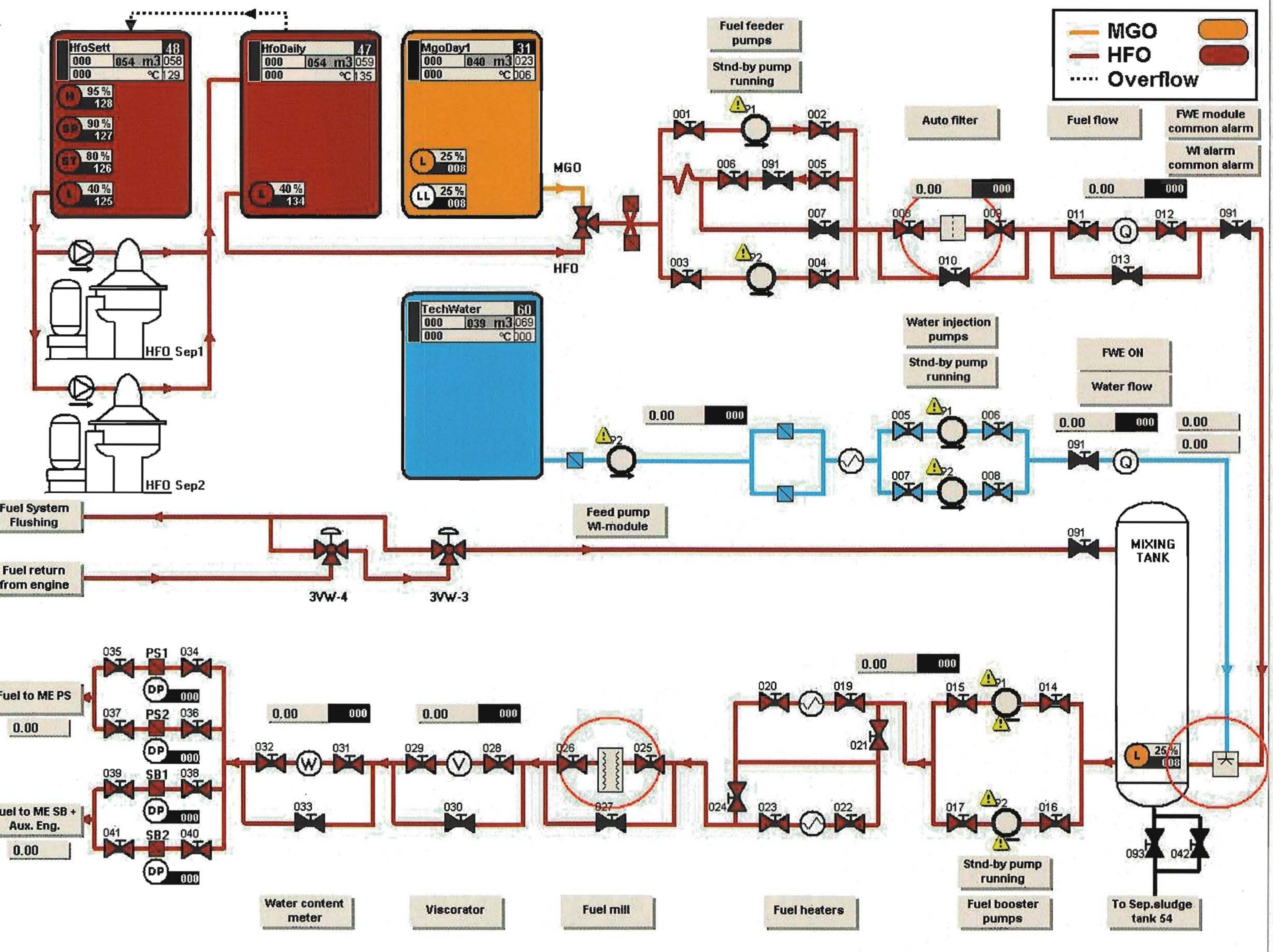


3 Colour Codes for piping systems

Piping systems in engine rooms are often colour coded to identify the contents of the pipes

For easy reference, these codes are also used in some of the lists of alarms and measuring points.

PIPE IDENTIFICATION		
SEA GOING SHIPS	COLOUR	SAMPLE
SEA WATER	GREEN	
FRESH WATER	BLUE	
FUEL OIL	BROWN	
OIL NOT FUEL	ORANGE	
LUB OIL	LIGHT BR	
STEAM	SILVER	
FIRE FIGHTING	RED	
VENT AIR	WHITE	
FLAMM. GAS	YELLOW	
NON FLAMM GAS	GREY	
WASTE	BLACK	



21. NAUTICAL EQUIPMENT

This chapter describes the standard navigation and nautical package mandatory for a ship for unrestricted service.
Navigation has changed enormously with the introduction of the global positioning system (GPS). To determine the position of a ship the sextant was for many years the tool to use. As this method uses visual orientation to the stars, planets, sun and moon weather conditions often hindered its use.

With satellites and sophisticated computer systems navigation has evolved to an accurate all-weather tool.

1 Bridge equipment.

1.1 Compass systems

1.1.1 Magnetic compass

From 150 GT upwards all ships shall be fitted with a steering compass.

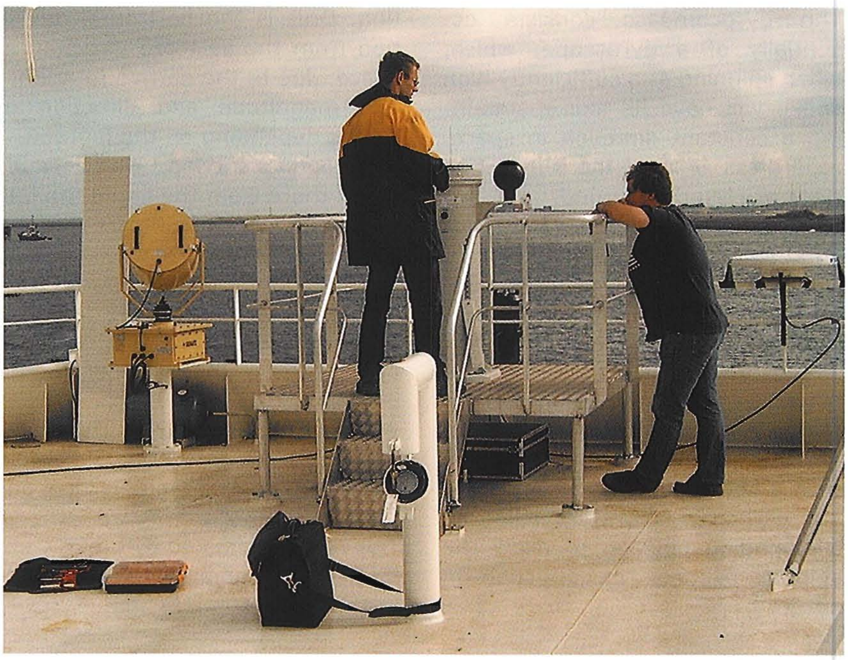
The magnetic compass is the oldest and simplest. The system is using the earth magnetism.
Disadvantage is, that the direction of the magnetic field of the earth is different from the direction of the earth's axis of rotation.

The south pole of a magnetic bar, when suspended from a string free in the air, will point at the earth's magnetic north pole.
A magnetic standard compass is still required for all ships.
Magnetic compasses indicate the direction to the magnetic north pole, which is not located at the geographical north pole, but at present some 100 miles away.

The location of the magnetic north pole changes continuously.
The magnetism, when observed on board of a ship, is influenced by the steel of the ship itself.
The compass has therefore to be calibrated to compensate for the magnetic field of the ship itself, when commissioned, and eventually later, when deviations are becoming too high.

The compass is also influenced by the cargo, when this is sensitive for magnetism.

The magnetic standard compass and the compensation engineer at work



A view on the bridge

1.1.2 Gyrocompass

Ships of 500 GT and upwards have to be fitted with a gyrocompass.
There are 3 different types of gyrocompasses:

- Liquid
- Dry
- Fibre optic.

The gyrocompass depends contrary to the magnetic compass, on the earth's angular velocity, as it points itself to the earth's axis of rotation.

The gyrocompass consists essentially of a gyroscope, which, when spinning at a sufficiently high speed will have its axis maintaining a constant direction in space, regardless of how the supporting rings are tilted or turned.
This property is known as the rigidity in space.
Magnetic forces do not have influence on the maintained direction.

The gyrocompass is installed in a binnacle, where the spinner is installed inside a ball shaped housing. This ball floats in a special liquid, with a specific gravity keeping the ball vertically accurately inside its surrounding housing to allow the spinner to seek its direction in space.

Inside the floating ball, an electric motor is installed, with the rotor as the gyro-spinner.
Electric contacts are ensured by sophisticated sliding devices.
When suitable controls are applied, the axis of the gyroscope seeks the direction of the true north.
Because of the rotation of the earth, the axis of the gyro appears to move, although maintaining its direction in space.
This motion is a combination of drift and tilt, together the apparent motion. Drift is the horizontal deviation from the selected direction in space, due to the earth's rotation.
The magnitude and direction of drift is depending on the latitude.
By creating friction, which is already there from the liquid the ball floats in, the axis points itself in the direction of the earth's axis, i.e. in the direction of the true north.
Tilting is a result of the latitude. When at the equator, the direction of the axis is the same as to the horizon.
When at higher latitude, the direction to a point above the north pole of the earth results in a vertical angle with the horizontal.
This can be adjusted by gravity, i.e. by a weight or a system with adjustable floats in mercury.

Added weights give the ball a position parallel to the horizon.
Settings depend on the actual latitude.
The ship's speed is producing another deviation.
The gyro will adjust itself rectangularly to the resultant of the true course of the vessel and the eastgoing direction of the earth.
The instrument itself also has some constant deviation.
Above deviations are corrected by various electronic devices.

The binnacle is normally installed in a technical room near the wheelhouse of the ship.
Often at a lower deck, to reduce transversal forces due to the ship's movement.
At various places repeaters are installed, showing the directional information wanted for navigation (or other purposes).
Normally at the steering position, at both bridge wings, sometimes near the magnetic compass for easy calibration of that compass.

The principle of the dry gyro is the same as of the liquid gyro. However, the big advantage is there is no maintenance required during its MTBF (mean time between failure).

1.1.3 Fiberoptic Gyrocompass

The last development of the gyro principle, also electrical, is the Fiberoptic Gyrocompass.

This is a complete solid unit, which has no rotating or other moving parts. It is based on a laser beam sent into a horizontal glassfibre coil, split in two halves when entering the coil.

One half goes left, the other half right.

When the coil has not turned, both beams return at the entering point at the same moment.

If the coil has turned, the beams do not return at the starting point at the same time, resulting in a phase difference.

Three coils at the x, y and z axis, enable the calculation of the true north.

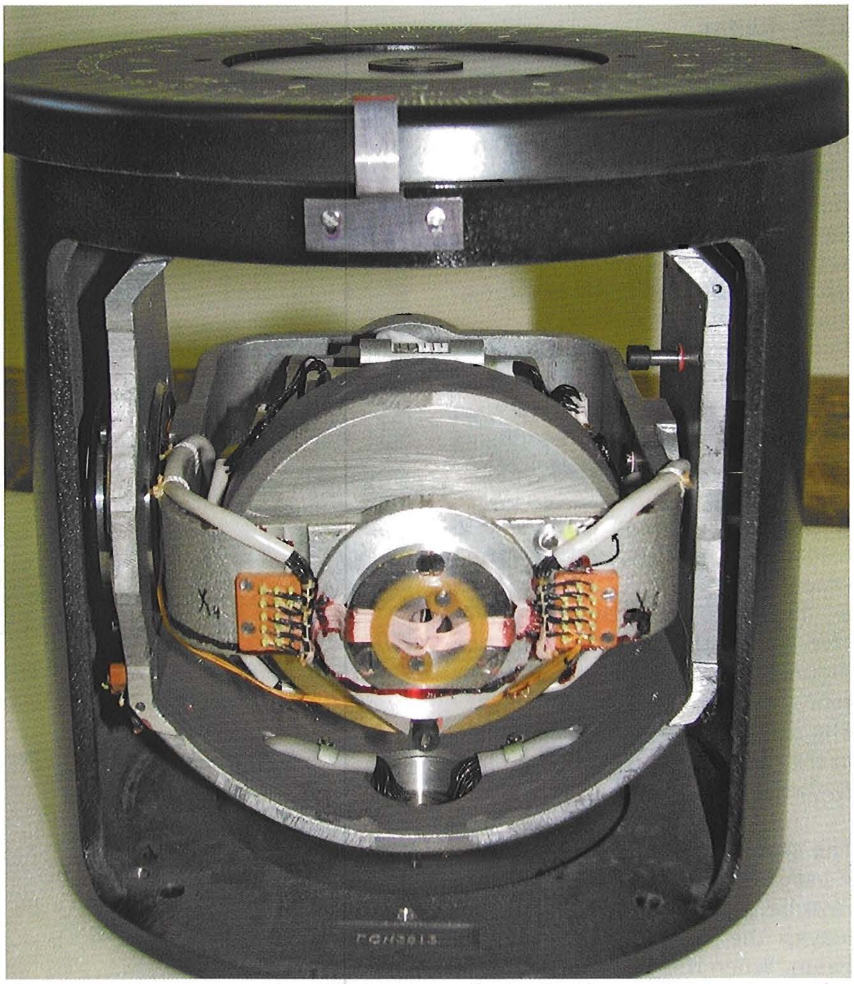
The device is made in solid state and needs only an short settling time.

1.1.4 Fluxgate compass

A fully electrical compass is the Fluxgate compass.

Two coils under 90° produce an electric current by the magnetic flux passing through the coils.

From the difference in measured current the direction of the magnetic north can be calculated.



A gyrocompass opened up.The grey cylinder in the center contains the gyro spinner. Cooling is provided by liquid.

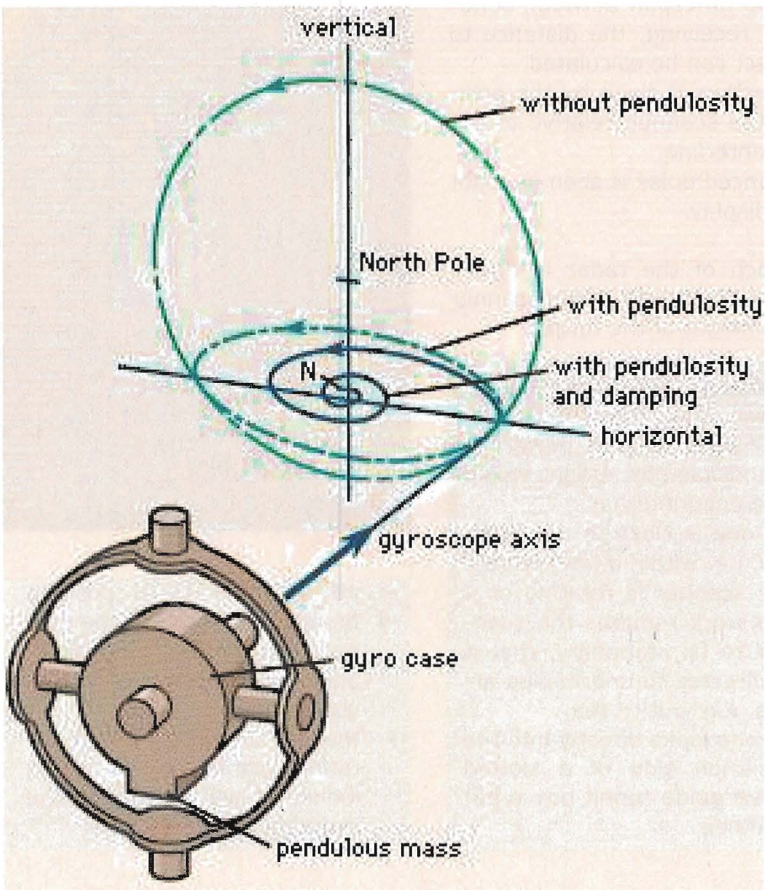
1.2 Off-Course Alarm

When a ship, whilst on passage changes course unwanted, an alarm has to sound.

Often this is a device coupled to the gyro.

Also the magnetic compass must be used for this purpose.

Allowed degrees off course are to be set. When coupled to the gyro this can be done automatically.

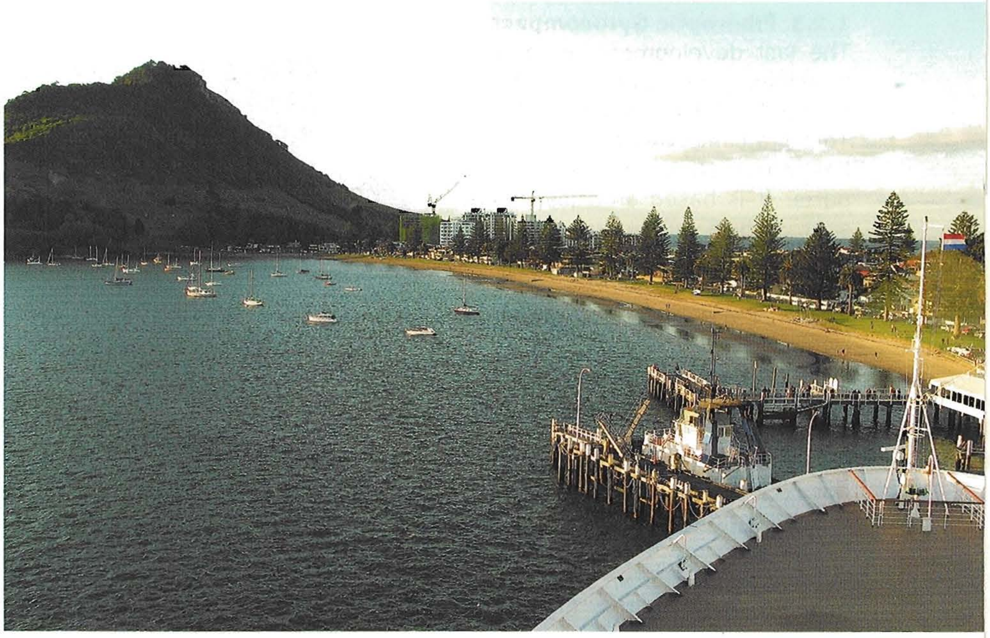


Circular line shows the apparent motion of the axis of a gyroscope around the pole star in the absence of a pendulous mass.

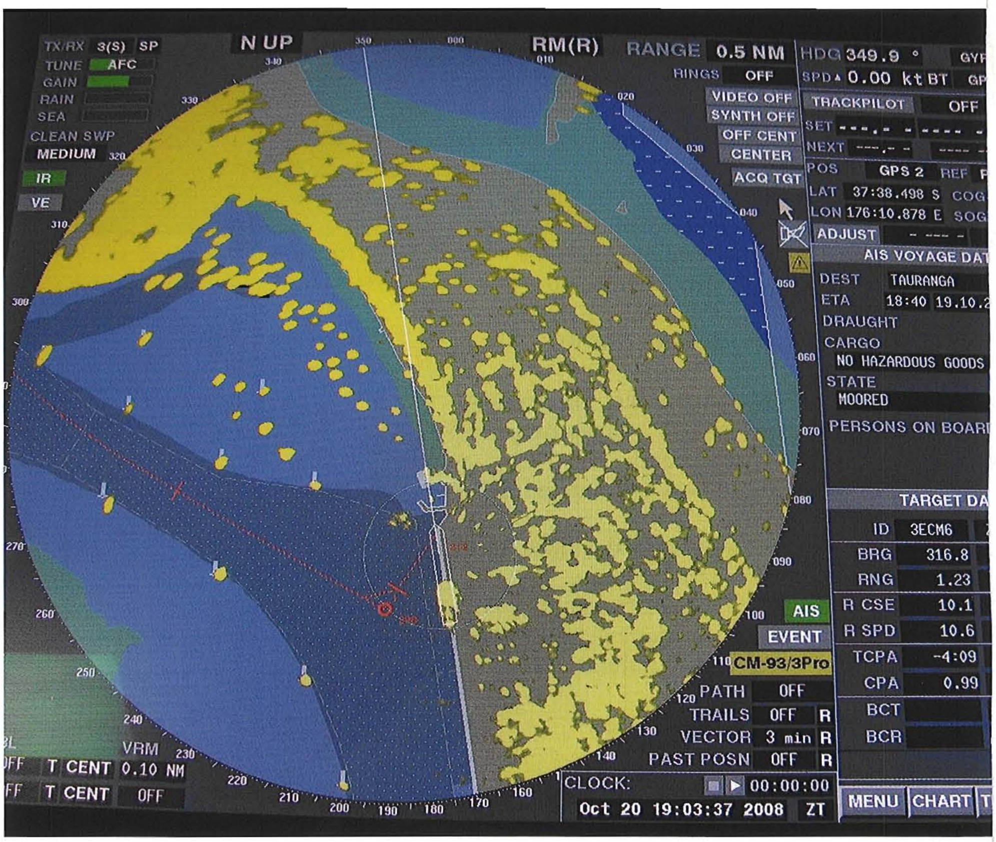
The addition of the pendulous mass (lower drawing) converts the circular motion into an ellipse; the ellipse can then be damped out and the gyroscope becomes a gyrocompass pointing to true north.

1.3 Radar

A RADAR **(Radio Detection and Ranging)** with automatic plotting (ARPA) function and rotating transmitting/receiving aerial, usually the X-band (frequency 8-12 GHz). For ships bigger than 3000 GT a second radar has to be provided, usually an S-band radar in the frequency range of 3-4 GHz.
The reason to select two radars with different frequency bands is their different capabilities to cope with the environmental conditions such as fog, rain, sea clutter.



A cruise vessel is moored alongside a jetty. The above picture shows the real situation. Below the same location as seen on the radar screen.



A radar installation comprises a transmitter/receiver, and a rotating antenna.
A display shows the outcome. The transmitter/receiver is a box mounted directly under the antenna.
The antenna or scanner, is installed in the radar mast, usually on top of the wheelhouse.

The scanner is rotating.
A very short pulse is sent from the raytube to the scanner mirrors and leaves the scanner as a narrow beam. When this beam bounces on an object, part of it can be received in the scanner.
From the timespan between sending and receiving, the distance to the object can be calculated.
The direction is given by the position of the scanner, relative to the ship's centerline.
The bounced pulse is seen as a dot on the display.

The reach of the radar is determined by the height of the scanner and the height of the target.

Sensible precautions
If radar equipment is to be worked with under power in port, sensible precautions would include ensuring that:

- no one is close to the scanner, i.e. within a few metres,
- the scanner is rotating or if the work requires the scanner to be stationary, that it is directed to unoccupied areas, e.g. out to sea,
- no one looks directly into the emission side of a slotted wave guide (open box type) scanner,
- no one is able to position themselves between the output horn of the transmitter and the reflector of larger scanners,
- the risk of being hit by a rotating scanner is not overlooked if work close to the installation is necessary.

Any work carried out on such equipment should be carried out by competent persons, operating a safe system of work, so that they put neither themselves nor others at risk.

1.4 Global Positioning System, GPS

GPS is simple to use and so reliable that nearly all ships, from small yachts to the largest ships at sea, are fitted with one or more GPS receivers.

GPS is an independent auto-position fixing system, with omnidirectional aerial. The input data are produced by satellites.
The system was originally designed for the US defence department but has been made available for civilian use.
Europe is working on an alternative independent system, Galileo.

DGPS or Differential Global Positioning System, is a more accurate GPS, by the installation of an additional signal from a reference transmitter. The location of this transmitter is accurately known, so improving the outcome of the position calculation. Due to the limited reach of this additional transmitter, this is a local improvement.

Global positioning systems operate on low power signals, transmitted by a large number of satellites, which orbit the earth at an altitude of 20,000 kilometres.
Normally there is input from some 8 satellites at every moment.

This (D)GPS gives not only the actual position in coordinates, but when the receiver (the ship) is moving, it calculates also speed and course over the ground.

1.5 Autopilot

1.5.1 Automatic course function

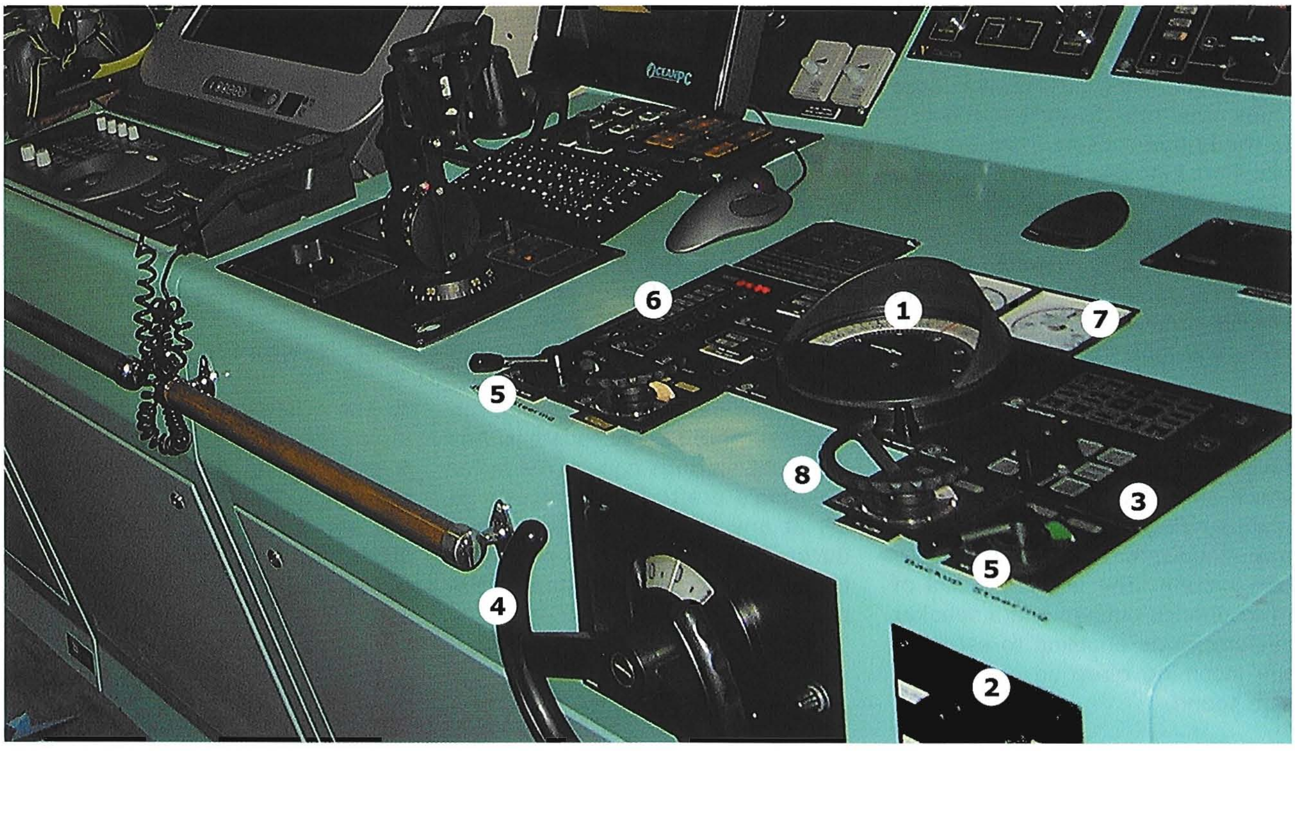
Automatic pilots are control devices that compare the actual course on the gyrocompass with the set course, and take corrective measures if the actual course is deviating from the set course. Most of these control devices are now adaptive, which means that it adapts to the ship's characteristics by applying minimum rudder angle to get back to the set course. Autopilots can be adjusted for gain, maximum rudder angle and maximum rate of turn.
The modern autopilots are so sensitive that they operate the rudder at a minimum deviation of the set course before the helmsman would notice. This way steering a more straight course than a helmsman would do. A straighter course saves fuel and time.

GPS display

1.5.2 Autotrack function

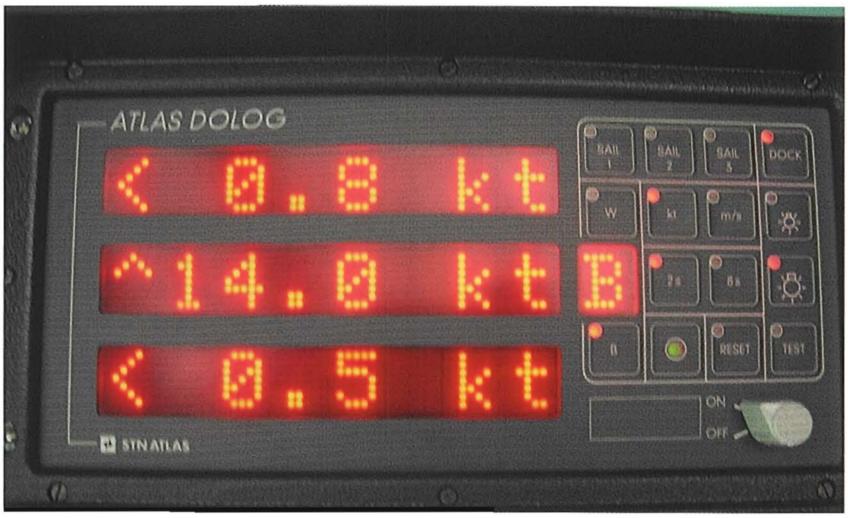
GPS positioning giving course and speed via ECDIS or GPS over the bottom makes it possible to steer according to a planned track.
Way points can be added and at the way points the vessel will slowly turn to the next track, after a warning and being acknowledged.

1. Gyro repeater
2. Steering mode selector switch
3. Autopilot
4. Follow-up steering wheel
5. Non-follow-up steering wheel
6. Steering-gear controls and alarms
7. Rudder angle indicators (twin rudders)
8. Course selector



1.6 Speed and Distance (Log)

On ships over 500 GT the speed and distance through the water has to be measured.
One log with speed and distance indication through the water has to be installed. This can be for instance an electromagnetic log. In shallow water the so-called Doppler log can measure speed through the water and over the ground, water track or ground track.
This can be chosen at the display.
Dual-axis logs measure speed in forward and aft direction as well as transverse movements.
The latter for very large ships (tankers, bulkcarriers), to control the impact forces on the jetty during mooring.



Doppler log display showing speed in bottom track mode and sideways speed bow and stern

1.7 Rudder angle indicator

The physical position of the rudder has to be shown on a display. Normally this is displayed on a deckhead-mounted indicator visible from everywhere in the wheelhouse.

1.8 Rate of turn indicator

Rate of Turn Indicator has to be installed on ships of 50,000 GT and upwards. The rate of turn is important for large ships, to determine the time needed to come to a decided course.
In advance of a turn, the helm has to be moved in the position to get the ship turning. Especially large ships need time to start to react.
In the bridge console there are displays for RPM and turning direction of the propeller. Or the pitch in case of a controllable-pitch propeller.
Displays are also installed on the bridgewings, as these parameters are very important during manoeuvring and mooring.

1.9 Wind and sound

Ships with an enclosed wheelhouse, which are vulnerable to wind during manoeuvring, are to be fitted with a wind indicator and a sound reception system. The latter consists of microphones outside and a speaker system inside enabling to establish the incoming direction of the outside sound.

Echosounder display showing depth under the keel

1.10 Echosounder

The water depth under the ship is measured with an echosounder. A transducer in the ship's bottom sends a sound pulse downward, and receives the bounced pulse. The distance between ship's bottom and seabed can be calculated from the time between sending and receiving.
The speed of the pulse through the water is more or less constant. Adjustment settings can be made for the ship's draft. An alarm can be set at any depth below the transducer. The sent sound beam has a conical shape, with the top of the cone at the transducer.

1.11 Daylight Signal Lamp

All ships over 150 GT, must have a daylight signal lamp. The source of electric power has to be independent of the main power supplied to the wheelhouse equipment. Often an ordinary battery is used.

1.12 Navigation Lights panel

In the wheelhouse an alarm and indication panel is to be installed to control and monitor the navigation lights. Most of the time next to this panel is a control panel for the signal lights like NUC (Not Under Command) lights.

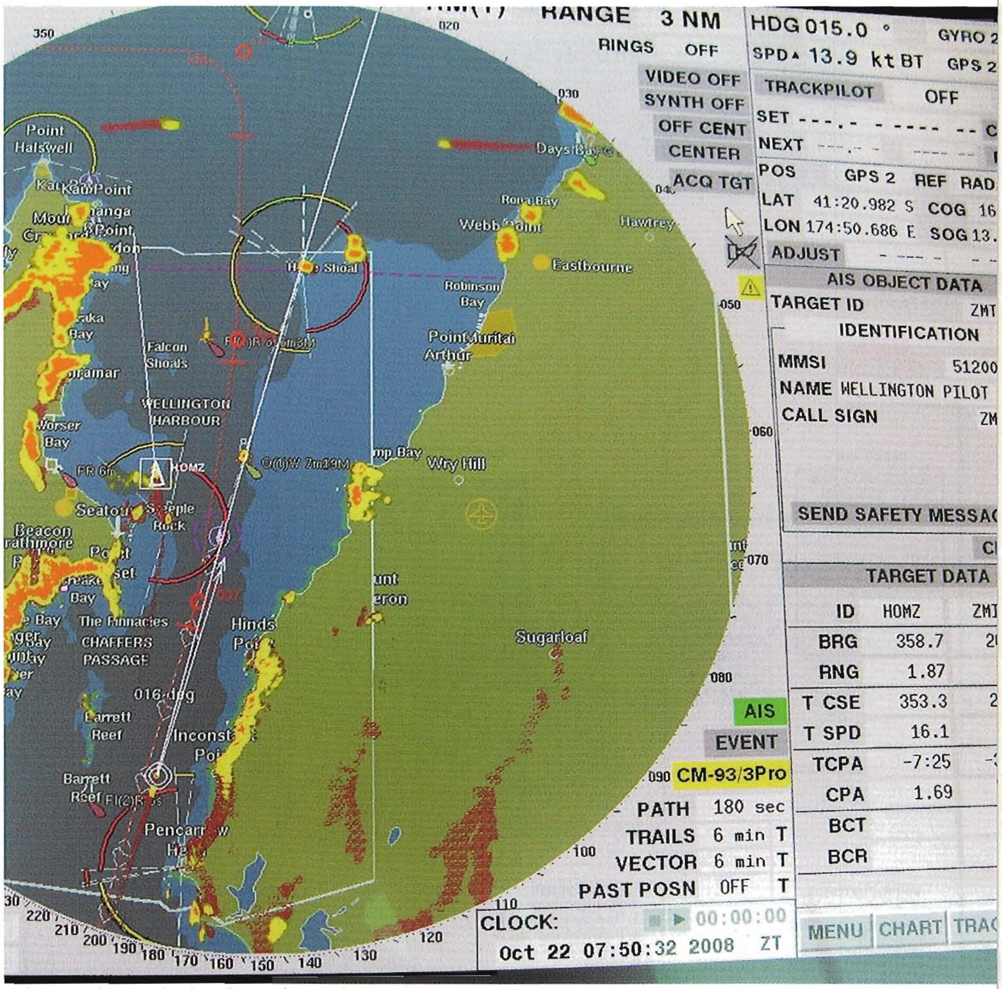
1.13 Voyage Data Recorder

Passenger ships and ships other than passenger ships of 3000 gross tonnage and upwards constructed on or after 1 July 2002 must carry voyage data recorders **(VDR, Black Box)** to assist in accident investigations.
Details can be found in SOLAS. Such a unit consists of a data acquisition unit, acquiring all necessary data from the various instruments and a data capsule.
The device records information regarding course, speed, communication, alarms, alterations, engine particulars and what has been said in the wheelhouse.
Data can, if wanted, be transmitted to the shorebase of the vessel.

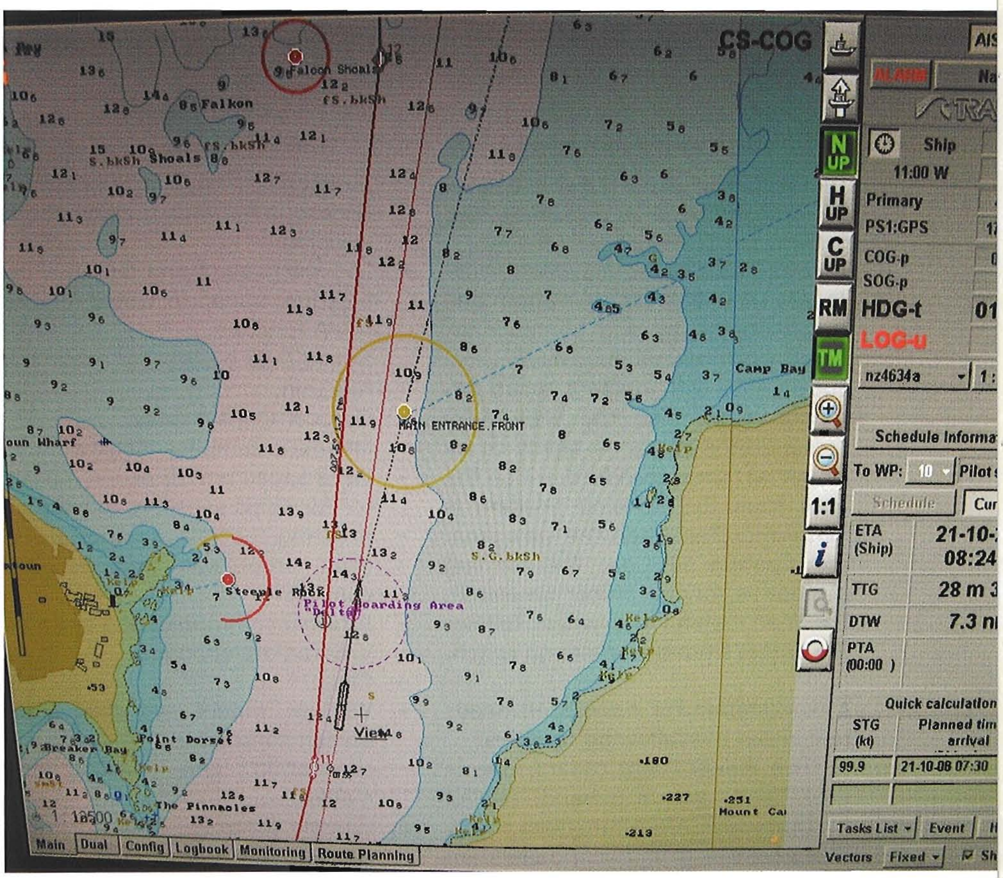
Like the black boxes carried on aircraft, VDRs enable accident investigators to review procedures and instructions in the moments before an incident and help to identify the cause of any accident.
The data acquisition cabinet is normally installed in or near the wheelhouse, the data capsule on the wheelhouse top.
The latter has to be installed so, that it floats up in case the ship sinks.
The device has to be tested yearly by an approved company.

1.14 Electronic Chart Display. (Ecdis)

Instead of paper charts, the information is displayed on a computer screen. On this screen also the ship's position is shown.
The charts can be raster-type, which means that they are scanned paper charts, or vector type, fully digital. The last type has advantages.
The electronic chart can be combined with AIS and Radar, this means that all information can be made visible on one screen.
Updates of the charts are carried out digitally.
A second system has to be provided for back-up. Paper charts also can be the back-up, but this means that they have to be corrected.
Raster-type charts are not approved for paperless sailing

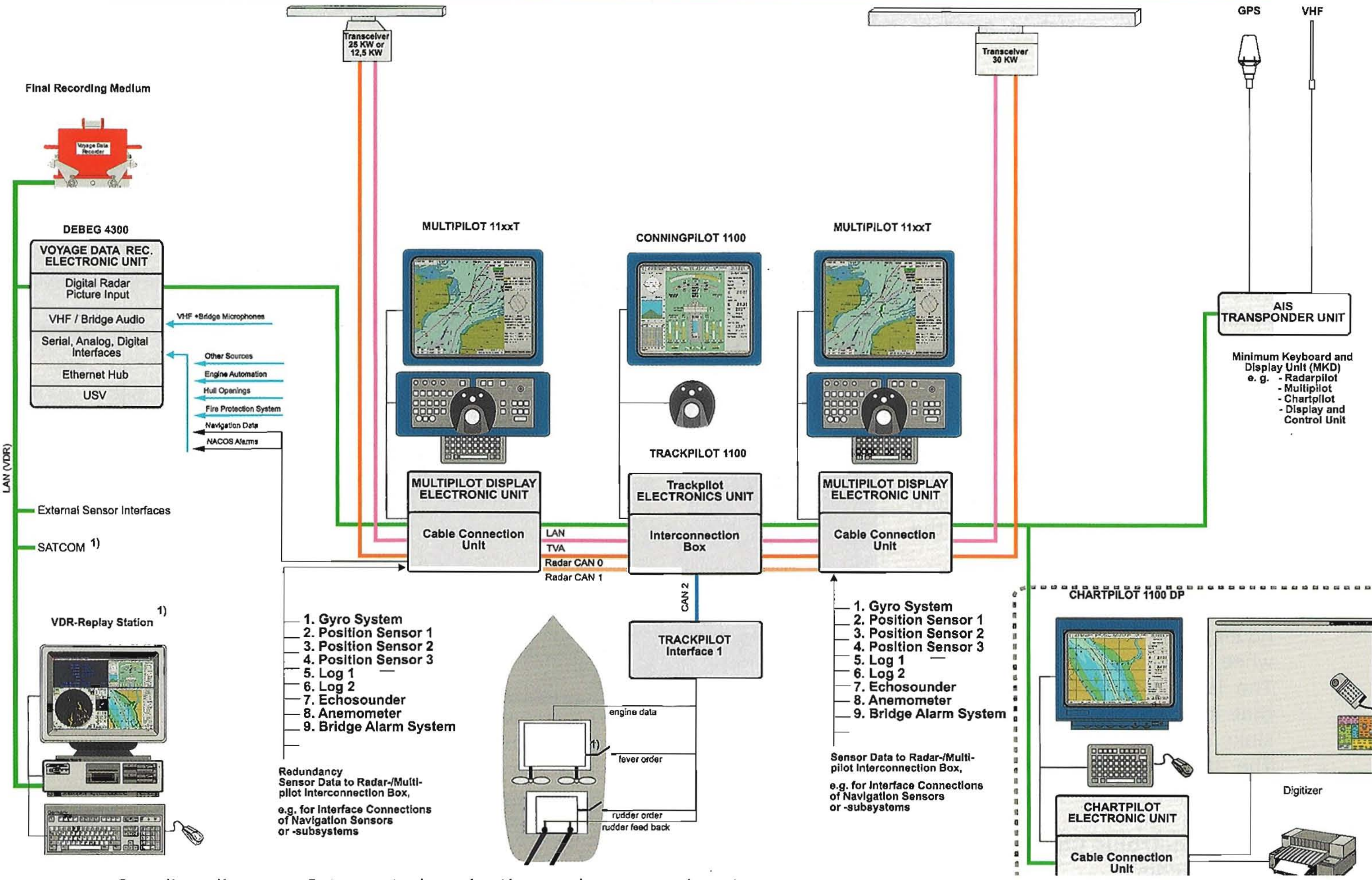


Above the AIS displayed on the radar screen.
Below the ECDIS display of the same area.
The ship is displayed on both screens



2 BRIDGE WITH ONE PERSON ON WATCH

Ships can have an optional class notation for optimizing the environment on the bridge for navigational tasks including periodic operation of the ship under the supervision of a single watchkeeper. The related requirements are in addition to those applicable in other parts of the Rules. The requirements are based on the understanding that the International Regulations for Preventing Collisions at Sea and all other relevant regulations relating to Radio Communication and Safety of Navigation are complied with.



One-line diagram. Intregrated navigation and command system. All functions can be carried out from every workstation

The next step up, and a consequential development is the Integrated Bridge.

Today's state of the art wheelhouses are suitable for operation and watchkeeping by one person only. Apart from wheelhouse layout requirements with respect to an all-around view, also the view from the operator positions needs to be looked at. On a standard bridge the view from the conning position is more important than the view from the steering position. The conning position is for the officer on watch, the man behind the wheel follows the orders from the officer on watch.

A workstation for navigation needs to contain the following facilities:

- Two independent radars, one in X-band, one in S-band, one of them with ARPA function
- Indicators from two independent autopositioning fixing systems,
- Echosounder with shallow depth warning,
- Log with speed and distance indication, speed in water for the ARPA function,
- Speed over bottom for autotrack function,
- Gyrocompass display,
- Magnetic compass display,
- Wind speed and direction indicator for ships sensitive to wind,
- Steering controls and indicators,
- Main propulsion and thruster controls.
- Internal communication systems
- VHF radiotelephones
- Clock
- Window wipers and clear view screen controls
- Navigation light controls and alarms
- Whistle controls
- Decklighting controls

This list shall be completed with additional equipment as required for the special purpose of the ship, when applicable.

A voyage-planning workstation shall be provided with a chart table with instruments, position fixing systems and time indication.

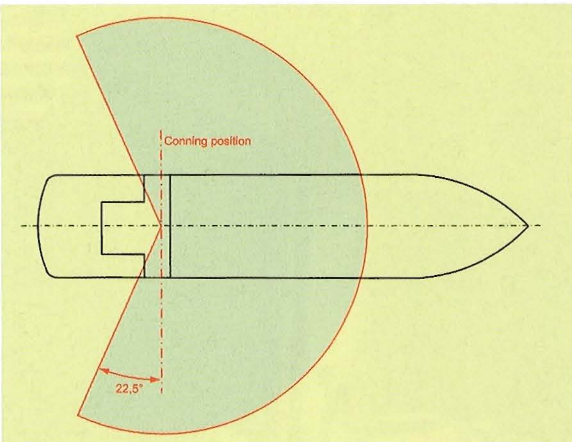
A navigation alarm system shall be fitted consisting of following alarms:

- Closest point of approach from ARPA radar,
- Shallow water warning from echosounder,
- Off-course alarm from a directional device,
- Navigation light failure,
- Power failure to the navigation and nautical supply panels.

Any of these alarms has to be accepted by the watchkeeper within 1 minute.

1. Wind
2. Speed (speed over ground)
3. Course record
4. Rate of turn
5. Heading
6. Course
7. Speed (speed through water)
8. Propulsion information
9. Rudder positions
10. Voyage planning
11. Position

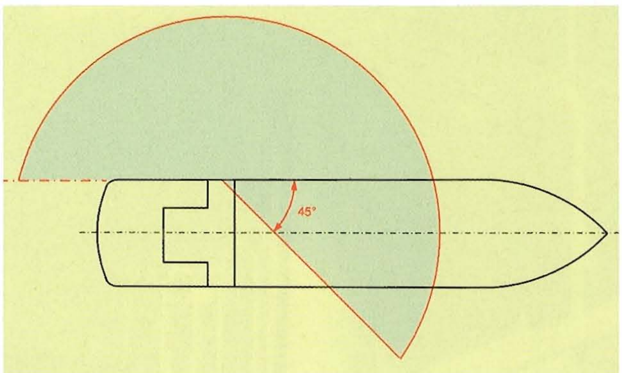
Display on conning position.



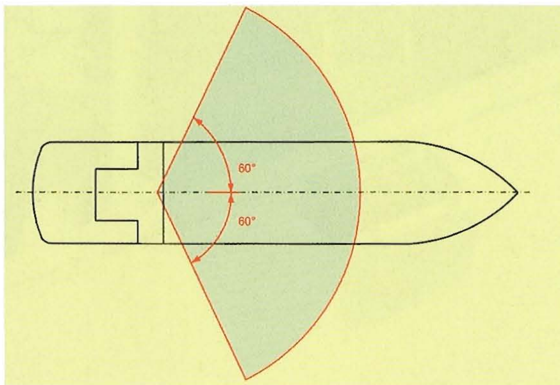
Required view from conning position and navigation workstation

Also the watchkeeper safety timer (11 minutes) has to be accepted by the watchkeeper within 1 minute. When acknowledgement is not given by pushing a button, the captain and the second watch keeper on duty will be alarmed.

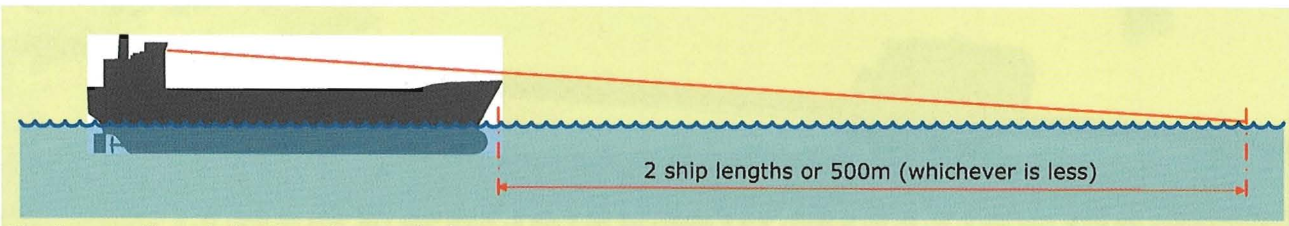
Alternative for the reset of the safety timer, operation of any of the bridge equipment may reset the timer.
It is then advised to reduce the time-leg.



Required view from bridge wing



Required field of view from main steering position"



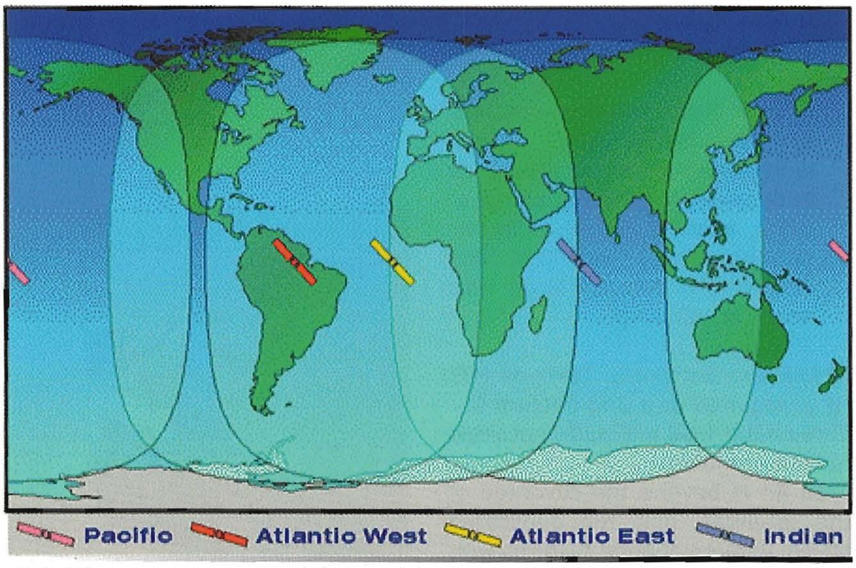
Maximum allowed dead angle in sight line from bridge

22. COMMUNICATION SYSTEMS

1 Ship - Shore

Communication between ship and shore and between ships and ships is worldwide standardised in the GMDSS system.
The international Maritime Organisation, IMO , is the regulating body.

GMDSS stands for Global Maritime Distress and Safety System. It makes use of the satellite communications now available through the international maritime satellite INMARSAT system. INMARSAT is a co-operative organisation, which includes about sixty countries, which fund and take compensation according to each member's use of the system. Geostationary satellites are positioned about 36,000 kilometres over the equator to provide nearly complete global coverage (A3). The extreme north and south polar regions are not covered (A4).
The system provides automatic communications with an override facility for distress calls.
Several service standards are provided.
INMARSAT B and C have a distress alerting facility at the press of a button.
Areas served by VHF shore stations are called A1 and areas served by MF/HF shore stations are called A2.

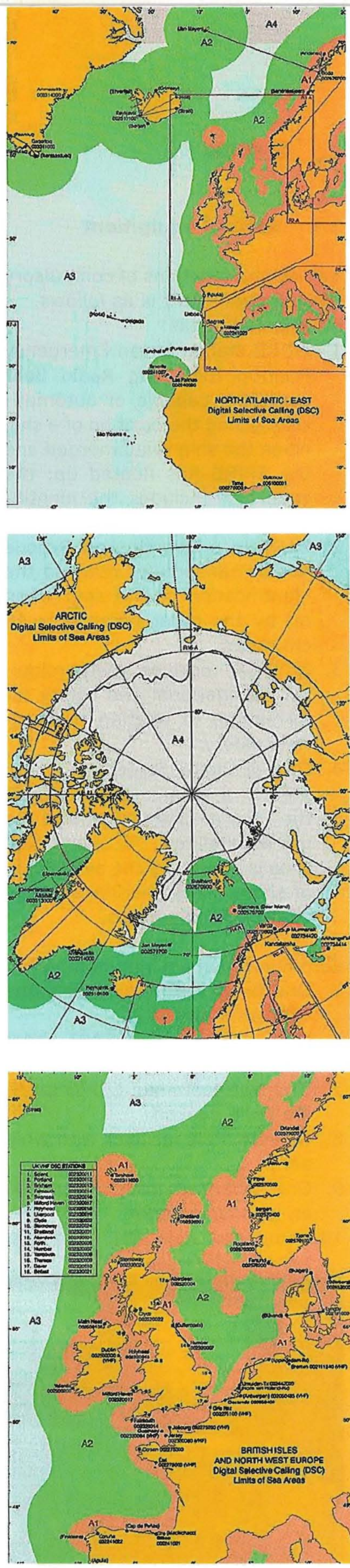


Satellite coverage around the world.

The four GMDSS sea areas are designated A1, A2, A3 and A4:

- Sea Area A1 means radio coverage of at least one VHF coastal station in which continuous DSC alerting is available. In principle, this is within 20 miles from the coast of populated areas.
- Sea Area A2 means within radio coverage of at least one MF coastal station in which continuous DSC alerting is available. Range about 40 miles from the coast of populated areas.
- Sea Area A3 includes the rest of the seas within reach of an INMARSAT stationary satellite in which continuous alerting is available.
  The satellites are located above the equator and cover the earth from 70° South to 70° North.
- Sea Area A4 means all areas outside A1, A2 and A3, which in practice means the polar regions of the Arctic and Antarctic.

For the coastal areas, the requirements depend on the capabilities of the coastal stations. Large unoccupied coastal areas have no coastal stations so that equipment for area A3 has to provide communication in those areas.



Charts showing A1 and A2 around the North Sea and the East Atlantic coast. These charts are available for all parts of the seas.
The Atlantic falls primarily in area A3 and north of the Atlantic in the polar area A4.

2. GMDSS

2.1 GMDSS equipment

Names and functions of compulsory GMDSS equipment is as follows.
All ships, all areas:

1. EPIRB stands for an Emergency Position Indicating Radio Beacon. It is capable of automatically giving the position of a ship when the ship is submerged and the EPIRB has floated up; the code also includes the identification of the ship.
2. SART is a Search And Rescue Radar Transponder relaying the identification of the ship when hit by the radar beam of a 10 cm radar.
3. NAVTEX receives meteorological, navigational and safety information, in relation to maritime safety.
4. DSC or Digital Selective Calling. This is a means of alerting in the case of distress without the use of satellites. The operational area is limited by the availability of shore based maritime rescue co-ordination centers.

Communication equipment area A1:

5. One fixed VHF Radio telephone with whip aerials
6. One self-contained SART radar transponder
7. One self-contained EPIRB satellite radio beacon
8. One NAVTEX receiver with whip aerial
9. One enhanced group call receiver, with whip aerial
10. Two hand held VHF self-contained radio telephones

Area A2 includes the above plus the following:

11. One MF Radiotelephone with Digital Selective Calling and either a wire aerial or a tall vertical whip aerial between 9 and 16 metres high or alternatively.
12. One INMARSAT-C satellite communication system with a gyro stabilized, omnidirectional antenna teletype and data. New miniature system SATCOM-M has voice fax and data capabilities and a gyro stabilised directional antenna.

For A2 MF/HF with DSC is mandatory. VHF must be duplicated. Satcom is not Mandatory.

Most in use is SATCOM-C. Newest used Satcom is Inmarsat-F and Fleet Broadband.
A3 includes the above plus the following:

13. One MF Radio telephone system and an INMARSAT-C system with aerials or alternatively, as duplication for the Satcom systems, another MF/HF radio telephone system with DSC and TELEX with another large wire aerial or tall whip.

MF/HF and Satcom C. Telex on MF/HF is required or a 2nd Satcom C
Three hand-held VHF self-contained radio telephones.
Area A4 is beyond the coverage of the satellites, only the duplicated MF/HF Radiotelephone systems with DSC and TELEX are acceptable.

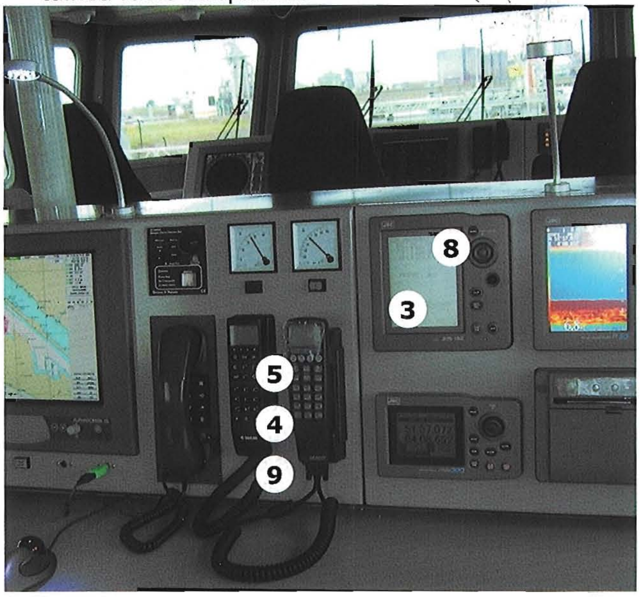
2.2 AIS, LRIT and SSAS

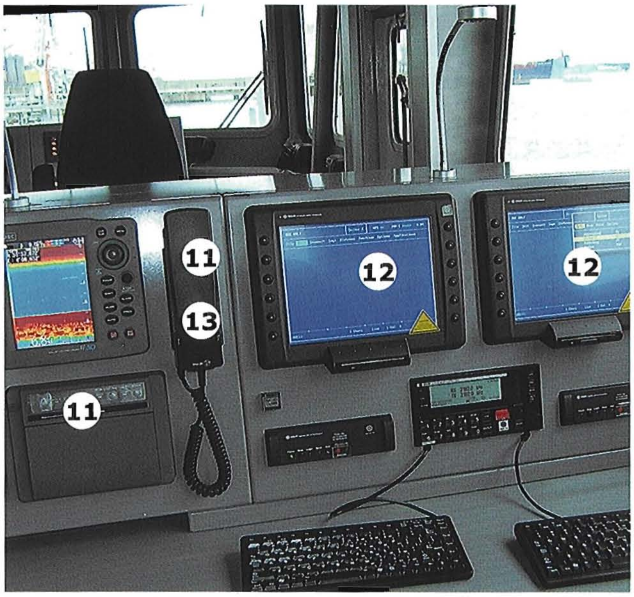
2.2.1 Automatic Identification System

AIS is a transponder system that transmits the ship's data:
name, call sign, dimensions, type of ship, IMO number and variable data as position, course and speed, draught, cargo, destination and Estimated Time of Arrival (ETA) in the VHF band.

The data received from the vessel are processed and combined with the next map of the area where the ship sails and nowadays also posted on the internet. The picture on the next page shows an example of the ships sailing in the English channel with details of one vessel in a pop-up screen after "mouse over".

Epirb





2.2.2 Long Range Identification and Tracking system (LRIT)

The ISPS regulations of IMO require ships to transmit their position every six hours to a central database.
This allows flagstates to verify the position of vessels in their administration worldwide.
This data is transmitted automatically through a suitable transmission system in the radio zones for which the vessel is certified.
The LRIT equipment has to be type-approved.

2.2.3 Ship Security Alert System

A Ship Security Alert System (**SSAS**) is a satellite radio system, providing the ship's staff with a means to alert the homebase, in case of for instance a pirate attack.
In the wheelhouse and somewhere else in the ship, usually the engine room control room, an alarm push-button is installed.
When this pushbutton is used an automatically arranged radio alarm message will be sent to an appointed agent, who on reception can warn the operator and authorities.

2.2.4 Antennas

All equipment mentioned above requires aerials of some sort which have to be located on the topside of the ship. Each aerial has its preferred location, but as space is limited, a compromise has to be found based on the purpose of the ship. Possible interference between the antennas must also be considered (see chapter on EMC).
Other equipment that requires aerials are radio and tv systems and for instance a V-Sat system for telephone and internet communications. More often these are gyro stabilized dish antennas, mounted in domes, that use satellites for data transfer.

3 Maintenance

Maintenance is also part of the GMDSS requirements and is defined as onboard maintenance, shore-based maintenance and maintenance by duplication of equipment on board.
For ships sailing in areas A1 or A2, any of these methods may be adopted in accordance with guidelines contained in the respective IMO resolution.
Shore-based maintenance is the most widely adopted for all areas with the addition of duplication of equipment for areas A3 and A4.
The flag country is usually responsible for the approval of the external communication package.

4 Internal communication

A ship will also have a number of internal communication systems such as:

- automatic telephone
- public address
- general alarm
- radio paging

Sometimes public address and general alarm are combined into one system, escpecially on passenger ships.
Furthermore there may be a number of entertainment systems such as:

- Radio
- Satellite
- Internet

Example of AIS data.
Ships in passage in the English Channel with one ship highlighted.

Antenna and radar mast.
Six whip aerials on left and right, two dome antennas and two radar scanners in the middle and four GPS antennas on top.

23. SAFETY SYSTEMS

When there is fire or flooding in a ship the **Safety Systems** are there to give detection of these events at the earliest time, warn crew and passengers and limit the effects as much as possible. The aim of these actions is to keep the ship in a condition that it remains afloat and safe for crew and passengers to remain on board.

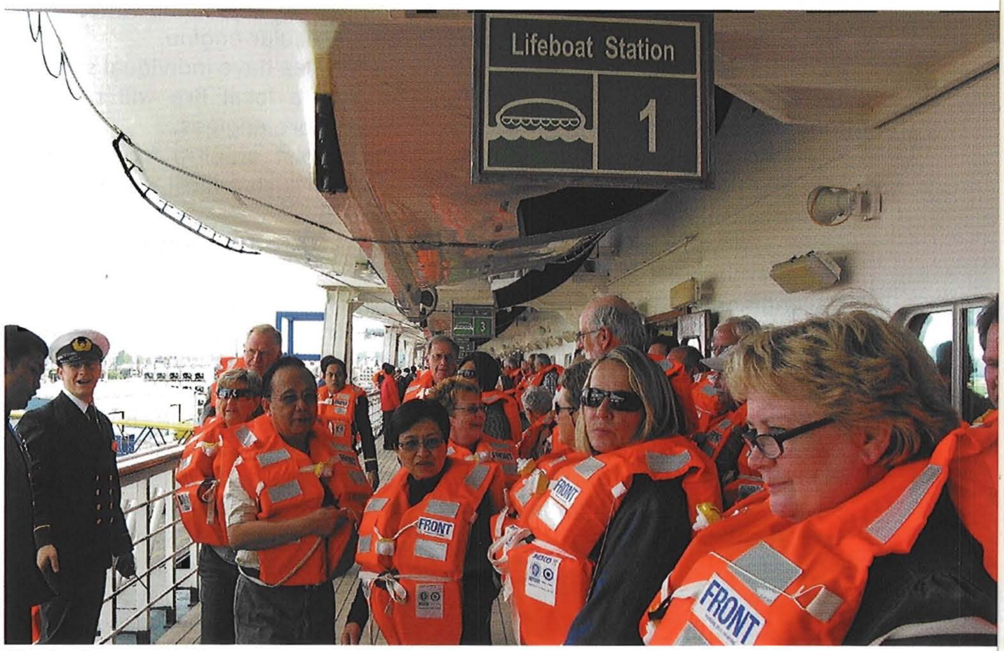
Safety systems can be:

1. Fire safety systems related to the prevention, detection, alarming, encapsuling (limiting to a space) and extinguishing of fires.
2. Crew and passenger safety systems related to alarming people in case of fire or a general alarm and safe evacuation.
3. Watertight subdivision of the ship as well as the outside hull openings.
4. The ship as its own lifeboat.

1 General

When one fire zone or watertight compartment of the ship is damaged all safety systems shall continue to operate in all other sections. That means that cables have to be carefully routed, and that fire resistant cables and junction-boxes have to be used for those systems that should remain in operation when a fire or flooding incident occurs.
Fire detection systems cabling has to be routed carefully and when passing from one zone into another or from one engine room into another, the cabling has to be separated.
In this way the detection system continues to monitor all the not yet affected zones.
A public address system, for information to crew and passengers, as well as abandon ship alarms or fire alarms need to have duplicated amplifiers and duplicated fire resistant cable routes.
The junction boxes to the individual speakers have also to be fire resistant, with fused circuits to each speaker.
Power for fire fighting systems and control systems shall not be hampered by a failure in an adjacent zone. So emphasis has to be laid on cable routing and partly fire resistant cabling.

Fire in a container on a containership.



Mustering excercise

Fire station. Hydrant and hose inside the box.

2 Fire safety systems.

2.1 Fire detection and alarm systems.

Detectors consist of heat detectors in galley and laundry, smoke/ heat detectors in cabins and public spaces and smoke/ heat/flame detectors in engine room spaces.
Most systems for larger ships are addressable so that a fire is pinpointed to a cabin or limited space and not to a complete loop that covers a fire zone with many spaces, and many detectors. This makes it easier to attack the fire.

2.2 Fire doors and fire dampers

Fire doors and fire dampers are automatically operated by the detection system or by a heat melting fuse inside the fire damper. Fire doors separate fire zones by closing corridors, normally by deactivating a magnet, keeping the door open when de-activated.
Fire dampers act the same way in airconditioning trunks in the accommodation and in ventilation ducting of in- and outlet trunks of the engine rooms.
In addition to the magnet controls, automatic melting fuses are fitted in the larger dampers to close the damper in case of a high temperature at the fire damper.

2.3 Deluge (drenching) systems

Deluge systems use seawater for car decks of ferries. Dry, open systems are mostly used. When a fire is detected on the car deck the crew will manually start the deluge pumps. The deluge pumps will then pump seawater under high pressure to the effected section of the car deck.

2.4 Local fire fighting

Systems to extinguish a local fire on an engine. In addition to the detectors of the general fire detection system above main auxiliary engines, locally dual detectors are fitted. They operate a shut down and fire extinguishing function for the particular engine.
All engines have individual systems so that a local fire will not shut down more engines.
Water mist or ultra fog is mostly used for such a local system.

2.5 Ultra fog systems

Ultra fog systems use high pressure fresh water which is sprayed through nozzles forming a water mist.
This water mist will cool the fire and extinguish this by taking away the air. This system is mainly used in accommodations where sometimes also sprinkler systems can be used. If the ultra fog system runs out of fresh water it switches over to seawater but this causes more damage to the interior.

2.6 Fire pumps

A number of **fire pumps** is present, pumping water from outboard, and all connected to the fire main line, with connections (hydrants) for hoses so that every location on board can be reached.

2.7 Carbon dioxide

Carbon dioxide (CO_2) or another gas related fire fighting system for engine rooms, cargoholds and galley hoods is always manually operated. When the release box is opened, an audible and visual alarm is activated to warn people inside the relevant space.
The warning system must have two separate, monitored, power supply circuits.

3 Crew and passenger safety systems

- General alarm system, alerting the crew and passengers, ordering them to the assembling locations (muster stations).
- Public address system for the same purpose
- Escape route markings together with emergency lighting.
- Low level lighting to indicate the escape routes in the accommodation in case of smoke.

4 Safety regulations also apply to:

- Watertight doors in watertight bulkheads
- Stern and side doors in the shell plating
- Bow doors, also in the shell
- Subdivision doors in ferry car deck spaces, to avoid the accumulation of large volumes of water on one side that could de-stabilize the vessel and may cause it to capsize.

Test of the drenching system on the car deck of a Ro-Ro ferry

5 The ship as its own lifeboat

In open sea, the largest floating object is the ship itself.
For the safety of people on board, the main challenge is to keep that ship afloat with the vital systems working, and the next challenge is to return to port.
As long as the casualty threshold has not been passed, certain systems should be kept working.

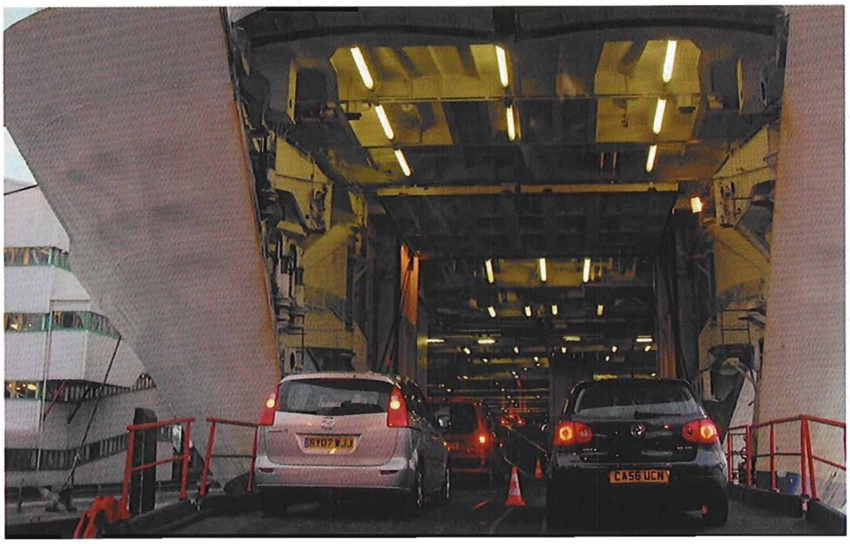
This includes
Machinery:
propulsion, steering, fuel oil transfer, safe area support

Safety:
communications, fire and bilge systems, fire safety and damage control.

When these primary systems can be kept alive and the ship is floating it can be decided to stay on board. Then the decision to sail to a nearest port will be made between the crew and the port authorities and others involved.

The first steps for these safety arrangements have to be made in the design period, where impact on propulsion, power generation, duplication of main components in different compartments is essential.
Passenger ships are usually provided with twin propeller arrangements, but when installed in separate engine rooms, it provides possibilities to enhance safety of the vessel.
It has impact on pipe and cable routing and is similar to DP systems with their redundancy classes.
Electricity in all its forms has to be looked at from this point of view.
Duplication of components also means duplication of power cables and cables for control systems.

This philosophy of the ship as its own lifeboat was developed over the recent years and primarily for cruise ships.
The number of passengers on cruise ships is growing from 2000 to over 5000 and maybe even more in the years to come.



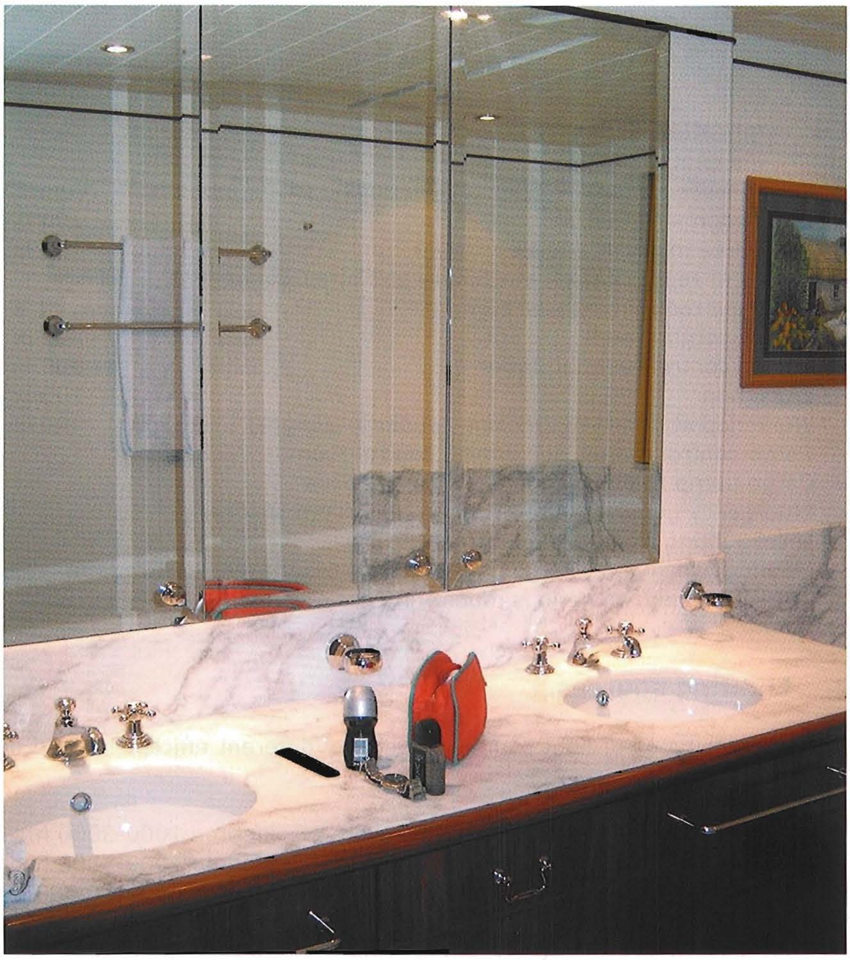
Bow doors of a Ro-Ro car ferry

Ferry with the lower car deck on fire. Note the positions of the A-60 bulkheads between the burnt out car deck and the ventilation ducts and with the accommodation spaces more forward.

Evacuating these large numbers at sea would be an enormous operation so keeping the ship afloat and in operation to some extent would have great advantages.
When a cargo ship is provided with a twin propulsion system, it is worth investigating the impact on such an arrangement as well.

Manual fire alarm push button.

24. LIGHTING SYSTEMS



Lighting systems are designed and installed for several purposes and in accordance with to different requirements.
Examples of lighting systems are work-lighting where the type of work determines the lighting level, orientation-lighting to guide the way without disturbing others and emergency lighting and low level escape lighting for abandoning spaces in case of emergency.

1 Lighting systems

The following lists give a first guidance for lighting levels in work areas. Final figures must be obtained from the applicable Rules & Regulations under contract.

1.1 Living areas:

- Captain class dayroom 150 lx
- Captain class bedroom 100 lx
- Cabin 100 lx
- State -/passenger room 100 lx
- On desk 250 lx
- Berth at pillow 200 lx
- Mirror front 200 lx
- Bathroom 50 lx
- Lavatory/ toilet 50 lx
- Barber shop 200 lx
- Dining saloon/messroom 200 lx
- Dining table 250 lx
- Recreation room 200 lx
- Gymnasium 200 lx
- Bars/lounges 50 lx
- Shopping area 200 lx
- Passages/ alleyways 50 lx
- Staircases 50 lx
- Passenger entrance 100 lx
- Outer passage 10 lx
- Swimming pool 50 lx

1.2 Navigation area:

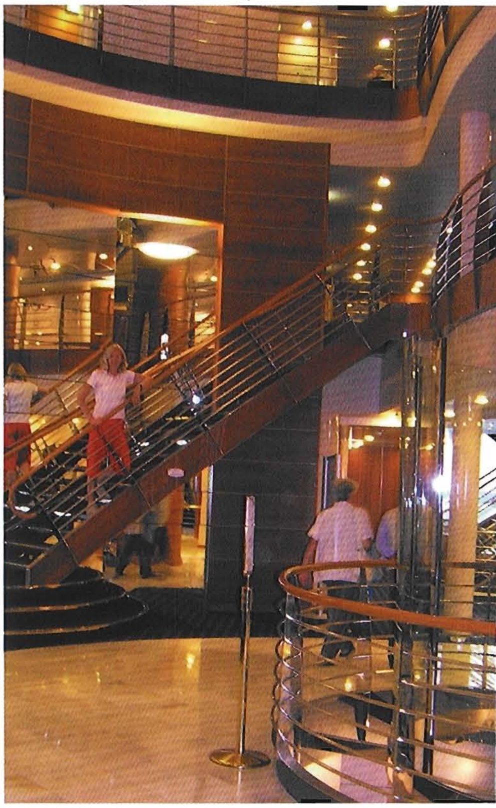
- Wheelhouse 50 lx
- Chart room 50 lx
- Chart table centre spotlights 250 lx
- Radio operator table centre spot lights 250 lx
- Pilot house 200 lx

1.3 Service areas

- Office 100 lx
- On desk 250 lx
- Galley 100 lx
- On cooking range 250 lx
- Provision stores 50 lx
- Laundry 100 lx

1.4 Operating areas

- Main passage, stairs, entrance main engine room, aux. engine room and boiler rooms 100 lx
- Work area in above spaces 150 lx
- Access at rear of tanks, machinery and other equipment in engine room and boiler room 20 lx
- Engine control room 200 lx
- Engine control room at desks 300 lx
- Workshop 100 lx
- Workshop at bench or machine (under local light) 300 lx
- Cargo control rooms, see engine control rooms
- Cargo pump rooms, see engine room spaces
- Emergency generator room, see engine room spaces. Local lighting from local batteries
- Mooring winch area, cargo hold area and other areas that require inspection only, no serious monitoring of equipment 20 lx

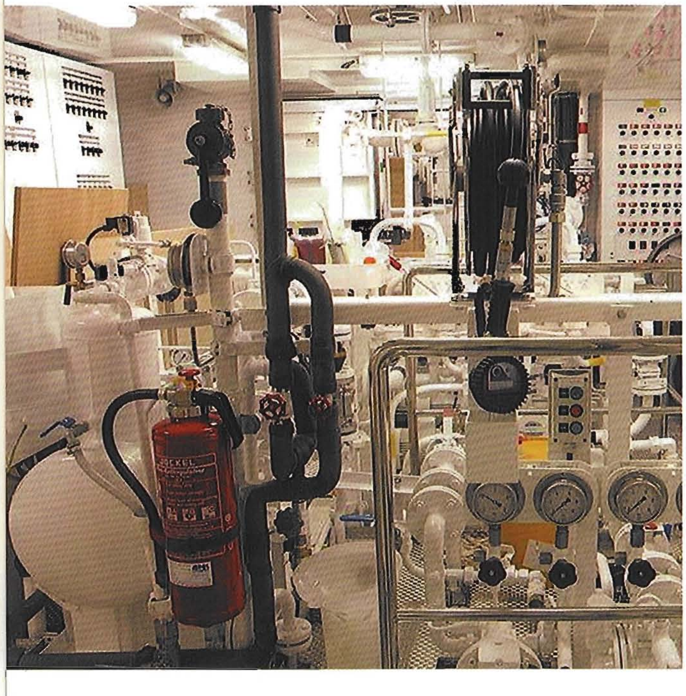


2 Lighting sources.

The different types of light sources have very different efficiencies and life times.

Incandescent bulbs	8-15 lm per Watt,	lifetime 1000-3000 hrs
Low voltage halogen	12-25 lm per Watt,	lifetime 2000-3500 hrs
High voltage halogen	12-25 lm per Watt,	lifetime 4000-10,000 hrs
Fluorescent lighting	47-104 lm per Watt,	lifetime 6000-40,000 hrs
Energy saving bulbs	40-80 lm per Watt,	lifetime 8000-16,000 hrs
High pressure mercury	30-140 lm per watt,	lifetime 10,000 hrs
High pressure natrium	60-140 lm per Watt,	lifetime 8000 hrs
Light emitting diodes	20-50 lm per Watt,	lifetime 50000 hrs
Induction lights	65-70 lm per watt,	lifetime 80000 hrs

When comparing LEDs with traditional halogen spotlights, energy savings of 50% can be attained not only in lighting power, but additionally in the amount of heat produced, which results in less cooling to be done by the air-conditioning system.
Induction lights are not dimmable or available in large types and are considered not suitable for domestic use.



3 Types of lighting systems

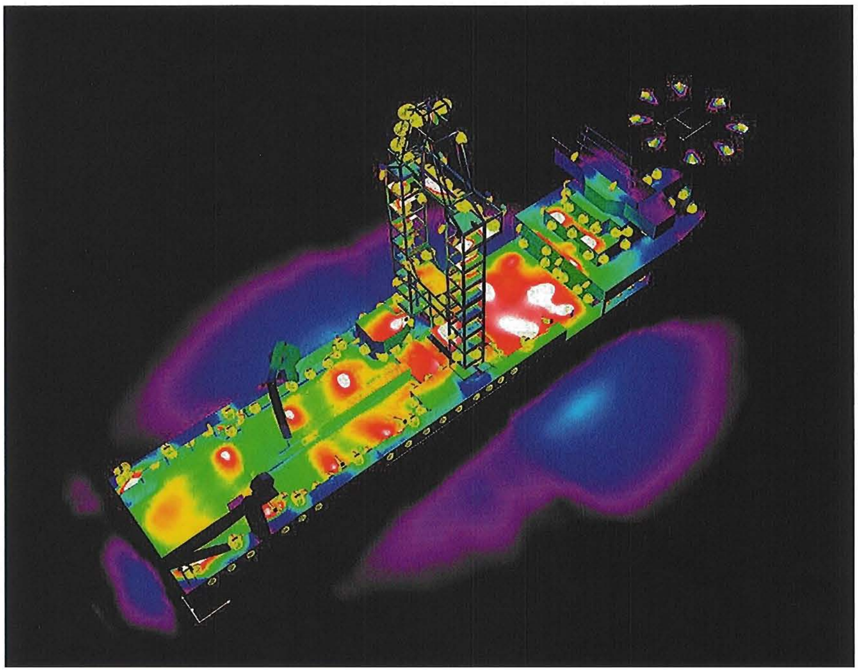
Normal lighting systems are all the systems supplied by the main power source.
The normal lighting system has to be arranged in such a way that a fire or other casualty in the spaces containing the emergency generator, transforming equipment and emergency lighting switchboard does not have any effect on the main lighting system.
Emergency lighting systems must be independent of the main power source and the spaces containing it. Emergency lighting can be subdivided into general, transitional and supplementary lighting.
Escape route or low location lighting is required for passenger ships and has to be independent of other fire zones by means of local power supply units with batteries or fire resistant cables, both ensuring availability of the system for one hour.
Transitional emergency lighting must come from a separate battery, rated for half an hour and has to be adequate to permit safe evacuation in an emergency.

The picture on the previous page (bottom, right) shows various types of plugs for lighting systems.
In Europe the two largest countries France and Germany have developed a plug for earthed circuits that fits in both national standards.
This plug combines the German rim earth with the French third pin earth and is used now in most European countries.

Italy and Great Britain as well as Switzerland are still different but the unearthed European plug fits in the sockets of Switserland and Italy.

Lux is the value for light intensity. Lx in short.
Lumen is the value for light radiation, or the quantity of light in a lightbeam.
1 Lux = 1 Lumen / sq.m.

Dialux overview lighting lay-out Drilling Vessel



Dialux result of lighting calculations in false colours

4. Lighting Calculations

Making lighting calculations during the design period and using the outcome for the installation helps to avoid costly modifications during completion when the actual lighting levels are measured.

There are many lighting calculation programs on the market, both commercial and non-commercial. The pictures on this page are screen shots from the lighting calculations for a Drilling Vessel using such program.

5. Lighting Measurements

On completion the lighting levels should be measured under operational conditions i.e. with all equipment installed and the accommodation spaces with all furniture.

For the lighting measurements a calibrated instrument should be used and the measured data presented in a report. The newer types of lighting measuring instruments have data logging which can be transferred to a PC for further processing.

25. DYNAMIC POSITIONING

This paragraph refers to special ships which are required to stay in position during operation, without the use of anchors or other means fixing them to the seabed.
Dynamically positioned ships include crane vessels, ships for cable laying, pipe laying, pipe trenching, stone dumping, diving support, dredgers and even bunker boats, large yachts and recently, passenger ships visiting exotic locations.

The same systems, known as autosail and auto track, are also used to control a ship when moving from one position to another and when the environment cannot be disturbed by anchors. More and more ships are equipped with such control systems.

DP (AAA) pipelaying vessel at work in deep water

The left page shows the individual thruster control console of a crane and pipe laying barge. These controls are not for operation, as this is nearly impossible for an operator, but for testing procedures of individual thrusters. In the center of the console is a combined control unit, enabling the combined handling of all thrusters to obtain a total output in force and direction.

The basic design criteria, what, where and how are very important for DP applications.

1 DP Notations

Redundancy for vessels with a DP notation is often described as Class 1, 2 or 3.

Class 1 is for simple work with a single automatic control system having a manual back-up, where a loss of position would not lead to a critical situation.
This can be an offshore standby vessel, a yacht or perhaps a passenger ship staying in position with a manned bridge.

Class 2 is for more complicated work with a duplicated automatic control system, where loss of position could lead to more critical situations. Examples are ships for cable laying, pipe laying, trenching, or stone dumping.

An FMEA is required for the control system and the propulsion controlled by the system.
A single failure , such as fire and/or flooding of a space, has to be considered. Notation (AA).

Class 3 is the highest class in redundancy and in use for high-tech deep water pipe laying ships, heavy-lift ships or diving support ships, where loss of control could lead to dangerous situations.
An FMEA is required for the control system and propulsion system, based on a single failure. Flooding and/or fire in a space is also considered. Notation (AAA) or DP3.

When flooding and fire are a consideration for the FMEA, the cable routing from the duplicated control systems to the thrusters and other controlled equipment is vital.

2 DP systems lay-out

A dynamic positioning sytem is built up from hardware, such as propellors and thrusters, where output and direction is controlled by computers, which get information (software) from various sensors regarding wind, position, heading, speed etc.

Depending on the classification of the DP system, redundancy is provided by the number and power of thrusters, computers and input-sensors. The computers process the input and translate this into commands to the thrusters.

The result for the ship may be to stay in position or move according to a defined course and over a defined distance.
It can also be used to sail along a defined track with waypoints. mostly used for cable laying operations which can be done at speeds up to ten knots.

An essential part of a DP system is the Power Management System (PMS). This system regulates the generation and distribution of electrical power. Special operational load calculations are made during the design period including load flows, selectivity issues and switchboard configurations like open or closed bus tie breakers.

DP system designers will use resulting data to calculate the DP capabilty of a ship and produce a so-called DP-footprint. A DP-footprint indicates the operational limits of a DP-ship in relation to the environmental conditions like current and wind and the available thrust.

Redundancy is often determined by a Failure Mode and Effect Analysis (FMEA), a requirement for all ships with a high DP notation.

This analysis does not address the control system only, but all equipment, electric or not, required to stay in position or to perform auto-sail or auto-track as defined in the first design criterion "WHAT".

3 Input sensors

These environmental sensors consist of:

3.1 Gyrocompass

Two or more gyrocompasses determining the heading of the vessel

3.2 Vertical reference units

Two or more vertical reference units which determine roll and pitch of the vessel

3.3 Wind speed and direction

Two or more wind speed and direction monitoring systems enabling the system to react to wind force and gusts before the vessel starts moving.

3.4 DGPS systems

Two or more DGPS systems determining the position of the vessel. Also heading and speed are calculated, provided the ship is moving. Two or more differential receivers for the correction signals of the global positioning system.
For details of navigation and nautical equipment, see paragraph 21

3.5 Taut wires

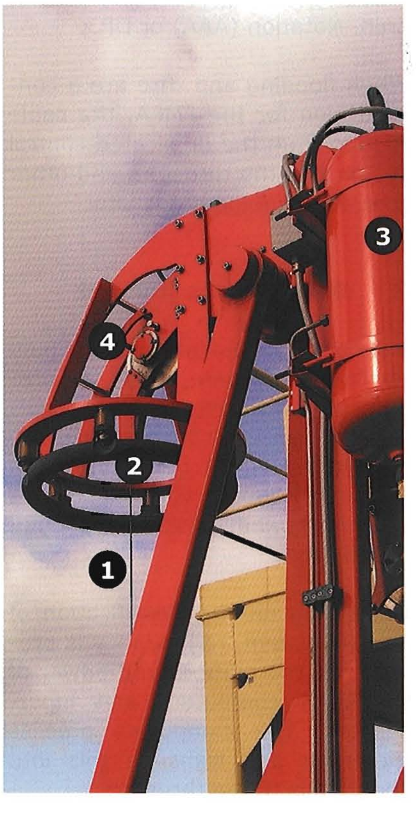
A taut-wire system is basically a self-tensioning winch keeping a steel wire, connected to a weight on the seabed, under constant tension. The wire is led through a gimbal head with transmitters collecting data about the directional angle of the wire in two directions and thus determining the relative movements of the ship.

Computers calculate the movement from the angle, corrected by the angle of the ship from the vertical reference units and the measured wire length or water depth.

1. Wire
2. Ring is limit switch for upper position of taut-wire weight
3. Heave compensator
4. Angle sensor for transverse movement of vessel

3.6 Radar based position systems

Other position reference systems are ARTEMIS: A radar-based system measuring distance and heading from one or more transmitters located at a fixed location.



3.7 Laser based systems

A more modern above water system is FANBEAM, a laser-based system which measures distance and heading from a reflector at a fixed location.
Sometimes this system reacts to the reflectors on safety clothing.

3.8 Under water position systems

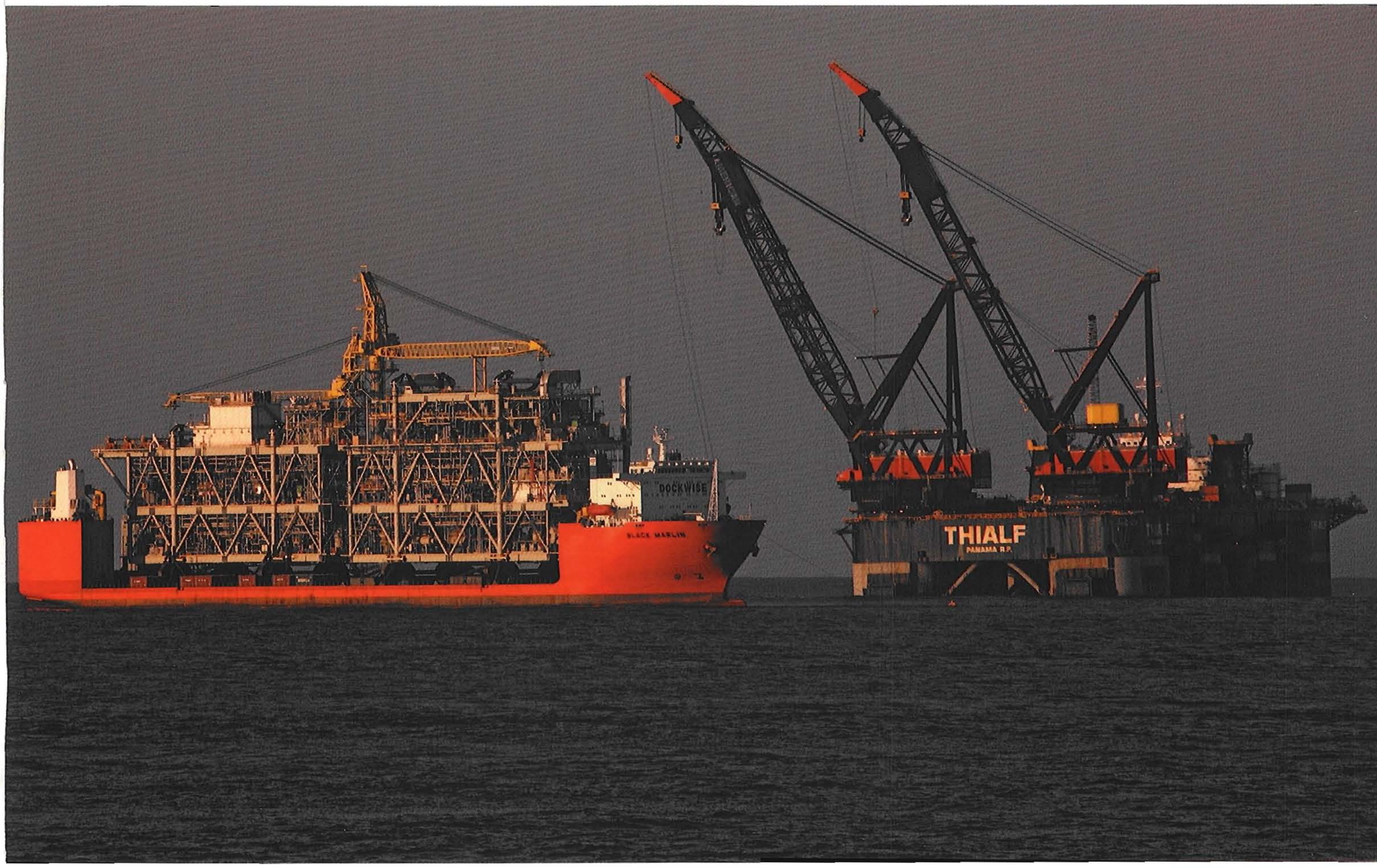
Under water, there are SONAR-based systems reacting to transponders positioned on the seabed. A transponder replies to the sound signals transmitted from the ship and again, distance and heading is measured.

4 Sensor off-sets

For an accurate system all the relative distances between the DGPS aerials, the locations of the taut wires, the LASER directors and the SONAR beams. have to be known and fed into the computer systems. The signal input to the computer has to be corrected for all these permanent off-sets.
Also the changes as a result of the movement of the vessel are corrected by the computer system.
As an example the system will try to keep the antenna of the DGPS system in a fixed position.
Rolling of the ship will move the position of the antenna and if not corrected will activate thrusters.
The same will happen if the operator changes from DGPS1 to DGPS2 if the system does not know the off-sets of the antennas.

The location on the ship to be kept in place by the DP system can be selected depending on the type of work.

Depending on the type of work, and the location of the tool on board to do the work with, offset can also be determined for the tool.
For a stone dumper, the end of the fallpipe can be the important location.
For a crane vessel the position of the hook.



DP Cranevessel is making preparations to lift a topsides from the submersible heavy cargo ship

5 Locations and types of propulsors

These different applications determine the required locations and types of propulsors.
The name propulsors is chosen to address the variety of thrusters such as:
- Variable pitch fixed speed unidirectional thruster
- Fixed pitch variable speed omni-directional thrusters

Both types are also available as Azimuth thrusters where the direction of the thrust can also be controlled. azimuth thrusters are made as fixed and as retractable.
Fixed pitch variable speed reversible tunnel thrusters as well as variable pitch fixed speed tunnel thrusters are used.

These thrusters can be diesel driven or diesel electric from one or more generators.

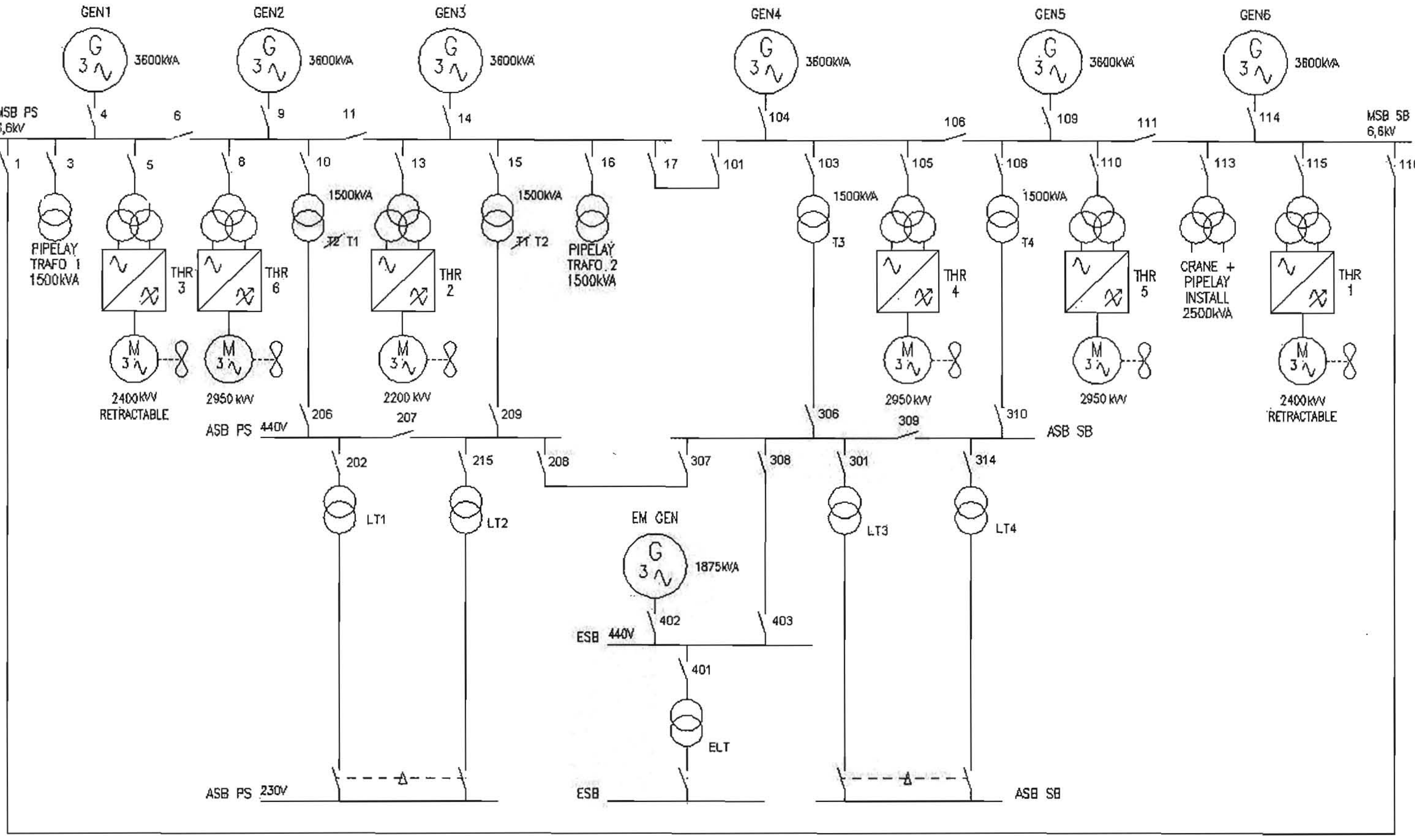
6 FMEA : Failure Mode and Effect Analysis

6.1 Preface to FMEA

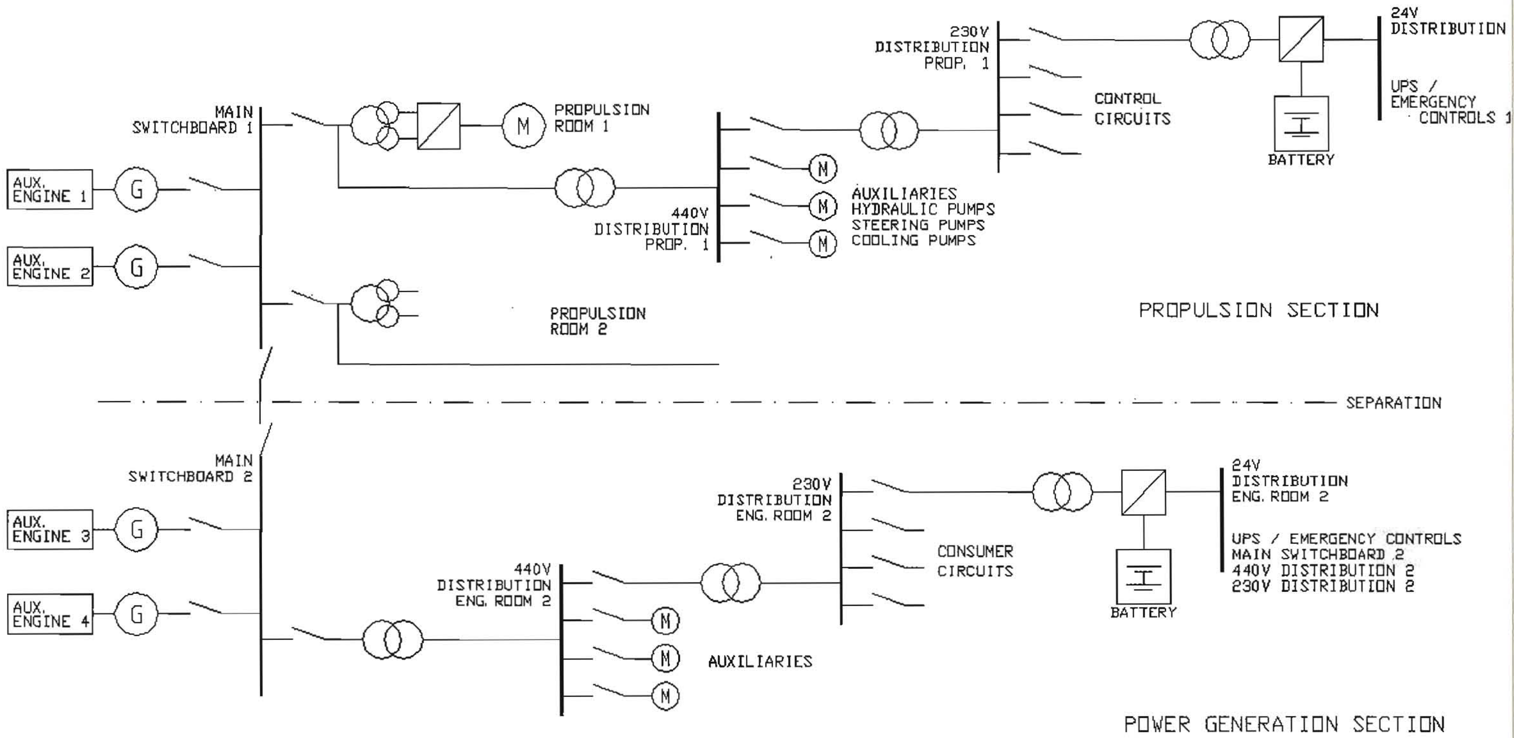
Both notations DP (AA) and DP (AAA) have to be verified by a FMEA. This is a method used to determine the consequences of a single failure in the propulsion system and the propulsion control system.

For a diesel electric propelled vessel it begins with the fuel tanks and fuel system, identifying single failures on an empty tank, a failing separator and a failing booster pump and lists the consequences for the propulsion system.
As long as only one propulsor gets involved there is no cause for alarm. As soon as more than one propulsor gets damaged by a single failure upstream of the propulsors, it should be identified so that possible solutions can be determined.

The fully redundant system does not only take into account the equipment located in a space, but also the cable routes to and from the redundant equipment.
An example of non-redundant cable routing is: A power cable for thruster 1 and a control cable of thruster 2, (which is intended to be the back-up of thruster 1), both located at the same cable tray, would not be redundant in case of fire in this space.
Also, if a thruster requires more power sources, for instance 10kV for the main motor, 440 volt for the hydraulic pumps and the lubricating oil pump, 220 volt for the main control system and 24V DC for the emergency control system, it may be far more redundant to obtain all the AC voltages from a single source and obtain the emergency controls from a common DC system.


GEN1
3600kVA
GEN2
3600kVA
GEN3
3600kVA
GEN4
3600kVA
GEN5
3600kVA
GEN6
3600kVA
MSB PS 6,6kV
MSB SB 6,6kV
PIPELAY TRAFO 1 1500kVA
THR 3
THR 6
THR 2
THR 4
THR 5
THR 1
1500kVA
T1
T2
T3
T4
PIPELAY TRAFO 2 1500kVA
CRANE + PIPELAY INSTALL 2500kVA
2400kW RETRACTABLE
2950 kW
2200 kW
2950 kW
2950 kW
2400kW RETRACTABLE
ASB PS 440V
ASB SB
LT1
LT2
LT3
LT4
EM GEN
1875kVA
ESB 440V
ELT
ASB PS 230V
ESB
ASB SB


SEVEN SEAS



6.2 Example cable laying and repair ship

A visual example provides more information than pages of text. At first, a simplified one-line diagram, with, at the top, the power distribution to the propulsors and their auxiliaries.
The other 3 propulsors have a similar arrangement: one more from switchboard 1 and the two others from switchboard 2.

The engine rooms are self-supporting, so there is no common failure that can affect two engine rooms;, however,, there are common systems for two generator sets such as fuel, seawater and freshwater. This allows fewer generators to operate all thrusters during favourable weather conditions in order to save fuel.

An alternative would be diesel direct drive for each thruster in each thruster room with no common systems. At lower loads, this is not effective with regard to fuel, but a lot of equipment is not required in such a configuration (generators for propulsion, no HV switchboards, no transformers, converters and electric motors).
Instead, there are always four engines running, and because of their limited speed range, variable pitch thrusters are required.
Organizing these systems is an operational choice.
More equipment does not always mean more redundancy.

Direct drives are more efficient than diesel electric systems. The lower part of the above diagram shows half of the distribution system to the generator room auxiliaries.
Here, a common distribution system per generator engine room with one transformer from the high voltage switchboard, one 440V switchboard, and another single transformer 440/230V to another single 230V switchboard and a single 24V DC battery-fed UPS system for emergency controls.
This 24V DC could also control the HV circuit breakers which usually lock mechanically in their open or closed position and require power to be operated or opened.
This power is always from a UPS type of power supply to guarantee opening of the circuit breakers during short-circuit or black-out conditions.

The intention is that with a serious problem in one of the engine rooms, such as fire or flooding, the other operating engine room, with its switchboards HV and LV and 230V as well as 24V DC, is still capable of operating its engines, generators, auxiliaries, switchboards.

With the distribution lay-out to the thrusters, a single failure cannot affect more than one of the propulsors.
The locations and routing of the cables must be such that a fire does not influence more than one propulsor.
The control cables for propulsors supplied from one switchboard can be routed together because a failure of this switchboard would stop these propulsors too.

A similar analysis has to be conducted on the other systems which are required to run the generators and propulsors.
Thus, fuel tank arrangement, filling system, separators, etc. must not depend on any item in the other engine room.
Ventilation arrangement, location of fans, control gear and power supplies must be independent from the other engine room.

Cooling-water systems, both seawater and freshwater, in one engine room must be independent from the other engine room.
Also cooling water for one thruster must be independent from all other thrusters.

Hydraulics for a propulsor have to be independent of all other propulsors, thus, no common tanks.

The propulsion controls should be from the associated 24V DC source for each propulsor.

Within the dynamic positioning system, the control circuits must also be divided over different circuit boards in such a way that a single failure will not jeopardise the function of more than one thruster.

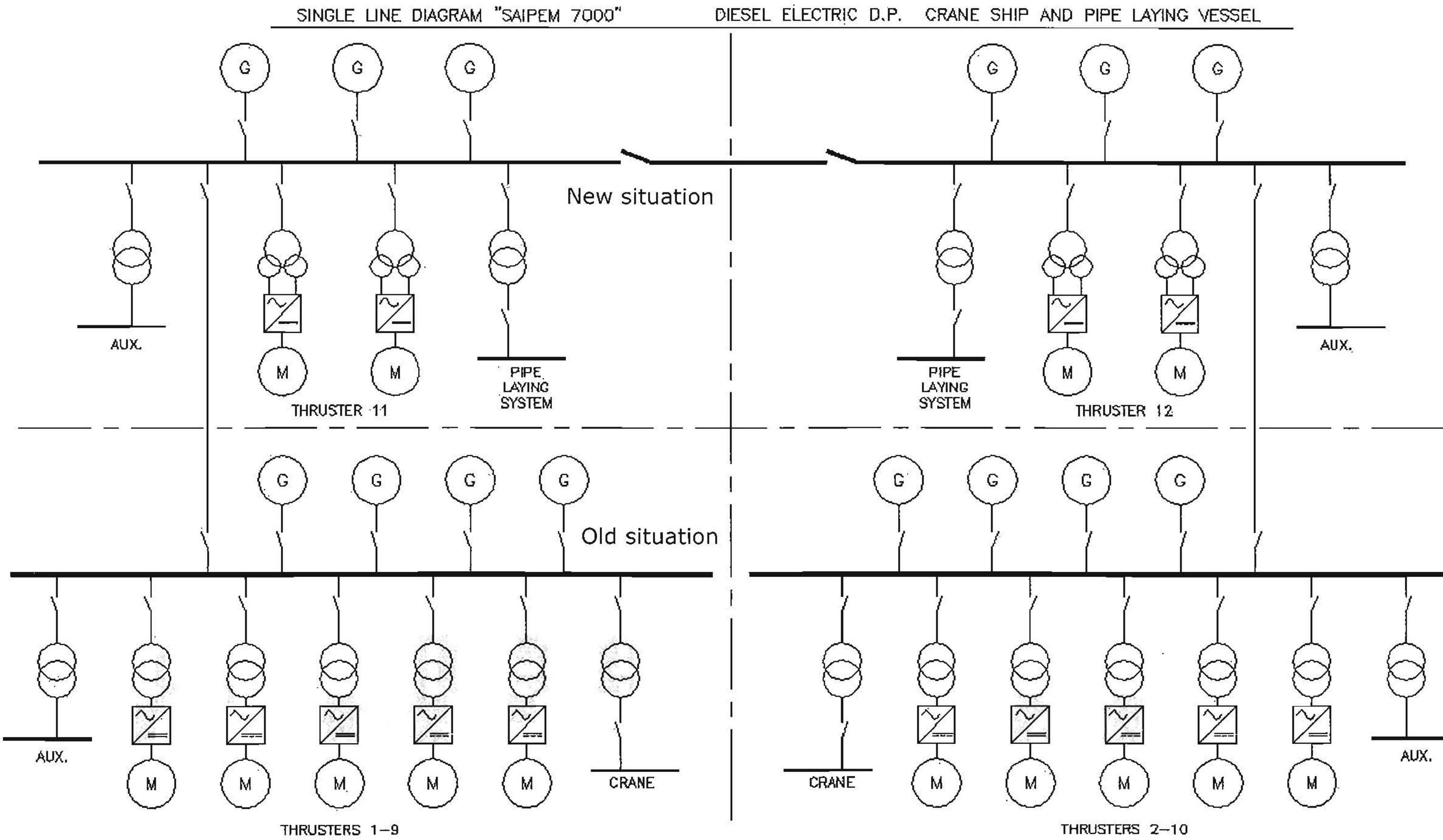
6.3 Example upgrading crane and pipe laying vessel

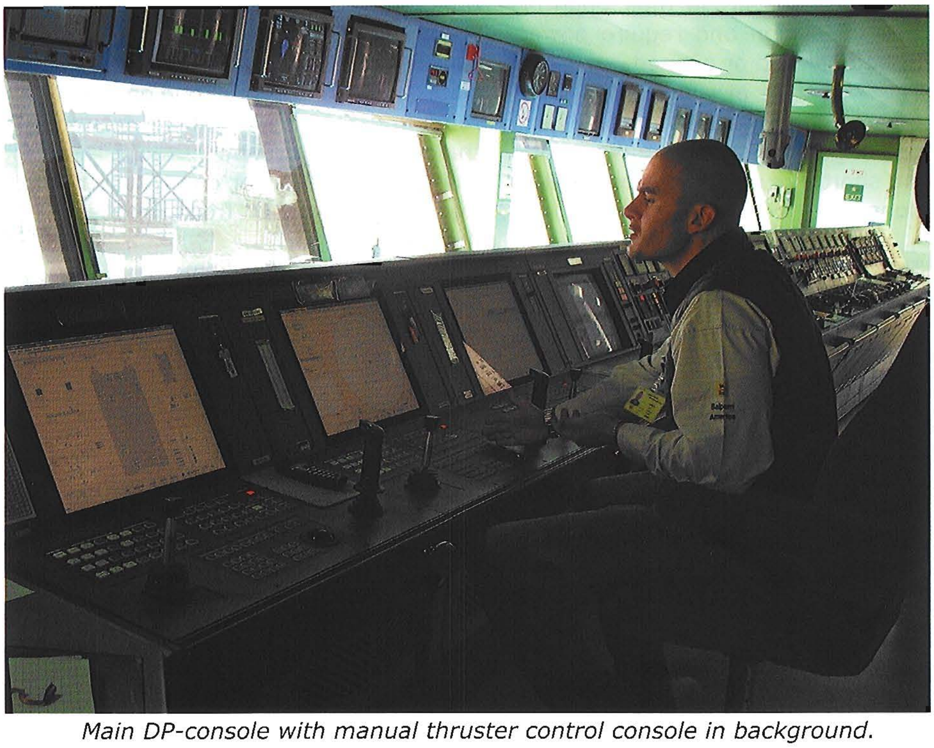
The upgrading of a large crane vessel involved two engine rooms, switchboard rooms and thruster rooms and four new thrusters.

This resulted in class 3 conditions rising from 50% to 75 % of the totally installed and increased generator capacity.

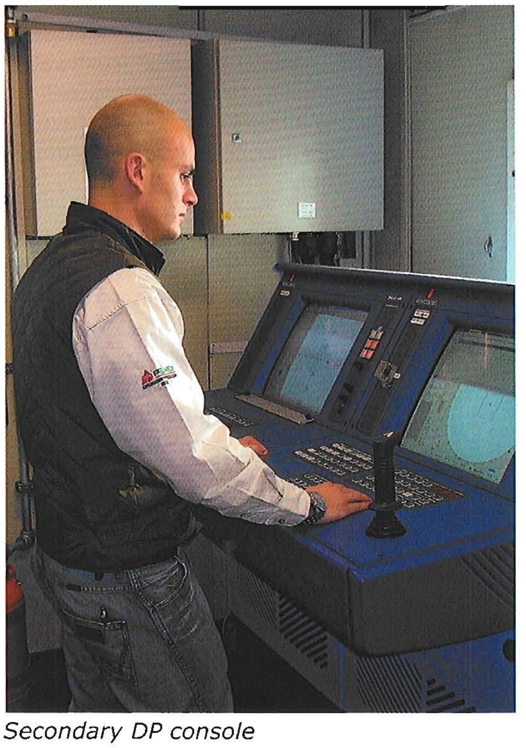
For a (AAA) certified system with a main and back-up computer control system located in a fire insulated (A-60) space, the control cable routing from the normal computer and the back-up computer must be separated over the full length.

The change over from main to backup controls must be physically located as close to the propulsor as possible.





Main DP-console with manual thruster control console in background.



Secondary DP console

6.4 Engine room and bridge checklist

To go into DP is a careful exercise and requires planned action and tests from both the bridge and engine room crew.

The procedures to change to and from DP-mode are as rigid as for the preparation of an airplane before take-off using check lists.

An example of an engine room checklist.

In this example, the Azimuth thruster T3 also requires fresh cooling water from the engine room which has been selected for electric power.

These valves are manually operated and must be in the correct position.

The checklist must be completed by the engine room crew and submitted to the bridge. The bridge crew checks their part of the system and completed their checklist.

When all settings and tests are correct, the vessel can go in DP-mode.

Engine room CHECKLIST				
DATE				
TIME				
DP CASS REQUIREMENTS	1	2	3	4
GENERATION SYSTEM	ON-LINE	AUTO	STAND-BY	UNAVAI-LABLE
MAIN GENERATORS				
G1 PORT OUTBOARD				
G2 PORT INBOARD				
G3 STBD INBOARD				
G4 STBD OUTBOARD				
BUSTIE PORT 690V	CLOSED	BUSTIE STBD	CLOSED	
OPEN		OPEN		
Engine room PORT			ENG.ROOM STB	
BUSTIE PORT 440 V	CLOSED	BUSTIE STB 440V	CLOSED	
OPEN		OPEN		
BUSTIE PORT 230V	CLOSED	BUSTIE STB 230V	CLOSED	
OPEN		OPEN		
	RUNNING	AUTO	RUNNING	AUTO
FUEL OIL BOOSTERPUMP1				
FUEL OIL BOOSTERPUMP2				
G1 LO PRIMINGPUMP			X	X
G2LO PRIMINGPUMP			X	X
G3LO PRIMINGPUMP	X	X		
G4LO PRIMINGPUMP	X	X		
SEAWATERPUMP1				
SEAWATERPUMP2				
FRESHWATERPUMP1				
FRESHWATERPUMP2				
STARTAIRCOMPRESSOR1				
STARTAIRCOMPRESSOR2				
EMERGENCY GENERATOR				
PROPULSION SYSTEM				
T1 PORT AFTER	AVAILABLE	UNAVAILABLE		
T2 STBD AFTER	AVAILABLE	UNAVAILABLE		
T3 AZIMUTH FWD	CB PORT		CB STBD	
	CLOSED	OPEN	CLOSED	OPEN
	F.W. VALVES PS		F.W.VALVES STB	
	CLOSED	OPEN	CLOSED	OPEN
	AVAILABLE	UNAVAILABLE		
T4 TUNNEL FWD	AVAILABLE	UNAVAILABLE		
T5 TUNNEL FWD	AVAILABLE	UNAVAILABLE		

BRIDGE CHECKLIST				
DATE	·	CURRENT SPEED	Kn	DIR degr
TIME		WAVE SIG m	WAVE HEIGHT MAX m	
DP CASS REQUIREMENTS	**1**	**2**	**3**	
MAIN GENERATORS				
ENGINERROM PORT				
G1 PORT OUTBOARD	ON-LINE	AUTO	STAND-BY	
G2 PORT INBOARD	ON-LINE	AUTO	STAND-BY	
Engine room STBD				
G3 STBD INBOARD	ON-LINE	AUTO	STAND-BY	
G4 STBD OUTBOARD	ON-LINE	AUTO	STAND-BY	
BUSTIE PORT 690V		BUSTIE STBD		
OPEN	CLOSED	OPEN	CLOSED	
Engine room PORT			Engine room STBD	
BUSTE PORT 440 V	CLOSED	BUSTIE STBD 440V	CLOSED	OPEN
OPEN		OPEN		
BUSTIE PORT 230V	CLOSED	BUSTIE STBD 230V	CLOSED	OPEN
OPEN		OPEN		AUTO
PROPULSION SYSTEM				
T1 PORT AFTER	AVAILABLE	UNAVAILABLE		ON-LINE
T2 STBD AFTER	AVAILABLE	UNAVAILABLE		ON-LINE
T3 AZIMUTH FWD	CB PORT		CB STBD	
	AVAILABLE	UNAVAILABLE		ON-LINE
T4 TUNNEL FWD	AVAILABLE	UNAVAILABLE		ON-LINE
T5 TUNNEL FWD	AVAILABLE	UNAVAILABLE		ON-LINE
REFERENCE SYSTEMS				
DGPS1	SATLOCK	DIFFLOCK	MF/HF SAT B	ON-LINE
DGPS2	SATLOCK	DIFFLOCK	MF/HF SAT B	ON-LINE
DGPS3	SATLOCK	DIFFLOCK	MF/HF SAT B	ON-LINE
TAUTWIRE	FRAME OUTBOARD	CONTROL		ON-LINE
HIPAP	VALVE OPEN	DEPLOYED	CONTROL	ON-LINE
SONARDYNE	VALVE OPEN	DEPLOYED	CONTROL	ON-LINE
FANBEAM			CONTROL	ON-LINE
GYRO1	HEADING		ENABLE	PREF
GYR02	HEADING		ENABLE	PREF
GYRO3	HEADING		ENABLE	PREF
WIND1	DIRECTION	SPEED	ENABLE	PREF
WIND2	DIRECTION	SPEED	ENABLE	PREF
WIND3	DIRECTION	SPEED	ENABLE	PREF
VRS1	ROLL	PITCH	ENABLE	PREF
VRS2	ROLL	PITCH	ENABLE	PREF
MAIN CONTROL SYSTEM				
POSITION	**N**	**E**	HEADING	
LAMPTEST	DONE			
GAIN	HIGH	MEDIUM	LOW	
SPEED SET m/s	ROTATION SET degr/MIN			
CENTRE OF ROTATION	MOONPOOL	CRANE SB	CRANE PORT	
LIGHTS AND SHAPES	LIGHTS	SHAPES		
CONTROLLERS On-line	**A**	**B**		
AUTO ENABLE	ON	OFF		
UPDATE On-line	Y/N	Y/N		
OPERATORST ON-LINE	**1**	**2**		
REFERENCE SYSTEMS				
DGPS1			AVAILABLE	ON-LINE
DGPS2			AVAILABLE	ON-LINE
DGPS3			AVAILABLE	ON-LINE
TAUTWIRE			AVAILABLE	ON-LINE
LIMITS F/A m	LIMITS P/S m	WATERDEPTH m		
HIPAP			AVAILABLE	ON-LINE
SONARDINE			AVAILABLE	ON-LINE
FANBEAM	RANGE	BEARING	LEVEL	ON-LINE
BACKUP CONTROL SYSTEM				
POSITION	N	E	HEADING	
LAMPTEST	DONE			
GAIN	HIGH	MEDIUM	LOW	
SPEED SET m/s	ROTATION SET degr/MIN			
CENTRE OF ROTATION	MOONPOOL	CRANE SB	CRANE PORT	
REFERENCE SYSTEMS RENCE SYSTEMS				
DGPS1			AVAILABLE	On-line
HIPAP			AVAILABLE	On-line

26. SPECIAL SYSTEMS

6.4 Engine room and bridge checklist

To go into DP is a careful exercise and requires planned action and tests from both the bridge and engine room crew.
The procedures to change to and from DP-mode are as rigid as for the preparation of an airplane before take-off using check lists.

An example of an engine room checklist.
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When all settings and tests are correct, the vessel can go in DP-mode.

Engine room CHECKLIST				
DATE				
TIME				
DP CASS REQUIREMENTS	1	2	3	4
GENERATION SYSTEM	ON-LINE	AUTO	STAND-BY	UNAVAI-LABLE
MAIN GENERATORS				
G1 PORT OUTBOARD				
G2 PORT INBOARD				
G3 STBD INBOARD				
G4 STBD OUTBOARD				
BUSTIE PORT 690V	CLOSED	BUSTIE STBD	CLOSED	
OPEN		OPEN		
Engine room PORT			ENG.ROOM STB	
BUSTIE PORT 440 V	CLOSED	BUSTIE STB 440V	CLOSED	
OPEN		OPEN		
BUSTIE PORT 230V	CLOSED	BUSTIE STB 230V	CLOSED	
OPEN		OPEN		
	RUNNING	AUTO	RUNNING	AUTO
FUEL OIL BOOSTERPUMP1				
FUEL OIL BOOSTERPUMP2				
G1 LO PRIMINGPUMP			X	X
G2LO PRIMINGPUMP			X	X
G3LO PRIMINGPUMP	X	X		
G4LO PRIMINGPUMP	X	X		
SEAWATERPUMP1				
SEAWATERPUMP2				
FRESHWATERPUMP1				
FRESHWATERPUMP2				
STARTAIRCOMPRESSOR1				
STARTAIRCOMPRESSOR2				
EMERGENCY GENERATOR				
PROPULSION SYSTEM				
T1 PORT AFTER	AVAILABLE	UNAVAILABLE		
T2 STBD AFTER	AVAILABLE	UNAVAILABLE		
T3 AZIMUTH FWD	CB PORT		CB STBD	
	CLOSED	OPEN	CLOSED	OPEN
	F.W. VALVES PS		F.W.VALVES STB	
	CLOSED	OPEN	CLOSED	OPEN
	AVAILABLE	UNAVAILABLE		
T4 TUNNEL FWD	AVAILABLE	UNAVAILABLE		
T5 TUNNEL FWD	AVAILABLE	UNAVAILABLE		

BRIDGE CHECKLIST				
DATE		CURRENT SPEED	Kn	DIR degr
TIME		WAVE SIG m	WAVE HEIGHT MAX m	
DP CASS REQUIREMENTS	**1**	**2**	**3**	
MAIN GENERATORS				
ENGINERROM PORT				
G1 PORT OUTBOARD	ON-LINE	AUTO	STAND-BY	
G2 PORT INBOARD	ON-LINE	AUTO	STAND-BY	
Engine room STBD				
G3 STBD INBOARD	ON-LINE	AUTO	STAND-BY	
G4 STBD OUTBOARD	ON-LINE	AUTO	STAND-BY	
BUSTIE PORT 690V		BUSTIE STBD		
OPEN	CLOSED	OPEN	CLOSED	
Engine room PORT			Engine room STBD	
BUSTE PORT 440 V	CLOSED	BUSTIE STBD 440V	CLOSED	OPEN
OPEN		OPEN		
BUSTIE PORT 230V	CLOSED	BUSTIE STBD 230V	CLOSED	OPEN
OPEN		OPEN		AUTO
PROPULSION SYSTEM				
T1 PORT AFTER	AVAILABLE	UNAVAILABLE		ON-LINE
T2 STBD AFTER	AVAILABLE	UNAVAILABLE		ON-LINE
T3 AZIMUTH FWD	CB PORT		CB STBD	
	AVAILABLE	UNAVAILABLE		ON-LINE
T4 TUNNEL FWD	AVAILABLE	UNAVAILABLE		ON-LINE
T5 TUNNEL FWD	AVAILABLE	UNAVAILABLE		ON-LINE
REFERENCE SYSTEMS				
DGPS1	SATLOCK	DIFFLOCK	MF/HF SAT B	ON-LINE
DGPS2	SATLOCK	DIFFLOCK	MF/HF SAT B	ON-LINE
DGPS3	SATLOCK	DIFFLOCK	MF/HF SAT B	ON-LINE
TAUTWIRE	FRAME OUTBOARD	CONTROL		ON-LINE
HIPAP	VALVE OPEN	DEPLOYED	CONTROL	ON-LINE
SONARDYNE	VALVE OPEN	DEPLOYED	CONTROL	ON-LINE
FANBEAM			CONTROL	ON-LINE
GYRO1	HEADING		ENABLE	PREF
GYR02	HEADING		ENABLE	PREF
GYRO3	HEADING		ENABLE	PREF
WIND1	DIRECTION	SPEED	ENABLE	PREF
WIND2	DIRECTION	SPEED	ENABLE	PREF
WIND3	DIRECTION	SPEED	ENABLE	PREF
VRS1	ROLL	PITCH	ENABLE	PREF
VRS2	ROLL	PITCH	ENABLE	PREF
MAIN CONTROL SYSTEM				
POSITION	**N**	**E**	HEADING	
LAMPTEST	DONE			
GAIN	HIGH	MEDIUM	LOW	
SPEED SET m/s	ROTATION SET degr/MIN			
CENTRE OF ROTATION	MOONPOOL	CRANE SB	CRANE PORT	
LIGHTS AND SHAPES	LIGHTS	SHAPES		
CONTROLLERS On-line	**A**	**B**		
AUTO ENABLE	ON	OFF		
UPDATE On-line	Y/N	Y/N		
OPERATORST ON-LINE	**1**	**2**		
REFERENCE SYSTEMS				
DGPS1			AVAILABLE	ON-LINE
DGPS2			AVAILABLE	ON-LINE
DGPS3			AVAILABLE	ON-LINE
TAUTWIRE			AVAILABLE	ON-LINE
LIMITS F/A m	LIMITS P/S m	WATERDEPTH m		
HIPAP			AVAILABLE	ON-LINE
SONARDINE			AVAILABLE	ON-LINE
FANBEAM	RANGE	BEARING	LEVEL	ON-LINE
BACKUP CONTROL SYSTEM				
POSITION	N	E	HEADING	
LAMPTEST	DONE			
GAIN	HIGH	MEDIUM	LOW	
SPEED SET m/s	ROTATION SET degr/MIN			
CENTRE OF ROTATION	MOONPOOL	CRANE SB	CRANE PORT	
REFERENCE SYSTEMS RENCE SYSTEMS				
DGPS1			AVAILABLE	On-line
HIPAP			AVAILABLE	On-line

26. SPECIAL SYSTEMS

In most cases, **special systems** are in use on special ships.
Its impossible to list all special systems and this chapter therefore highlights some to give an impression.

1 Types of special systems

General cargo vessels like bulk carriers and multi-purpose cargo vessels do not require special systems. They have a number of straightforward systems which have been discussed in previous chapters.

Some examples of vessels with special systems are:
Container ships which have a heeling system to keep the vessel upright when loading and unloading containers.
These ships also have sometimes sophisticated supply and monitoring systems for the cooled containers.
Very Large Crude Carriers (VLCCs) which have large cargo oil pumps on high voltage for cargo discharge.
Luxury yachts that have sophisticated computer controlled lighting and entertainment systems and high-tech AC systems.
Passenger/car ferries have three distinguished areas with each special systems:
passenger areas, car decks and engine spaces.
Dredgers which have large hydraulic control systems for valves and cargo doors, sophisticated electronic systems to control and monitor the dredging process and sometimes very large high voltage dredging pumps.
Chemical tankers which have hydraulic control systems for the cargo valves on deck, tank level monitoring and an emergency propulsion system which is discussed later in this chapter.
Drill ships which have specialized drilling related systems and sophisticated electronic systems to support the drilling process such as a DP system.
A Remote Operated Vehicle (ROV) system is also part of the equipment.
Cable laying vessels, **Pipe laying vessels** and **Diving support** vessels with DP systems have been discussed in an earlier chapter.

Very Large Crude Carrier (VLCC) and car ferry

2. Examples of special systems

2.1 Helicopter facilities

Helicopter facilities are provided on many ships.
Large oil tankers, bulk carriers and container ships have helicopter landing areas on deck to get a pilot on or off the ship.
Special, pre-fabricated large helicopter platforms usually installed on large offshore equipment, such as drilling rigs, diving support ships, pipelaying barges, crane vessels, etc. These are normally made of aluminium.
These platforms are then used for crew changes and or delivery of supplies when the vessel is remote from shore. When the distance is large from the shore base a helicopter must be refuelled on the vessel and the helideck then will have a heli refuelling system.

Large yachts increasingly have helicopter facilities and sometimes indoor stowage facilities for a small, two- or four-seat, helicopter.

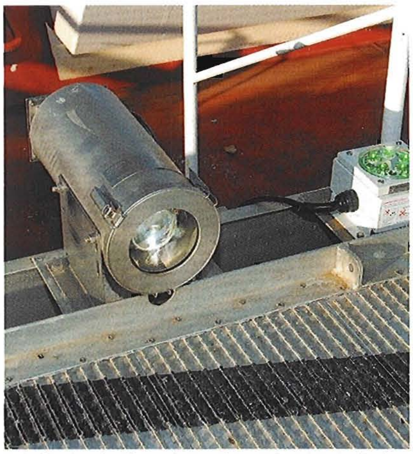
For larger certified helicopter decks there are a number of requirements to be fulfilled which are detailed in the Offshore Helicopter Landing Areas - Guidance on Standards CAP 437 which is issued by the UK Civil Aviation Authority.

Larger certified helicopter decks have special lighting arrangements for night operations with perimeter lighting, flood lights and windsock lighting.
When there are large objects in the approach path of the helicopter these have to be provided with red obstruction lights.
In addition to the above, drilling vessels must have one or more Heli Status Lights which are connected to the Emergency Shutdown System (ESD) and are activated when there is a degradation of the safety level on the vessel. An approaching helicopter will be warned not to land. When already landed to take off immediately.

When helicopter refuelling is required the fuel pumps must be provided with an emergency stop from a safe location and the associated control equipment must be an explosion-proof type.
Furthermore an approved semi-conducting delivery hose on a storage reel must be fitted and a suitable (high visibility) bonding cable must be used to earth the helicopter frame to the ship's construction before any refuelling (or de-fuelling) commences.

Helicopter systems also include communication systems and approach beacons.

Heli windsock


Heli deck flood and perimeter light

2.2 Shaft Generators

Electric power on board ships is normally created by independent diesel generators.
However, necessary power can also be produced by the main engine through an attached generator, which is either always rotating when the main engine is running or attached via a coupling.
With a coupling the generator can be connected when required.
When the shaft generators have the same rating as the diesel generators these can be switched off at sea. This electricity produced by the main engine is cheaper due to the use of cheaper fuel.

Various configurations and options are available. One main engine or two. One shaft generator or more. Direct-driven or via a reduction gearbox.

When the main engine is a long stroke slow-running engine, a very big multi-pole shaft generator running at shaft speed or a step-up gear is necessary to drive the generator.
Between the diesel and the shaft generator other kinds of drives can be used: V-belts or even chains or a clever type of transmission which changes variable speed into constant speed within certain limits.

2.3 Exhaust-gas powered generators

Large container ships produce a lot of heat with the huge, high powered main engine. This heat, in the form of exhaust gas, is utilized for other purposes as far as practicable, by making steam in an exhaust-gas boiler. The steam, when superheated, is sufficient to drive a steam generator.
This steam turbine driven generator produces more than sufficient electric power for the ship's normal use. This surplus power can be used in an auxiliary electric propulsion motor and provides power for the propeller shaft. In this case, a shaft generator is not needed as the heat from the main engine can be used to produce the necessary electric current.

Auxiliary diesel generators are installed to produce power when the ship is in port.

2.4 Emergency propulsion

Emergency propulsion is a system which is used on for instance chemical tankers where an accident with the vessel and spill of its cargo could have grave consequences.

The basis of emergency propulsion systems is a shaft generator or PTO (power take off) generator, converted by switchgear into an electric motor, supplied by auxiliary generators.

As a generator is not identical to a motor it can only produce torque as a motor after it has been synchronised and switched to the main power plant.

Some systems use a small electric motor, a pony motor, to drive the generator up to synchronous speed and then synchronising and closing the circuit breaker.
Another solution is to change the generater into a motor during this running up period.
This is done by short-circuiting the rotor windings with a device fitted on the rotor. As soon as the rotor runs synchronously, the short-circuit is interrupted and the rotor is excited by the AVR.

For inland tankers on the River Rhine it is obligatory to have emergency propulsion capable of reaching 10 km/hr.
In some cases this is provided by the omnidirectional bow thruster, using the thrust in aft direction or through a shaft generator, configured as an electric motor.

2.5 Remote Operated Vehicle

Remote Operated Vehicles **(ROV)** are small robots with cameras, lights and arms that can be used to survey the seabed and work on connections.
Special consideration should be given to the quality of the power supplies to a ROV.
Any disturbances, from for example harmonic distortions in the ship's electrical system, are amplified due to the capacity and the length of the umbilical cable.
In some cases it is therefore advised to use a rotating motor-generator converter to produce clean power to the ROV system.

An ROV is launched from the vessel and then controlled from a ROV control desk.
The electrical supplies and controls are transferred via an umbilical cable.
As an ROV can operate at great depth the power supply for the propellers on the unit are fed with 3000V from a dedicated switchboard.

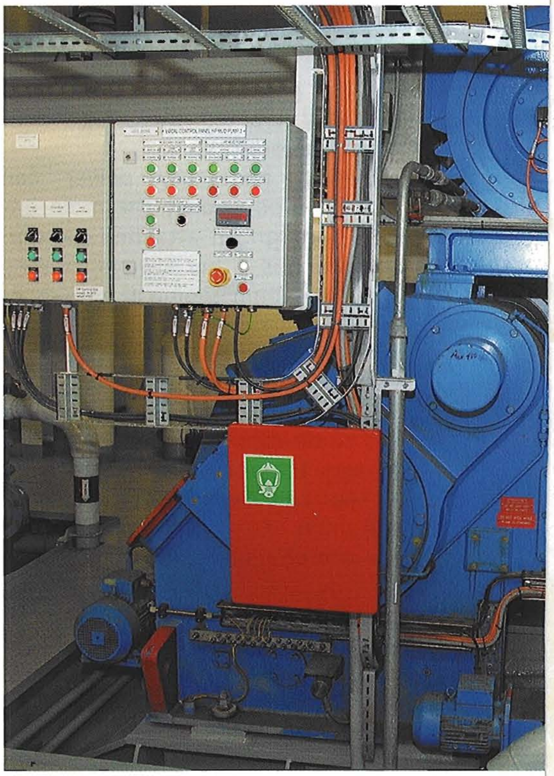
ROV launch equipment

ROV Control desk

2.6 Drilling Equipment

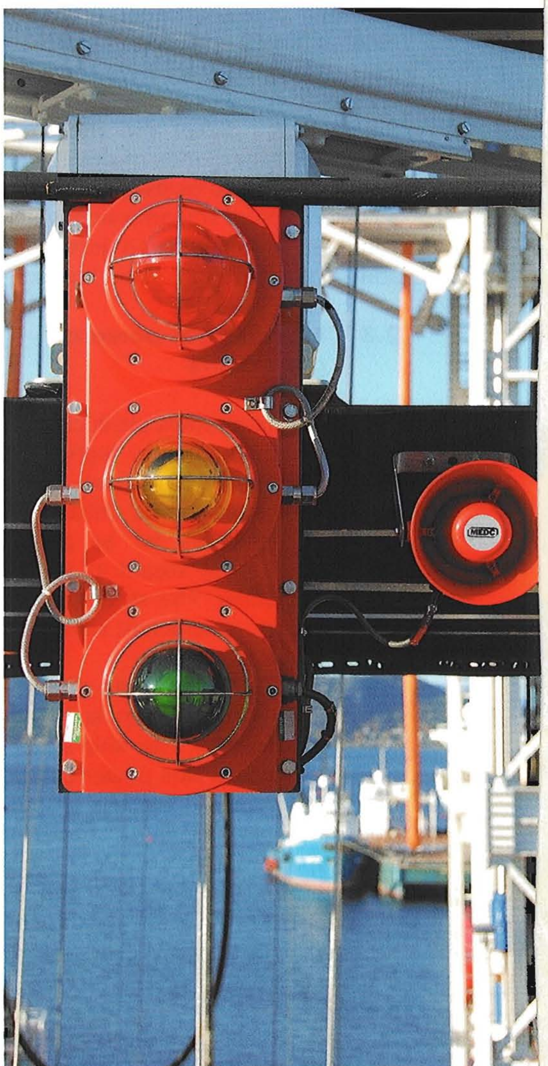
Drilling vessels have many highly specialized systems on board.
Although the type of drilling determines the typical configuration there are a number of standard systems like the drill equipment and iron roughneck, the system to hold the drill pipe, that can be found on all drilling vessels.
A low and high pressure mud system, to bring mud for drilling to the bore hole, will also be installed.
When the operations involve drilling for oil or gas there will be extensive hazardous areas with safety systems, such as fire and gas detection and an emergency shutdown system.

To alert the crew when the DP system is degraded or when the DP cannot hold position due to changed environmental conditions a DP alert system will be fitted. This system comprises signal colums as a sort of traffic lights and an alarm horn which will sound on a change of status.



HP Mud pump with auxiliary controls

Drill floor with topdrive



DP alert column with alarm horn

2.7 Pipe laying barges

Pipe laying at sea is a complicated procedure, especially when dealing with large pipe diameters in the order of one metre.
Pipe laying vessels most of the time are converted ships or barges on DP, where the thrust of the propulsers is not only used to hold the vessel on location but also to deliver the pulling force for the pipe, hanging down from the barge.
The pipe is held strongly by the tensioners, large hydraulic clamps, preventing the pipe dropping from the vessel.
The water depth can be as much as 2500 metres.
The electrical demand is huge.
The main consumers are the thrusters, tensioners, welding, lots of hydraulic systems, many cranes, and an accommodation for up to 400 persons. And all those systems are in use at the same time, 24 hours a day.
Six or eight large capacity diesel generators, each in the 3-4 MW range to produce electrical power, is normal for this type of vessel.
Redundancy requirements are maximal, which means complete double engine rooms, and thruster capacity (DP3 class).

The Dynamic Positioning is complicated. Weather vaning, (heading resulting from wind and current) which is acceptable for a drillship, as the drillstring is the decisive location, is not good enough for laying pipes.
The pipe has to be layed along an accurately planned track, and the ship or barge has to be kept above that line, in the proper direction.
Current and wind/waves can be from abeam.
When a weld in the pipe is completed, the ship has to move forward the length of the 'joint', 12, 24 or 36 metres. The necessary allowance in fore and aft position, controlled by the tensioners and limited by the size of the welding stations, is about one metre.
Moving from one job to another is done under own power, using the thrusters assisted by tugboat(s), or at the propulsion system of the original ship.
An example of a one-line diagram for a pipe laying vessel is shown in chapter 25.

*DP Pipelaying vessel, converted from a Panamax bulk-carrier.
The original engineroom aft is still in use for propulsion. DP is achieved through 6 retractable azimuth thrusters, served by two newly created enginerooms. The old engineroom is not part of the FMEA*

2.8 Yachts

Yachts, in a way, have often unusual features, compared with 'normal' commercial ships.

Their kind of systems has to be linked to classification requirements. And these requirements are not tailor-made for this kind of ships.
Classification Rules and Regulations for electronic systems for instance, are updated regularly. They are always behind the wishes and capabilities of the yacht-owners, the yacht builders and the electrical subcontractor, simply because the electronic equipment advances too fast for the regulatory bodies to keep track.
Most yacht-owners for instance want a state-of-the-art 'design' bridge without all the usual type-approved and often ugly control and communication equipment. This type-approved equipment of different makes and shapes and with even different finishing colours, would make the wheelhouse of a yacht look very similar to the bridge of a standard cargo ship, and that is considered unacceptable by the yacht-owner.
This equipment is not only different in appearance but also in operation, and consequently, when it has to work in combination, or even integrated, operator unfriendly.

Most yachts are built according to the Rules for Special Service Craft. This allows, when compared with the Rules for 'normal' ships some relaxation in required equipment, but these rules basically have been written for simple craft. The Notation 'Yacht (P)' results in some additional requirements related to those for passenger ships.

If the gross tonnage measurement of the yacht exceeds 500, SOLAS is also applicable.

More and more yachts are equipped with sophisticated control equipment such as DP, single joystick controls, assisted mooring and integrated presentations.
These features are not clearly described in the rules for Special Service Craft, but are more clearly stated in the Rules for Special Purpose Ships and are then followed insofar considered applicable to these yachts.
The part-application of rules, rules which are intended for more complicated ships, gives the designer possibilities, and the Classification guidance how to judge such a design.

Yachts and passenger ships are increasingly equipped with local personal computers, serving a particular space, and taking care of environmental control, lighting, audio and video systems, often (partly) wireless. These PCs are connected by a high speed network to a server, providing programs and data. A high speed satellite link can be part of the system. Such systems are preferred in order to reduce the total cable length in a ship.
As long as safety is not involved, there are no Class requirements for such systems.

Emergency systems, however, such as alarms, escape lighting, and fire detection have to be independent of these PCs. Otherwise, the Classification will require duplication, FMEA if applicable, redundant cables and power supplies, in order to result in a reliable system in accordance with the SOLAS requirements.

27. TESTING, COMMISSIONING AND CLASSIFICATION

Commissioning is the process of getting the installed equipment to work properly and fulfill its functions. It is done in steps, starting at the manufacturer's workshop where the essential equipment is tested before it is transported to the shipyard. These tests at the makers are called Factory Acceptance Tests (FAT) and certify that the equipment performs properly, when leaving the workshop. Essential equipment includes generators, motors, switchboards and control gear assemblies, transformers, alarm and monitoring systems.

1 Factory acceptance tests (FAT)

1.1 Rotating machines

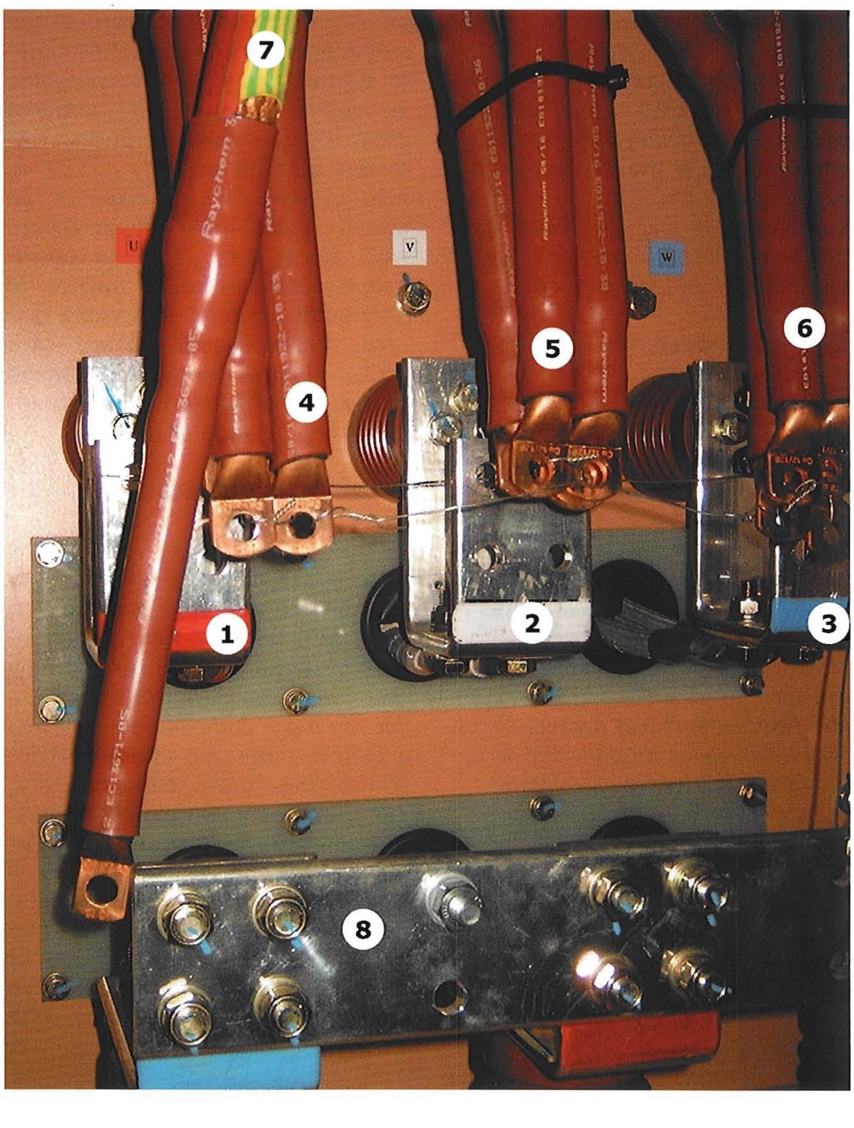
Generators and motors, usually identified as rotating electrical equipment, have to be subjected to a heat run test, to demonstrate that the rotating equipment can perform its duty within the temperature limits of the materials used.
Heat run tests can be performed under actual conditions, under load with the same characteristics and cooling conditions as the expected load in service. It is often simulated by a no-load test and a short-circuit test. The sum of the rise in temperature represents the actual temperature rise.
It is often limited to the electrical windings of a machine, but should also include mechanical parts such as bearings.
In addition, megger tests, insulation resistance tests and high voltage tests as well as overspeed tests at 120% for two minutes, are carried out. If possible, load steps and other dynamic tests are run.
If dynamic tests cannot be carried out in the workshop, they must be done during the harbour acceptance tests (HAT) or during sea trials.

High voltage connection box:
1. Terminal L1
2. Terminal L2
3. Terminal L3
4. Conductors L1
5. Conductors L2
6. Conductors L3
7. Earth conductor
8. Starpoint

1.2 Cables

Cables used onboard of ships must be type-approved, meaning that they have been subjected to a series of tests together with an approved quality assurance system of the manufacturer.
These cables are listed in the type-approved equipment of the various classification societies.
In general, these cables are specially designed and are suitable for conditions with respect to vibration. Thus, stranded conductors, fire retardant and low smoke and low halogen insulation.

Cables temporarily disconnected for testing purposes



1.3 Switch and control gear

Very few have type approval, but most switch gear and control gear assemblies have been built from type approved parts. All main and emergency switchboards must be factory tested to verify operational and insulation quality by Megger and high voltage tests.
The tests consist of checks of interlocks, synchronisation, autostart and autoclose of generators and circuit breakers, sequential restart, load shedding, depending upon the ship's specification.

1.4 Circuit breakers.

Circuit breakers have to be adjusted and tested by the manufacturers. Certificates of required settings and test results must be submitted and verified. Nameplates must be fitted adjacent to the circuit breakers in the switchboard referring to the adjusted settings to enable replacement.

1.5 Starting devices

Large starting devices (>100kW) must be tested at the manufacturer's workshop as far as practicable. The tests are more or less identical to the tests of switchboards.

1.6 Converting equipment

Large converting equipment (> 100kW) must be tested at the manufacturer's workshop.
For rotating converting equipment, the same tests are applicable as for rotating machines.
For static converting equipment, built from type-approved parts, functional tests have to be done simulating the performance of the converter and checking temperature rises of the approved parts in the assembly. This can be done during a full load test with the same cooling arrangements as in the ship's design standards.
This usually means cooling air of 45ºC, cooling water, if direct seawater is used, of 32ºC, but mostly freshwater through a heat exchanger of 37ºC, or air, cooled by either sea or fresh water with maximum temperatures of 37 and 42ºC respectively, allowing a temperature difference over the water/air heat exchanger of 5ºC.
Sometimes, if a chilled water system is installed, chilled water with a temperature of 6ºC is used.

1.7 Transformers

Large transformers (> 125 kVA or 100kW) with a power factor of 0.8 have to be tested at the manufacturer's workshop. The test must include a megger test, a high voltage test and a megger test again, as well as a heat-run determining the temperature rise of the windings at full load conditions.
Similar to rotating machines, often the test is done by a combination of a no-load test and a short-circuit test which gives a good idea of the temperature rise at actual load.

1.8 Automatic control systems

Large control systems, or better complicated control systems, have to be tested at the manufacturer's. This means building up the various components, such as equipment, control-stations and work-stations and connecting these, making it a complete system. It is more efficient to test a complicated system at the manufacturer's, as all control locations are close together and the changes of control positions are more easy to test. Transfer of control from one location to another shall be bumpless and accepted by the other location. This to avoid unacceptable surprises.
Failure of a power supply shall not cause change in control result or alarms only.

1.9 Alarm and monitoring systems

Alarm and monitoring systems must also be tested at the manufacturer's.
These include simulation of alarms, checking of group alarms at the bridge, and of engineer's alarms.
Duty selection, safety timer for not accepting alarms, safety timer for one person on watch, automatic change over from unmanned to manned operation when accepting an alarm in the engine room, at the same time starting the safety timer to protect the engineer attending an alarm. Graphics and trending must also be checked during this factory acceptance test.
Also system failures have to be tested. Thus, main power failure with alarm only, back-up power failure, communication failure of distributed systems and cable failures. Printed circuit board card (PCB) failures must be restricted to that part only. Alarms have to indicate the location of the fault.

1.10 Dynamic positioning systems.

Dynamic positioning systems vary from simple computer assisted systems with Notation AM, via redundant systems Notation AA, to fully redundant systems Notation AAA. For the more complicated systems, a failure mode and effect analysis (FMEA) has to be made, identifying the consequences of all possible failures. This is the basis for the test procedures. The functional tests are more difficult to simulate. As most of the systems have to be adjusted to the characteristics of the ship, especially for the first ship of a series, these are usually done during sea trials.

1.11 Systems in general.

It should be clear that all factory acceptance tests have one common purpose: that is to confirm the suitability of equipment to be installed onboard.
Every step in the FAT testing programme has one major purpose. This is to ensure performance during the harbour acceptance tests (HAT) and of course, during the final acceptance test, the sea trials.
Consequently, the above testing must be executed with all new and essential equipment or systems working.

1.12 EMC/THD tests

All navigation and nautical equipment has been tested for electromagnetic compatibility during the type approval procedure. Interference between components should not exist as long as all equipment is installed in the original housing and in accordance with the instructions of the manufacturer.
When in the open deck area other sensitive equipment is installed, such as a frequency converter operated deck crane, controlled from a control cabin with many windows in view of the radar antenna beam, also this control cabin has to be tested for EMC.
Measuring the Total Harmonic Distortion (THD) for different operational conditions is particularly advised when large Variable Frequency Drives are installed. These measurements are sometimes also required by Class.

1.13 Step loads

After testing of the individual diesel generators for proper operation the sets are tested in parallel operation. With 3 sets, first 1 and 2 in parallel, thereafter 2 and 3 and finally 1 and 3. When current and kW loadsharing is in order the engines and generators have to be subjected to step loads.
A step load is a suddenly applied load on the generator, to check the performance of the generator AVR as well as the diesel governor.
Usual steps are from 25 to 50 % and 50 to 100 %, whereby the minimum voltage and the minimum frequency during the process have to be checked.

Testmatrix	VHF 1 and 2	VH Navtex	HF2182kHz homing device	MF/HF transceiver	DGPS 1and 2	GSM 1 and 2	AIS	SATCOM C1 and C2	SATCOM Mini-M	TV/FM/AM	X-band RADAR	S-band RADAR	Magnetic compass	Wind speed	Gyrocompas	EM Log	Echo-sounder	Steering system	Automatic Telephone	Batteryless telephone	Public address	Propulsion control
VHF 1 and 2	x																					
VH Navtex		x																				
HF2182kHz homing device			x																			
MF/HF transceiver				x																		
DGPS 1and 2					x																	
GSM 1 and 2						x																
AIS							x															
SATCOM C1 and C2								x														
SATCOM Mini-M									x													
TV/FM/AM										x												
X-band RADAR											x											
S-band RADAR												x										
Magnetic compass													x									
Wind speed														x								
Gyrocompass															x							
EM Log																x						
Echosounder																	x					
Steering system																		x				
Automatic Telephone																			x			
Battery-less telephone																				x		
Public address																					x	
Propulsion control																						x

Another test of the diesel and generator performance is the switching off of a certain load whereby the overvoltage and maximum frequency of the sets are checked during the process.
This is usually done in parallel, operating by switching off circuit breakers.

1.14 Example of EMC interference

EMC interference problems are sometimes hard to trace like in this example of an Offshore Construction Vessel.
When the ship got operational it appeared that the crane would not work although this had been succesfully tested during harbour trials.
It took a long time to find the reason for this failure of the crane but in the end it appeared that the beam from the radar disturbed the crane controls.
By screening some cables in the control cabin of the crane the problem was solved.
The test matrix for commissioning should include verification of this sort of interferences.

After the Factury Acceptance Tests are completed to satisfaction, the equipment has to be installed on board. When completed, a new series of tests has to be carried out: The Harbour Acceptance Test, or HAT.
Before this testing can be carried out, cables, pipes, safety systems, such as firedetection, bilgealarm, etc, have to be ready and have to be tested. This is in fact pre-testing, and part of the HAT. There is an overlap with the actual HAT, which is carried out when all systems and equipment is supposed to be ready.

2 General shipboard testing.

Before a new installation is put into service, the following tests are to be carried out. These tests are in addition to any acceptance tests which may have been carried out at the manufacturer's .

2.1 Insulation resistance

The insulation resistance of all systems and electrical equipment has to be measured using a direct current insulation tester, between:

a. connected current carrying parts
b. as far as reasonably practicable all current carrying parts of different polarity or phase.

The installation may be subdivided and equipment may be disconnected if initial tests produce resistance values lower than the required resistances.

2.2 Earth conductors

Tests are to be carried out to verify the effectiveness of the earth continuity conductor and the earthing of non-current carrying exposed metal parts of electrical equipment and cables.

2.3 Generators

Tests are required to demonstrate satisfactory performance of each generator and engine by means of a test run at full rated load and at 110% overload for at least 15 minutes. Engine temperatures should stabilize and not exceed the maximum figures as determined by the manufacturer.

27.1	INSULATION RESISTANCE	MEGGERREADING
	PROPULSION AUXILIARIES	MΩ
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E317	Stabilizer hydraulic pump main	100,00
E317	Stabilizer hydraulic pump main	100,00
E317	Stabilizer hydraulic pump emergency	100,00
E317	Stabilizer hydraulic pump emergency	100,00
E347	Water mist Emergency supply	100,00
E610	Main engine Lub oil priming system	100,00
E610	Main engine Lub oil priming system	100,00
E610	Main engine Coolant pre heating unit	80,00
E610	Main engine Coolant pre heating unit	80,00
E650	Generator pre-heating	60,00
E650	Generator pre-heating	60,00
E650	Generator pre-heating	60,00
E650	Aux eng SW pumps exhaust	100,00
E650	Aux eng SW pumps exhaust	100,00
E650	Aux eng SW pumps exhaust	100,00
E710	Starting air comprssor	100,00
E710	Starting air comprssor	100,00
E714	Air Dryer	80,00
E720	Fuel oil booster pump	100,00
E720	Fuel oil transfer pump	100,00
E730	Lub oil transfer pump	100,00
E730	Gearbox Trailing pump	100,00
E730	Gearbox Trailing pump	100,00
E810	Fifi/ bilge pump	100,00
E810	Fifi/ bilge pump	100,00
E810	Emergency fifi pump	100,00
E815	Bilge water separator	100,00
E810	Bilge valves	100,00
	Engineroom fans	100,00
	Engineroom fans	100,00
	Supply fans technical spaces	100,00
	SHIPS SERVICE AUXILIARIES	
E250	HPP- Aft: Tenderdoors/ bulwark doors/ te	100,00
E250	HPP Stern door+ passarelle	100,00
E250	HPP Seaterrace crew door and boarding l	100,00
E250	HPP Foredeck hatches,crane mast and a	100,00
E320	Anchor/ mooring winches Fwd	80,00
E320	Anchor/ mooring winches Fwd	80,00
E322	Capstan Fwd Port; Stbd	80,00
E322	Capstan Fwd Port; Stbd	80,00
	THRUSTERS	
E645	Bowthruster AC heating	50,00
E645	Bowthruster Air injection unit	100,00
E646	Hydraulic unit+ control+ AC heating Stern	80,00
	Bow thruster	100,00
	Stern thruster	100,00

Example of part of Megger list

Rated voltage U_n V	Minimum voltage of the tests, V	Minimum insulation resistance, MΩ
$U_n \leq 250$ $250 < U_n \leq 1000$ $1000 < U_n \leq 7200$ $7200 < U_n \leq 15000$	$2 \times U_n$ 500 1000 5000	1 1

Minimum test voltage and insulation resistance M_a

DIESELGENERATORS 1 + 2 PARALLEL						
Total Rating %	Diesel 1			Diesel 2		
	Kw	A	Hz	Kw	A	Hz
0	0	0	60	0	0	60
25	60	120	59.8	65	130	59.8
50	125	250	59.5	130	260	59.5
75	185	370	59.3	190	380	59.3
100	250	500	59	250	500	59
75	185	370	59.3	190	380	59.3
50	125	250	59.5	130	260	59.5
25	60	120	59,8	65	130	59.8
0	0	0	60	0	0	60

SINGLE DIESEL GENERATOR					
Power %	Power	Voltage	Current	Freq	Speed
	Kw	V	A	Hz	RPM
0%	0	455	0	60	
24%	60	454	125	59.8	1800
50%	125	452	250	59.5	
70%	185	452	375	59.3	1785
100%	250	450	500	59	
75%	185	451	275	59.3	1770
50%	125	452	250	59.5	
20%	60	454	125	59.8	
0%	0	455	0	60	1800

STEPLOADS								
Step 1 from 25 to 50% by switching off diesel 1								
Step 2 from 50 to 100% by switching off diesel 1								
Total Rating %	Diesel 1			Diesel 2				
	Kw	A	Hz	Kw	A	Hz	min V	min Hz
0	0	0	60	0	0	60		
25	60	120	59.8	65	130	59.8		
50	0	0	60	130	260	59.5	440	57
50	125	250	59.5	130	260	59.5		
100	0	0	60	250	500	59	435	56

STEPLOADS SWITCHING OFF							
Power %	Power	Voltage	Current	Freq	Speed		
	Kw	V	A	Hz	RPM	max V	max Hz
50%	125	452	250	59.5			
0%	0	455	0	60	1860	480	62
100%	250	450	500	59			
0%	0	455	0	60	1720	485	63

High Voltage test voltage depends on the nominal voltage of the system as in the following table:

Rated voltage, $U_n U_n$ V	Test voltage a.c. (r.m.s.), V
$U_n \leq 60$	500
$60 < U_n \leq 1000$	$2 \times U_n + 1000$
$1000 < U_n \leq 2500$	6500
$2500 < U_n \leq 3500$	10000
$3500 < U_n \leq 7200$	20000
$7200 < U_n \leq 12000$	28000
$12000 < U_n \leq 15000$	38000

2.4 Switchboards

During the full load tests, the temperatures of joints, connections, circuit breakers, bus-bars and fuses have to be monitored and may not exceed the maximum values.
For cables with XLPE insulation this value should be below 85°C.
Bus-bars in switchboards may reach 95 °C.

2.5 Synchronising equipment

During functional tests the operation of engine governors, synchronizing devices, overspeed trips, reverse-current relays, reverse-power and over-current trips and other safety devices must be demonstrated. Generators with a rating of more than 1500kVA must also be protected by a differential protection system, showing a possible current leakage.

2.6 Automatic Voltage Regulator

The voltage regulator of each generator has to be tested by opening its breaker when the generator is running at full load and also when starting the largest motor which is connected to the system.

Also the speed governor has to be tested by opening the circuit breaker at full load. This is not to result in overspeed trip. The minimum speed of a diesel generator has to be verified when starting the largest electric motor on board.

2.7 Parallel operation

Parallel operation and kW and kVA load sharing of all generators capable of being operated in parallel mode, at all loads up to normal working load, has to be tested.

2.8 Functional test

Essential equipment must be operated under service conditions, though not necessarily at full load or simultaneously, for a sufficient length of time to demonstrate that the temperatures stabilize and equipment does not overheat.

2.9 Safety systems

Fire, crew and passenger and ship safety systems must be tested for correct functioning.

2.10 General alarm systems

On completion of the general emergency alarm system and the public address system tests, the surveyor has to be provided with two copies of the test schedule, detailing the measured sound pressure levels. Such schedules are to be signed by the surveyor and the builder.

3 Harbour Acceptance Tests (HAT)

After the equipment is installed onboard the ship and connected, Harbour Acceptance Tests are carried out to prove that the equipment is capable of functioning properly.

3.1 Electric power supply system tests

An example is the load tests of the diesel generator sets in combination with the switchboard. Load tests are often done using a water resistance device that consumes electrical power by heating water.
A disadvantage of the device, is that it does not simulate the ship's load which is usually partially inductive. The power factor is 1 for a resistance load so that the maximum power for the diesel is reached at 80% current of the generator.
This is therefore, not a generator test where current is the limiting factor.
Load steps also give a good idea of the generator set's performance. Auxiliary engine protection and shutdown systems are to be tested as well as automatic starting of standby pumps and sequential restart of essentials after a blackout.

Further tests may include the load dependent start-stop by a power management system with automatic reduction of propeller pitch and/or RPM of electric driven thrusters in case of overload of the generator plant. Much of this testing can be done in harbour as it does not require the ship to be sailing.

3.2 Engine protection systems tests

Tests of safety stops for diesel generator engines, propulsion engines, boilers and likewise.

PROPULSION SYSTEM			
MAIN ENGINES>1500K	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	OIL MIST CONCENTRAT	HIGH	STOP
MAIN BEARING 1	TEMPERATURE	HIGH	STOP
MAIN BEARING 2	TEMPERATURE	HIGH	STOP
MAIN BEARING 3	TEMPERATURE	HIGH	STOP
MAIN BEARING 4	TEMPERATURE	HIGH	STOP
MAIN BEARING 5	TEMPERATURE	HIGH	STOP
THRUST BEARING	TEMPERATURE	HIGH	STOP
HT COOLINGWATER	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP
GEARBOX	LUBR OIL PRESS	LOW/LOW	STOP
AUXILIARY ENGINE 1	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP
AUXILIARY ENGINE 2	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP
AUXILIARY ENGINE 3	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP

Example of test sheet of safety systems of main and auxiliary diesel engines (see 27.2.2)

3.3 Automation system tests

Systems to be tested are the bridge control systems for main engines/clutches/propellers, transfer from engine room to bridge, bridge to bridge-wing and back, emergency stops, thrusters' start-stop and controls and pitch and RPM indicators. This can all be done at reduced load along the quay.
Additional testing is required for steering gear systems' pump start/stop with alarms, rudder position indicators, autopilots and propulsion safety systems, such as rudder limiters, interlocks between bowthruster and stabilizers.
The above tests have to be carried out prior to sea trials.

3.4 Fire protection

Safety systems such as fire detection, fire alarms, fire doors and shutters and fire fighting systems are to be tested before going on sea trials.
The fire detection in engine rooms consists of three types of sensors:
- Smoke detectors
- Flame detectors
- Heat detectors

Each type needs to be tested in its own way. See pictures.
During sea trials this test is repeated with engines and engine room ventilation running.

Smoke, heat and flametests.
Realistic test of the smoke, heat and flame detection is done by burning diesel oil in a drum.
Such tests are only carried out during sea trials to test the whole system.

Adequate precautions as a fire extinguisher and people with fire resistent clothing is a must.
During normal operation smoke detection is carried out using a spray can with a special testing liquid on a broomstick.

Flame detectors can be tested with a good torchlight, heat detectors with an ordinairy hair dryer.

3.5 Safety of people on board

Personal safety systems, such as internal communication, general alarm systems and public address systems have to be tested prior to leaving to sea.

Smoke test in progress

3.6 Alarm and monitoring system tests

See table on the right side.

3.7 Emergency Power

Autostart of the emergency generator, the transitional source of power, emergency lighting, escape lighting, lifeboat preparation lighting and lights required to launch the boats, are to be tested.

3.8 External Communication

External communication systems must be tested and certified by or on behalf of the national authorities.

3.9 Nautical systems

Radars, gyrocompasses, echosounders, speed log, DGPS positioning reference systems and vertical reference units must be functionally tested so far as is possible during quayside testing.

3.9. Lighting

Functional tests of emergency lighting, navigation lighting, signal mast lighting and anchor lights also have to be carried out.

After successful completion of the HAT, the ship will receive a temporary certificate of seaworthiness by the authorities and is allowed to go to sea.

Sea Acceptance Tests (SAT) complete the program by executing those tests which require sailing, including manoeuvring tests, stop tests and likewise.
All these tests must be well documented with values, figures.
in order to be available as a reference. Normally a booklet is produced by the shipyard with these data.

PROPULSION SYSTEM			TEST SHEET					
MAIN ENGINES > 1500 KW	SYSTEM	STATUS	RESULT	YARD	DATE	OWNER	DATE	CLASS
	LUB OIL SUMP LEVEL	LOW	ALARM					
	LUB OIL PRESS	LOW	ALARM					
	LUB OIL PRESS	LOW/LOW	STOP					
	LUB OIL TEMP	HIGH	ALARM					
	LUB OIL FILTER DIFF	HIGH	ALARM					
	OIL MIST CONC	HIGH	STOP					
MAIN BEARING 1	TEMPERATURE	HIGH	STOP					
MAIN BEARING 2	TEMPERATURE	HIGH	STOP					
MAIN BEARING 3	TEMPERATURE	HIGH	STOP					
MAIN BEARING 4	TEMPERATURE	HIGH	STOP					
MAIN BEARING 5	TEMPERATURE	HIGH	STOP					
THRUST BEARING	TEMPERATURE	HIGH	STOP					
HT COOLING WATER	HT CW OUTLET TEMP	HIGH	ALARM					
		HI-HIGH	STOP					
	HT CW INLET PRESS	LOW	SLOW					
	HT CW EXP TK LEVEL	LOW	ALARM					
LT COOLING WATER	LT CW OUTLET TEMP	HIGH	ALARM					
	LT CW OUTLET TEMP	HI-HIGH	SLOW					
	LT CW INLET PRESS	LOW	ALARM					
FUEL OIL	FO PRESSURE	LOW	ALARM					
	FO TEMPERATURE	HIGH/LOW	ALARM					
	FO LINE LEAKAGE	LEAK	ALARM					
START AIR	START AIR PRESSURE	LOW	ALARM					
CONTROL AIR	PRESSURE	LOW	ALARM					
ENGINE SPEED	OVERSPEED	HIGH	STOP					
CYLINDER 1	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 1	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 2	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 2	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 3	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 3	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 4	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 4	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 5	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 5	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 6	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 6	EXH GAS TEMP	DEVIATION	ALARM					
TURBO CHARGER	EXH GAS IN TEMP	HIGH	ALARM					
TURBO CHARGER	EXH GAS OUT TEMP	HIGH	ALARM					
TURBO CHARGER	LUB OIL PRESS	LOW	ALARM					
TURBO CHARGER	LUB OIL SUMP LEVEL	LOW	ALARM					
ENGINE OUTPUT	OVERLOAD	HIGH	ALARM					
GEARBOX	LUB OIL PRESS	LOW	ALARM					
	LUB OIL PRESS	LOW-LOW	STOP					
	LUB OIL TEMP	HIGH	ALARM					
	LUB OIL SUMP LEVEL	LOW	ALARM					
PROPELLER CONTROL	HYDR OIL PRESS	LOW	ALARM					
	CONTROL AIR PRESS	LOW	ALARM					
	ELECTRIC SUPPLY	FAIL	ALARM					
AUX DIESEL NR 1	LUB OIL PRESS	LOW	ALARM					
	LUB OIL PRESS	LOW-LOW	STOP					
	LUB OIL TEMP	HIGH	ALARM					
	CW OUT TEMP	HIGH	ALARM					
	CW OUT TEMP	HIGH-HIGH	STOP					
	CW INLET PRESS	LOW	ALARM					
	FO LINE LEAKAGE	LEAK	ALARM					
	OVERSPEED	HIGH	STOP					
	EXH GAS INLET	HIGH	ALARM					
	EXH FGAS OUTLET	HIGH	ALARM					
AUX DIESEL NR 2	SEE ABOVE							
BOILER	WATER LEVEL	LOW	ALARM					
	WATER LEVEL	LOW-LOW	STOP					
	WATER TEMPERATURE	HIGH-HIGH	STOP					
STEERING GEAR	ELECTRIC POWER	FAIL	ALARM					
	CONTROL EL POWER	FAIL	ALARM					
	HYDR OIL TANK LEVEL	LOW	ALARM					
	MOTOR OVERLOAD	HIGH	ALARM					
	PHASE FAIL		ALARM					
	HYDR. LOCK		ALARM					
ELECTRIC SYSTEM	Bus-bar VOLTAGE	HIGH / LOW	ALARM					
	Bus-bar FREQUENCY	HIGH / LOW	ALARM					
	OVERLOAD	NON-ESSENTIALS TRIP						
	Bus-bar INSULATION	LOW	ALARM					

On completion of the HAT, the ship goes for trials. At sea for large ships, inland at sufficient deep and wide water for smaller ships. The electrical installation can then be tested under 'normal' conditions and/or full load, on full speed, without ground or channel effect, what is normally not possible at the outfitting quay. Without speed, alongside, the propulsion system quickly comes in overload conditions.

4 Sea trials

During sea trials the final tests are carried out before delivery of the ship to the owner.
Sea trials prove the specified performance of the ship to the owner as well as demonstrate that the ship is capable of performing conformto the minimum requirements as determined in SOLAS.

Propulsion equipment is to be tested under working conditions and operated in the presence of the surveyors to their satisfaction.
Owners' requirements, such as speed, fuel consumption, noise levels, etc. are to be tested at full operating conditions or at whatever agreed figures or circumstances provided in the building contract.
For cargo ships maximum figures for sound or noise are given in SOLAS; for yachts and passenger ships there is a totally different list of figures.

Sound and vibration levels form a great part of the conditions for people's comfort onboard ships and these have to be verified under operational conditions.

All necessary parameters such as pressures, temperatures under different load conditions of the main engine are collected and recorded.
A booklet with all these data is produced and remains the reference throughout the lifetime of the ship.

On completion of the seatrials, the SAT, when the ship is considered completed is all respects, the cerificates are issued, as far as not already issue for completed items. With the necessary egards and often festivities, the initial Class certificates for Hull and Machinery are handed over. When all necessary other certificates are on board, the ship is allowed to take cargo and to leave port.

5 Periodical surveys

However when the ship is in service, to maintain the validity of the certificates, periodical surveys have to be carried out. Annuel survey, intermediate survey, and special survey, together with other compulsary certificates in a five years cycle. The basic annual electrical survey consists of the following tests and inspections, depending on the type of ship. For example:

5.1 General

- Testing of all bilge level alarms
- Testing of all watertight doors (operation and alarms), general survey conditions of watertight sealing of electrical equipment when this is intended to be used in submerged conditions
- Testing of main and auxiliary steering gear systems inclusive of alarms
- Survey of all escape routes, route signs, illumination low level lights
- Testing of communication systems between bridge and engine room and emergency control positions
- Testing of remote controlled valves and indications
- Inspection of main and emergency switchboards and associated cables. Examination under normal operation conditions. Testing of automation, black-out start, power depending start, power management systems, automatic sequential restart systems, non- essential tripping systems. Electric safety inspection, earthing of electrical equipment, especially in wet or dangerous areas
- All ships: General inspection of alarms and safety devices as well as autostart of standby generator and sequential restart of essential auxiliaries under normal service conditions
- UMS ships: General inspection under working conditions of automation systems such as standby pumps and auxiliaries. Sample tests of alarms inclusive of bridge, mess room and cabin alarms. Safety timer/dead man alarm systems. Survey as per approved test schedule. Testing of bridge control systems and bridge engine room communication systems.
- Navigation and nautical equipment. General inspection of all equipment under normal operation
- NAV 1 Ships, In addition to general inspection under working conditions of bridge equipment additional alarms and indications, also safety timer and cabin alarms. Survey as per approved test schedule.
- Radio / GMDSS / External communication survey
- Crew safety systems. General alarm and emergency lighting system, emergency generator automatic start and if emergency source of power is a battery, a load test of this battery.

Futher in addition to 5.1:

5.1.1 Ships transporting dangerous cargo in bulk

- Dangerous cargoes in bulk. Inspection of equipment in dangerous areas in relation to the gas group, temperature class and external damage, if any.
- Dangerous dusty cargoes. Inspection of equipment in dangerous area, type of enclosure, protection class, eventual external damage.

5.1.2 Tankers

- Dangerous liquid cargoes. Inspection of equipment in dangerous areas, in relation to gas group, temperature class and eventual external damage. Gases from some cargoes are heavier than air and thus form a layer on deck or in any space under the deck.
- Liquefied natural gas and liquefied petroleum gas carriers (LNG and LPG ships).
- Liquefied natural gas is lighter than air, while liquefied petroleum gas is heavier than air. Inspection of equipment in dangerous areas gas group and temperature class to be verified as well as inspection for damage to ship or equipment.

5.1.3 Passenger ships

- Ship safety systems
- Passenger safety systems. General alarm, public address, emergency lighting, transitional lighting systems and low level lighting systems. Batteries and UPS capacity tests are required. Automatic start of emergency generator and operation of associated equipment as fans, fire flaps, air louvres. to be demonstrated.

5.1.4 Car ferries with bow and stern doors

- Door alarms and indications, water level alarms, closed circuit TV monitoring systems (CCTV)
- Additional lighting systems for crew and passengers
- Equipment in dangerous areas, for instance the lowest 45 centimetres above the car decks where cars are stowed with petrol in their tanks are considered dangerous areas. Also attention for equipment under ramps and swing decks where cars can be stowed. Minimum requirements for equipment on cardecks, etc. above this 45 centimetre layer is protection class IP 55. Car deck ventilation must have at least 10 air changes per hour.

5.1.5 Dynamic positioned ships

Annual Survey under operational conditions, which means an annual DP trial at a convenient location, to demonstrate the operation of the control system completed with a survey of the total propulsion system, often diesel electric. Surveys and tests have to be carried out as per ship-specific approved test schedule. Special attention for UPS capacity tests. The basis for the tests is often the FMEA, failure mode and effect analysis.

5.1.6 Small ships and yachts

- Basic electrical installations
- Automation
- Equipment in dangerous areas, where all sorts of equipment running on petrol, is stored. For requirements see the ferry car decks. The ventilation must perform at least 10 air changes per hour. Gas detection must be fitted to an alarm and all equipment not suitable for this environment must be switched off.

5.2 Complete five year survey electrical installations

Every five years the electrical installation of a ship must be subjected to a special survey, equal to an annual survey along with the following tests and inspections:

- Electrical insulation resistance measurement of all cables and equipment, motors, generators, switchboards and all consumers, galley, laundry. Also high voltage cables and consumers, if any.
- Fittings of main and emergency switchboards to be inspected, which means checking of connections either by torque wrenches or by thermal inspections under load, using infra-red camera. Copper bus bars are relatively soft, the torque when setting bolts is therefore, important. Checking of bus-bar resistance by special low resistance measuring equipment. Testing of circuit breaker settings and inspections of contacts. Resistance measuring of contacts of vacuum circuit breakers. Calibration of circuit breaker settings and testing of non-essential tripping circuits. General inspection of switchboards.

28. MAINTENANCE

Maintenance onboard modern ships has to be planned very carefully. The required checks and tests are spread over the total maintenance period.

1 General

Maintenance is an essential part of a ship's installation; Planned Maintenance Systems (PMS) are designed to prevent failures.
A Failure Mode Effect Analyses which is a requirement for the higher classes of DP-notations also provide insight into the effects of single failures and methods to prevent unwanted consequences. Monitoring and collecting data of failure, parts involved, alarms prior to the failure, help to improve planned maintenance.
To aid maintenance, more and more ships have computer systems on board for remote monitoring and life cycle management.
Such a system is linked to the alarm data computer memory, coupling the type of alarm to the running hours of the relevant item, in order to generate maintenance planning.
By means of satellite communication equipment suppliers can monitor equipment on board and advise the crew or materials can be ordered to be available in the next port of call.

2 Rotating machines

2.1 Air-cooled machines.

Cleaning or replacement of air filters, visual inspection of windings of stator, visual inspection of windings of rotor.

Special attention for loose fixings of wires between rectifiers and windings on poles.
General cleaning when found dirty inside. Grease (roller) bearings as per maker's instructions.

2.2 Water-cooled machines.

As 2.1 air-cooled machines. In addition the testing of the cooling water leakage detection and alarm.

2.3 Large machines with sleeve bearings.

Check the circumferential clearance of the rotor in the stator. Register data and check bearing clearance and lubrication system

2.4 Machines with roller bearings.

Roller bearings have to be greased as per maker's instructions.

2.5 Insulation resistance

Measure insulation resistance and register data and conditions, i.e. warm after running, and/or cold after a longer period of standstill.

2.6 Slip rings and brushes.

Visual inspection to check for scratches and excessive brush wear

3 Cables

3.1 Cables in hot areas.

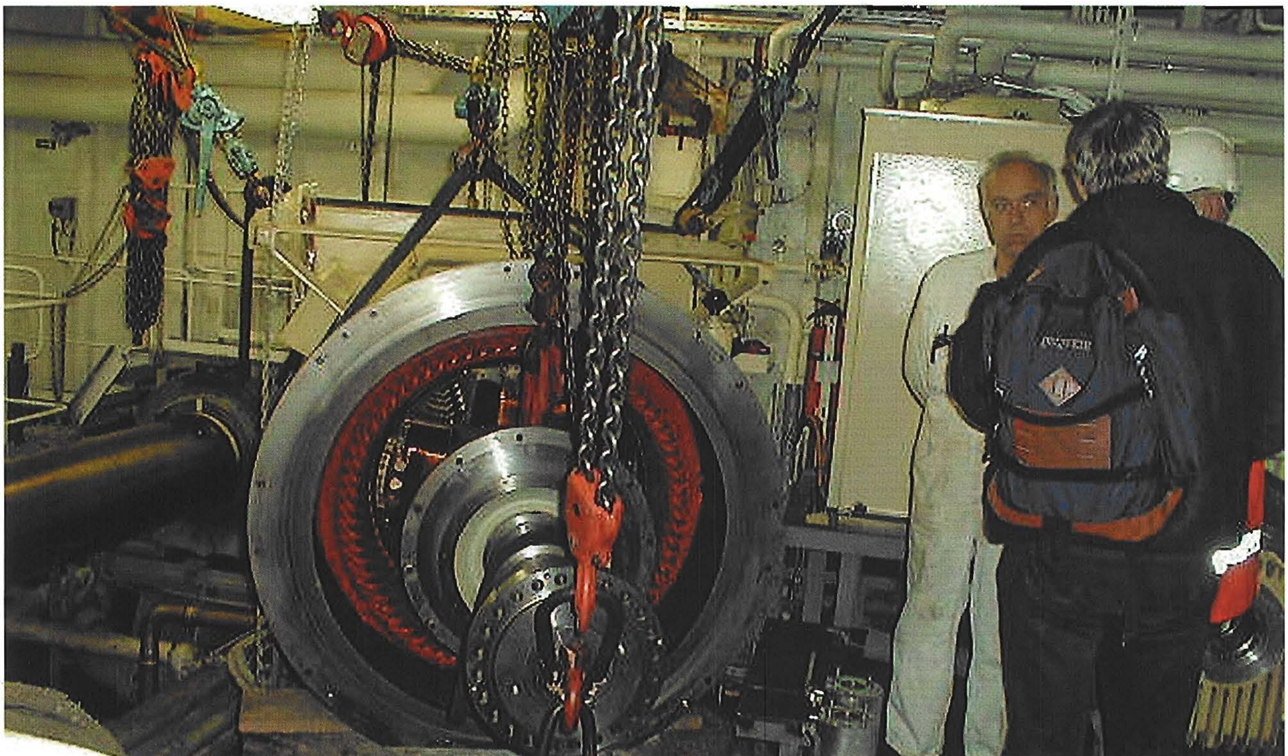
Visually inspect cables routed in hot areas, look for colour changes due to overheating of wires. Replace cables by heat resistant types if necessary.

3.2 Cables in dangerous zones.

Inspect cables for damage of outer sheaths. Repair if possible to avoid corrosion of metallic braiding underneath. Check glands of certified safe equipment for tightness.

3.3 Insulation resistance.

Measure insulation resistance of all cables in safe areas. Measure all outgoing groups of the power distribution system, inclusive of consumers. Use megger-list as provided at new building for reference.



4 Switchgear

4.1 Visual inspection for dirt

Cleaning or replacement of air filters, visual inspection of connections for discolouring of wires by overheating, visual inspection of bus-bars.

4.2 Visual inspection movable connections

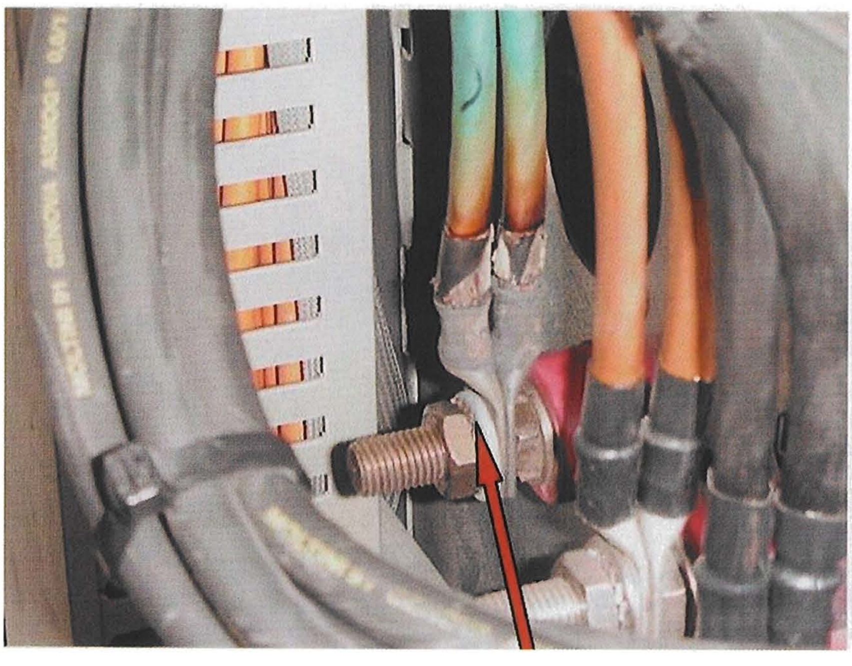
This is applicable to tulip contacts of withdrawable circuit breakers and starters. Check for proper working springs, if not accessible carry out conductivity tests.

4.3 Thermal photography.

Thermal photography with an infrared camera is a quick way to find bad connections. It has to be carried out with the circuits under load or shortly after having been under load. When a hot spot is found, also a colour image has to be made of the same location to identify the hot spot. Some thermal cameras adapt the scaling of their pictures to the hottest spot in that picture. So a bright yellow part can be 35 °C in one picture and 135 °C in another. Some switchboards have not sufficient access to photograph all possible hot spots. Those switchboards also have to be visually inspected after switching off and opening of the doors.
See pictures below.

4.4. Bus-bar connection conductivity and insulation resistance.

Bus-bars are usually made of electrolytic copper, a good conducting but rather soft material.
Bus-bar connections are made with steel bolts, nuts and spring washers. Bus-bars can have a temperature of 125° centigrade under full load. Locking nuts with PVC or nylon locks have to be suitable for this temperature. Nuts to be fastened with a torque wrench to avoid overstressing of the copper. Overstressing above the yield stress of the copper results in loose connections. Checking all the connections in a switchboard bus-bar system with a torque wrench is a lot of work, not to mention the opening and closing of the bus-bar compartments.
Another way to check these connections is to measure with a low resistance measuring device from one outgoing group at the cable connections to the second outgoing group at the cable connections. Followed by the second to the third and so on.
With all circuit breakers open the insulation resistance of the bus-bar system can be measured.



5 Circuit breakers.

5.1 Low Voltage

Most LV circuit breakers are air circuit breakers with main contacts, arcing contacts and arc extinguishing chambers. Arc chambers to be taken off and inspected for debris.
Arc contacts and main contacts to be inspected for damage. Interval time annually or after clearance of a serious fault.

5.2 High Voltage

Most HV circuit breakers are either gas filled or vacuum and cannot be opened for contact inspection. There, with the same current injection set as used for the bus-bar conductivity tests, the resistance in micro-ohms of the closed contacts can be measured.

5.3 Functional tests.

Check the circuit breakers in the test position for correct closing and opening. Check remote controls and check the synchronising mechanism (closing at the correct moment by the synchronising device as observed by the Synchronoscope).

5.4 Calibration of protection devices.

Calibration of protection devices such as over-current, short-circuit current, under voltage trip, reverse power, differential protection and their timing requires special tools and specialists. The interval between tests is usually five years.

6 Starting devices

Starters to be visually inspected for cleanness and cleaned if necessary.
Also inspection for hot spots:
- low voltage
- high voltage
- choke type
- autotransformer type.

7 Converting equipment

7.1 Air-cooled

Cleaning or replacement of air filters, visual inspection of windings, visual inspection of connections, checking for hot spots.

7.2 Water-cooled

Cleaning of heat exchanger, testing of leakage alarms, visual inspection of windings, visual inspection of connections, checking for hot spots.

7.3 Electronic components

Sensitive electronic devices such as printed circuit boards (PCB's) in rectifiers and converters must be kept clean of dust, salt deposits, and checked on a regular basis.

8 Transformers

8.1 Air-cooled

Cleaning or replacement of airfilters, checking of fans, if any, visual inspection of windings, visual inspection of connections, checking for hot spots.

8.2 Water-cooled

Cleaning of heat exchanger, testing of leakage alarms, checking of fans, visual inspection of windings, visual inspection of connections, checking for hot spots.

9 Emergency generator

The emergency generator has to be started every week. Both the first (battery) and second means of starting (usually another way, such as by spring or hydraulic power) are to be checked.
Automatic starting on the first starting arrangement by simulating no-voltage of the feed from the main switchboard to the emergency switchboard has to be tested.

10 Alarm and monitoring systems.

Correct functioning of temperature, pressure and flow switches to be checked.
This is a time-consuming process, as pressures, temperatures and flow have to be simulated.
Analogue transmitters are easier to check: with an engine stopped, all actual temperatures are indicated at the engine temperature panel, or the preheating temperature of the motor.
With running engine bearings, pressures and temperatures can be compared and faulty sensors are easily found. Same goes for exhaust gas temperature transmitters, from no load to full load all of them should indicate temperatures in the same range.
The list of inputs as from the commissioning shall be used as a reference

11 Batteries.

Batteries are to be checked for:
- correct liquid level
- corrosion-free connections
- cracks in the housing.

Also the battery capacity is to be checked by discharging the battery partly and measuring the battery voltage. Results depend on rating and type of battery. Data to be registered and by comparison the end of the life time can be predicted.

As the battery capacity is related to the ambient temperature the environmental conditions must be checked on a regular basis and through the seasons, especially during winter time.

1 Formulas

A formula is a concise way of expressing information symbolically or give a general relationship between quantities.

Formulas are used to solve equations with variables. For example the formula that describes the current flowing through a resistor when the voltage and resistance are known parameters is:

$$I = \frac{U}{R}$$

In which:
I representing the current in Ampere (A)
U the voltage in Volts (V)
R the resistance in Ohm (W)

In a general context a formula is applied to provide a mathematical solution for a real world problem. Formulae form the basis for all calculations.

Formulae are internationally standardized and enable professionals around the world to understand and use them appropriately.

Below is a selection of formulae, including those used in this book, with an explanation of their purpose. Also included are some short explanations of key parameters.

Some **common electrical units** used in formulas and equations are:
V = Volt, the unit of electrical potential.
W = Ohm, the unit of resistance.
A = Ampere, the unit of current
W = Watt, the unit of electrical energy or power.
VA = Volt Ampere, the product of volts and amperes.

Explanation: in direct current systems the volt ampere is the same as watts or the energy delivered. In alternating current systems the volts and amperes may not be 100% synchronous. When synchronous the volt amperes equals the watts on a wattmetre. When not synchronous volt amperes (VA) exceed watts (W)
cosφ = power factor, in short the ratio of watts to volt amperes or the ratio of the active (true or real) power to the apparent power.

Explanation: as this is an important issue in AC networks this is some explanation of the forms of power. There are three distinctive forms of power:
Active Power (P), measured in watts (W), is the power drawn by the electrical resistance of a network doing the actual work.
Apparent Power (S), measured in volt-amperes (VA), is the voltage on an AC network multiplied by all the current that flows in it. It is the vector sum of the active and the reactive power.
Reactive Power (Q), measured in volt-amperes reactive (VAR), is the power stored in and discharged by for instance inductive motors, transformers and solenoids. Reactive power is required for the magnetization of the steel cores but does not perform any action.

The power factor can be calculated from:

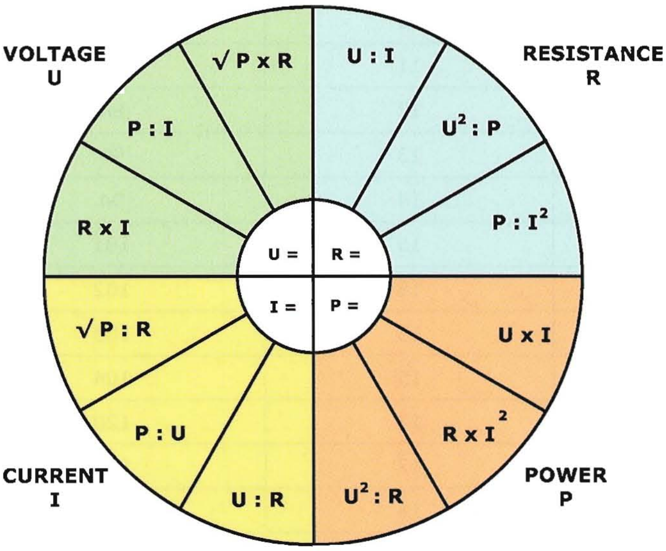
$$\text{Cos}\varphi = \frac{P}{S}$$

In which P = active power (W)
S = apparent power (VA)

Low power factors should be avoided as the circuit's wiring has to carry more current than what would be necessary with a normal power factor of around 0,8.

29. APPENDIXES

The formula wheel below visualizes Ohm's law for the calculation of voltage (U), resistance (R), Power (P) and current (I).



Example: application Ohm's law

A 24V battery supplies power to a resistance of 48W
The current can be calculated from:
I = U/R = 24/48 = 0,5A
The power can be calculated from:
P = U2 : R = 242 : 48 = 12W

Multiples and Submultiples of Units

When large numbers are part of formulas and equations it is common practice to use prefix names of multiples and submultiples of units to ease reading of these. Some commonly used, also in this book, are:

_ = micro, one-millionth or 0.000,001
m = milli, one-thousandth or 0.001
k = kilo, one thousand or 1,000
M = mega one million or 1,000.000

Examples: 1000 VA can also be written as 1kVA, 1000kVA can also be written as 1MVA which is:
1000 x 1000 = 1,000.000 VA.

Energy and Power

Electrical energy	E = U x I x t
Active Power	P = U x I x cosφ
Apparent Power	S = U x I
Reactive Power	Q = U x I x sinφ

Current calculations generators and motors

DC motors $$I = \frac{1000 \times PkW}{Udc \times h(A)}$$

Single-phase motor $$I = \frac{1000 \times PkW \times \sqrt{3}}{Udc \times h(A)}$$

Three phase motor $$I = \frac{1000 \times PkW}{\sqrt{3} \times Un \times \cos\varphi \times h\ (A)}$$

Three phase generator $$I = \frac{1000 \times SkVA}{\sqrt{3} \times Un\ (A)}$$

Electrical Motor Efficiency

The electric motor efficiency can be calculated from:

$$h = \frac{746\ Php}{Winput}$$

in which:
h = efficiency,
Php = output horsepower (hp)
Winput = input electrical power (Watts)

For Winput one can substitute: U x I x √3 x cosφ

Short-circuit calculations

See chapter 7, pages 50 and 51 for details

2 List of tables

3 Symbols

An electric symbol is a pictogram used to represent various electrical and electronic devices (such as generators, motors, batteries, cables, wires and resistors) in a schematic diagram of an electrical or electronic circuit. These symbols can (because of remaining traditions) vary from country to country, but are today to a large extent internationally standardized. Symbols enable professionals around the world to "read" and understand their meaning and use them appropriately.
Symbols in this book are based on IEC 60617 - Graphical Symbols for Diagrams
On this page is a small selection of symbols, including those used in this book, and their meaning. For other symbols the IEC standard should be consulted.

One general rule with the use of symbols is that as long as standard types or combination of those are used no further explanation on drawings is required.

Furthermore any combination of standardized symbols can be made to form a new symbol. The diagrams of a small and a large circuit breaker in chapter 8 on page 57 are examples of combinations of standard symbols.
When non-standard symbols are used, for instance purpose-made, these should be explained on the drawing or on a related document like a list of symbols.

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
[X]	VOLTAGES AND CURRENT	⎓	DIRECT CURRENT (DC)
∼	ALTERNATING CURRENT (AC)	**L1, L2, L3**	PHASE IDENTIFICATION
N	NEUTRAL IDENTIFICATION	**PE**	PROTECTIVE EARTH IDENTIFICATION
[X]	WIRING DIAGRAMS		CONTACT, BASIC
	CONTACT, POWER		CONTACT, DELAYED FROM LEFT TO RIGHT
	CONTACT, DELAYED FROM RIGHT TO LEFT		CONTACT WITH THERMAL OPERATION
	SINGLE SCREW TYPE FUSE	A1 Kx A2	RELAY COIL
X1 Hx X2	SIGNAL LAMP		
Sx	PUSHBUTTON 1 NO SPRING RETURN	Sx	PUSHBUTTON 1 NC SPRING RETURN
[X]	ONE LINE DIAGRAMS		SOCKET AND PLUG COMBINATION
△	DELTA CONNECTION (GEN., MOTOR, TRANSF.)	⅄	STAR CONNECTION (GEN., MOTOR, TRANSF.)
G	GENERATOR DC	M	MOTOR DC
G 3~	GENERATOR 3-PHASE AC	M 3~	MOTOR 3-PHASE AC
	TRANSFORMER		DOUBLE STOCK TRANSFORMER
	RECTIFIER AC TO DC		FREQUENCY CONVERTER
	BATTERY		EARTH, GROUND

Phase colours
Phase colours are used to easily identify the different phases, the neutral and the protective earth or ground in an electrical installation.
Unfortunately there is no worldwide standard for phase colours so one should always be cautious when servicing an electrical installation.

Below are some examples of phase colours as they are in use in the US, Canada and Europe.

Diagrams
For the sake of clarity it was decided for the diagrams in this book to use the phase colours as these were officially in use in the UK until April 2006. The phase colours as officially in use throughout Europe as per CENELEC 2006 would have been difficult to read.

Some standard phase colours

L1	L2	L3	N	PE	Description
Black	Red	Blue	White or Grey	Green, green-yellow striped	USA common
Red	Black	Blue	Grey or White	Green	Canada by law
Brown	Black	Grey	Blue	Green-yellow striped	Europe present as per CENELEC 2006
Red	Yellow	Blue	Black	Green-yellow striped	UK until April 2006 (used in this book)

4 Abbreviations

An **abbreviation** is a shortened form of a word or phrase used chiefly in writing to represent the complete form. Abbreviations are widely used among professionals with different occupations and consequently abbreviations may have different meanings from group to group.
To avoid confusion the following is a list of abbreviations used in this book.
The abbreviations are alphabetically sorted.
Abbreviations on P&IDs and those related to formulas, class notations and chemicals are not included.

For other meanings to abbreviations the internet can be a good source with for instance the internet site dedicated to abbreviations that can logically be found at www.abbreviations.com.

A

A	Ampere
ABS	American Bureau of Shipping
AC	Alternating Current
AC	Air Conditioning
AFE	Active Front End (Freq.Drive)
Ah	Ampere hour
AIS	Automatic Identification System
API	American Petroleum Institute
ARPA	Automatic Radar Plotting Apparatus
ATEX	ATmosphere EXplosive
AVR	Automatic Voltage Regulator
AWG	American Wire Gauge

B

BV	Bureau Veritas

C

CCTV	Closed Circuit Television
CEE	Commission (standard) for Electrical Equipment, common abbreviation for IECEE, International Electro technical Commission (standard) for Electrical Equipment
CL	Centre Line
CPA	Closest Point of Approach
CPU	Central Process Unit

D

DAD	Design Appraisal Document
DC	Direct Current
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
DOL	Direct on-line
DP	Dynamic Positioning
DSC	Digital Selective Calling

E

EC	European Community
ECDIS	Electronic Chart Display
EMC	Electromagnetic Compatibility
ENV	Environmental
EPIRB	Emergency Position Indicating Radio Beacon
EPL	Equipment Protection Level
EPR	Ethylene propylene rubber (cable)
ESB	Emergency Switchboard
ESD	Emergency Shutdown
ETA	Estimated Time of Arrival
ETD	Embedded Temperature Detector
Ex	Explosion

F

FAT	Factory Acceptance Test
FMEA	Failure Mode Effect Analysis
FPSO	Floating Production Storage and Offloading
FW	Fresh Water

G

GHz	Giga Hertz
GL	Germanisher Lloyd
GMDSS	Global Maritime
GPS	Global Positioning System
GT	Gross Tonnage

H

HAT	Harbour Acceptance Test
HF	High Frequency (radio)
HPP	Hydraulic Power Pack
HT	High Temperature
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
Hz	Hertz (frequency)

I

IEC	International Electric Committee
IMO	International Maritime Organisation
IP	Insulation Protection
ISM	International Safety Management
IWW	Inland Water Ways

J

K

kHz	Kilo Hertz
kV	Kilo Volt
kVA	Kilo Volt Ampere

L

LED	Light Emitting Diode
Lm	Lumen
LNG	Liquefied Natural Gas
LR	Lloyd's Register
LRIT	Long Range Identification and Tracking
LT	Low Temperature
LV	Low Voltage
Lx	Lux

M

MCA	Maritime & Coastguard Agency
MCT	Multi Cable Transit
ME	Main Engine
MED	Marine Equipment Directive (European)
MF	Medium Frequency (radio)
MHz	Mega Hertz
MODU	Mobile Offshore and Driiling Units
MSB	Main Switchboard
MW	Mega Watt (power)

N

NEC	National Electrical Committee (US)
NKK	Nippon Kaiji Kyokai (Japanese Class)
NMEA	National Marine Electronics Association

O

P

PCB	Printed Circuit Board
PLC	Programmable Logic Controller
PMS	Power Management System
PS	Portside
PTFE	Poli Tetra Fluor Ethylene (Teflon)
PTO	Power Take Off
PVC	Polyvinyl Chloride

Q

Qty	Quantity

R

RADAR	Radio Detection and Ranging
RC	Rotating Current
RINA	Registre Italiano Navale
RMS	Root Mean Square
ROV	Remote Operated Vehicle
RPM	Revolutions per Minute

S

SART	Self Activating Radio Transmitter
SAT	Sea Acceptance Test (Sea trials)
SB	Starboard
SCADA	Supervisory Control and Data Acquisition
SOLAS	Safety Of Life At Sea
SSAS	Ships Security Alert System
SSC	Special Service Craft
SW	Salt Water

T

TA	Type Approval
TBT	Tri Butyl Tin Fluoride
TEFC	Totally Enclosed, Fan Cooled
TFT	Thin film transistor (monitors)
THD	Total Harmonic Distortion

U

UHF	Ultra High Frequency
UMS	Unmanned Service
UPS	Uninterruptable Power Supply
UV	Ultra Violet

V

V	Volt
VDR	Voyage Data Recorder
VFD	Variable Frequency Drive
VHF	Very High Frequency
VLCC	Very Large Crude Carrier

W

X

XLPE	Cross-Linked Poli-Ethylene

Y

Z

30. USEFUL INTERNET LINKS

The **internet** nowadays is a vast domain of information but the quality of this information may vary from site to site. User discretion is therefore advised with using the internet as a source of information.
To help with gathering information via the internet following is a small sample of internet links that may be useful.
Although all links were tested when this book went into print users should be aware that the internet is changing all the time and that internet links may not be available when you try them (broken links).
A "clickable" version of this list can be found on the publisher's website:
www.dokmar.com

New interesting links that could be included in the next print of this book may be sent to the publisher's e-mail address: **info@dokmar.com**

1. Standards

www.imo.org	International Maritime Organisation
www.iso.org	International Organization for Standardization
www.cen.eu	European Committee for Standardization
www.cenelec.eu	European Committee for Electrotechnical Standardization
www.iec.ch	International Electrotechnical Commission
www.cie.co.at	International Commission on Illumination
www.itu.int	International Communication Union
www.bsigroup.com	British Standards, main internet site
www.ansi.org	American National Standards Institute with a vast Internet Resources Overview page some of which are also listed here.
www.uscg.mil	United States Coast Guard (USCG) main site
www.standard.no/en/sectors/Petroleum	Norwegian Standards for the Petroleum Industry

2. Ships Classification Societies

Some of the major ships classification societies are listed below. Only those societies are listed that are member of both the International Association of Classification Societies and the European Maritime Safety Agency.

www.iacs.org.uk	International Association of Classification Societies
www.emsa.europa.eu	European Maritime Safety Agency
www.lr.org/sectors/marine	Lloyd's Registers ships classification main internet site.
www.cdlive.lr.org	Lloyd's Registers marine classification information service with entries to lists of type approved equipment
www.eagle.org	American Bureau of shipping
www.bureauveritas.com	Bureau Veritas main internet site with link to Maritime Industry section
www.gl-group.com	Germanischer Lloyd
www.rina.org	Registro Italiano Navale (RINA)
www.classnk.or.jp	Nippon Kaiji Kyokai, known as ClassNK or NK, Japanese classification society
www.rs-head.spb.ru/en	Russian Maritime Register of Shipping
www.dnv.com/industry/maritime	Det Norske Veritas, Marine section

3. Large systems and equipment suppliers.

Some of the major international systems and equipment suppliers are listed below.

www.schneider-electric.com Schneider Electric, components, complete assemblies and systems. Main site with a large database with free downloads of Cahiers Technique in PDF format with very detailed design information on various subjects. Enter "cahiers" in the search input field to get a complete overview.

www.siemens.com Siemens, components, complete assemblies and systems. Main site with again lots of free information and download

www.abb.com ABB, components, complete assemblies and systems

www.ge.com GE, components, complete assemblies and systems

www.nema.org NEMA, the Association of Electrical and Medical Imaging Equipment. NEMA is the trade association for the electrical manufacturing industry in the USA and has approximately 450 member companies manufacturing products used in the generation, transmission and distribution, control, and end-use of electricity..

4. Material classification

www.ul.com Underwriters Laboratories (UL) is an independent product safety certification organization that is testing products and writing standards for safety

www.ptb.de/en The Physikalisch-Technische Bundesanstalt (PTB) is the German national metrology institute providing scientific and technical services. PTB certificates are applied for instance to explosion proof equipment

5. Ships Automatic Identification System (AIS)

Two examples of internet sites with live presentation of ships movements around the world

www.marinetraffic.com/ais

www.digital-seas.com

6. General science, basics for engineering

www.bubl.ac.uk BUBL LINK Catalogue of Internet Resources covering all academic subject areas

www.intute.ac.uk INTUTE is a useful site to find websites for study and research

www.unesco.org United Nations Educational, Scientific and Cultural Organisation and on their site more specific the Natural Science section (tab)

7. Various sites.

Below is a sample of internet sites that may contain useful information. This is a random selection from the millions of sites now available on the internet.

www.mathconnect.com Mathconnect, on-line calculations and conversions. Simple to use site with direct results.

www.thefreedictionary.com Free on-line English dictionary

www.wetransfer.com For transfer of big files which are difficult to attach to e-mails

www.stormy.ca Canadian internet site loaded with interesting information and more links

www.gizmology.net/batteries Some notes on the selection of batteries with an on-line calculation part

www.islandnet.com/robb/marine.html Site with some interesting guidance for testing

webbook.nist.gov/chemistry National Institute of Standards and Technology (NIST) Chemistry Web-Book with a search engine and database to find the chemical properties of 70.000+ materials

31. INDEX

ACKNOWLEDGEMENTS

Corrections and proof readings:

- Jan van Boerum,	Schiedam
- Carol Conover,	The Netherlands
- Mimi Kuijper	Terschelling
- Fred van Laar,	Voorschoten
- Mark Ringlever,	Schiedam
- Huib van Zessen,	Barendrecht

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Jan van Boerum,	Schiedam	51, 89, 97, 135, 137, 139, 164, 175, 183, 192, 194, 195, 196
Danny Cornelissen,	Rozenburg	162, 214, 215
Klaas van Dokkum,	Enkhuizen	6, 42, 66, 83, 166, 169, 172, 176, 177
GustoMSC,	Schiedam	219
Hans ten Katen,	Rotterdam	31,
OceAnco	Alblasserdam	39,
Klaas Slot,	Haarlem	4, 7, 8, 9, 14, 29, 39 157, 187, 193, 194, 206 t/m 209, 220,
221		

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