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Ships

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46.1 Introduction

Prior to 1950, electrical installations in ships (other than tankers) were predominantly d.c. This predominance has been reversed because of the higher power requirements of modern ships, for which a.c. systems have lower capital and maintenance costs. The main problems of this changeover have concerned the requirement, based on tradition, for variable-speed deck auxiliaries (winches, capstans and windlasses), pumps and fans. For the latter, makers have accepted single-speed or change-pole two- or three-speed induction motor drives, with additional throttle control in appropriate cases. For deck auxiliaries it was similarly found that for certain trades the change-pole induction machine was adequate, and that Ward–Leonard or other sophisticated systems could meet more demanding duty.

The development of North Sea exploration since 1970 led to the introduction of Mobile Offshore Installations generating large electrical power; their systems are invariably a.c., with d.c. conversion for operation of drilling machinery.

The concept of centralised control stations has been fully developed, with control gear, alarms and instrumentation grouped in enclosed, air conditioned and soundproofed rooms. With advances in the automatic control of steam raising plant, including the re-emergence of coal burning, engine rooms unmanned at night and with reduced manning by day have become the norm.

46.2 Regulations

With very few exceptions, every seagoing ship must comply with national, international and classification society rules and regulations. The leading classification societies (to which the administration of international requirements is sometimes delegated by the government concerned) include Lloyds Register of Shipping, Bureau Veritas, American Bureau of Shipping, Germanischer Lloyd, Nippon Kaiji Kyokai, Norske Veritas and Registro Italiano Navale. Lloyds Register of Shipping's Rules and Regulations for the Classification of Ships, which are reviewed regularly, lays down the necessary guidelines to ensure that all registered vessels are safely operated within the laws of the relevant nations. In addition to the well known larger societies, other smaller ones have emerged and unified requirements are promulgated by the International Association of the Classification of Ships.

Ships are to comply with the 1974 United Nations Resolution for the Convention for the Safety of Life at Sea (SOLAS), the 1986 consolidation and its 1988, 1990, and 1991 protocols. They must also comply with 1991 Marine Pollution (MARPOL) Consolidation which incorporates the International Maritime Organisation's (IMO) 1973 Convention on Marine Pollution and its subsequent protocols and with the acts of the various maritime nations. For British ships this includes the Merchant Shipping Act 1988. Passenger ships (carrying more than 12 passengers) must have a valid Passenger Safety Certificate and cargo vessels a valid safety Construction Certificate. Validity for communications including terrestrial radio and telex is encompassed by the Global Maritime Distress and Safety Systems which is covered in the 1988 amendments to SOLAS. The IMO is responsible for reviewing Conventions and Codes relating to the safety and operation of vessels at sea and any revisions must be accepted and acted on by the leading maritime nations.

Electrical construction and performance standards are set by each of the classification societies, SOLAS, government regulations, International Electrotechnical Committee (IEC) and, in the UK, by the British Standards Institution (BSI) and Institute of Electrical Engineers (IEE). The electrical regulations for offshore oil and gas rigs are incorporated in the IMO Code for the Construction and Equipment of Mobile Offshore Drilling Units 1991. The main IEE publication is the regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for their Implementation 1990. BSI publications include BS 2949:1960 which covers the construction and performance of rotating machinery and BS 3399:1961 which covers the regulations for transformers. The main IEC regulations are IEC 92 PT101 which cover the general requirements for electrical installation in ships, IEC 92 PT502 for electrical installations in tankers, and IEC 92 PT503 which is applicable to electrical installations with voltages in the range 1 kV to (and including) 11 kV.

46.3 Conditions of service

IEC Publication 92–101 specifies for ships on unrestricted service an ambient air temperature of 45 °C for all equipment other than rotating machines in machinery spaces, in galleys and on weather decks. For rotating machines in machinery spaces it is 50 °C. In all other spaces and for vessels on restricted service (i.e. coasters, tugs and harbour craft operating solely in temperate climate) 40 °C is recognised. For electronic devices, semiconductor diodes, etc., much higher ambient temperature conditions may have to be withstood.

Other onerous conditions are vibration, and inclination up to 15° transversely and with rolling up to $22\frac{1}{2}°$. Voltage variation may be +6 to −10%, with simultaneous frequency variation of ±2.5%. With a.c. generation a momentary voltage dip of up to 15% at the generator is permissible when large motors or groups of motors are switched direct-on-line.

From the point of view of electrical equipment, very severe conditions prevail while a ship is under construction. Welding and painting will be in progress in the vicinity, accompanied by dirt and exposure to the weather.

Skilled maintenance and repairs can be carried out only in ports where suitable facilities exist. This applies particularly to machine windings. Installations must therefore be of a high standard of reliability and suitable for operation over prolonged periods with a minimum of attention. Unlike industrial conditions, in which there are shut-down or reduced-load periods, apparatus on essential ship's services may operate continuously for several days.

46.4 D.c. installations

Standard practice is to use parallel-operated level-compounded generators with equaliser connections and reverse-current protection. For small installations 110 V may be used, but 220 V is the general norm. Installations of up to 3000 kW with individual machine ratings up to 1000 kW were formerly common, but the present preference for a.c. means that d.c. systems do not now exceed 1000 kW total with smaller generating units.

The hull return system of distribution is not permitted for any tanker vessel or for any ships of greater than 1600 t gross tonnage, unless an exception is granted by the appropriate classification society. Exceptions to this rule are:

(1) impressed current cathodic protection, and
(2) insulation monitoring devices.

46.5 A.c. installations

Tankers and passenger ships of recent construction are almost all equipped with a.c. systems—about 40% with a frequency of 50 Hz; the remainder of 60 Hz. As most marine generators and motors are special to this service, the choice of frequency does not have to be related to particular national supply systems. The frequency of 60 Hz gives the advantage of higher operating speed and lower weight. Motors built for 440 V, 60 Hz can operate from 380 V, 50 Hz shore supplies and (if some additional heat can be tolerated) on 415 V, 50 Hz. However, contactors and voltage operated relays may not always be amenable to such conditions; and 50 Hz motors may not operate satisfactorily on 60 Hz, particularly with centrifugal fan and pump loads.

In some tankers and passenger ships, high-voltage generation has been adopted, particularly in those vessels that are electrically propelled. IEC Publication 92, *Electrical Installation in Ships*, Part 503, and BS 3659 (replaced by BS 5311:1991:Parts 1–7) apply to vessels with high-voltage generation.

46.6 Earthing

Regulations permit isolated or earthed neutral systems, except for tankers, in which earthed systems are forbidden. The choice (where there is one) is almost always for isolation, the risk of overvoltage being accepted to avoid the loss of a vital service, e.g. steering, should one earth fault occur. A single earth fault on an insulated system can be detected, and does not result in an outage unless a second fault occurs; and in any case overvoltages are rare compared with the incidence of earth faults. Every insulated distribution system, whether primary or secondary, is required to be provided with means to continuously indicate the state of insulation from earth and is to be arranged in such a way as to give warning of abnormally low levels of insulation. However, care must be taken when designing the installation to protect electronic circuits, particularly those containing semiconductor diodes, from overvoltage ‘spikes’, direct or induced.

46.7 Machines and transformers

The construction, installation and performance of rotating machinery on ships is dealt with in BS 2949:1960, BS 4999:1992, and IEC 92 PT202. Transformers for high voltage discharge lighting should comply with BS 3535:1990. Other transformers are covered in BS 3399:1961, BS 3535:1990 and by IEC Publication 92–303. It is recommended, except for those used for motor starting, that they should be doubly wound, i.e. with separate windings and that dry types should be used in preference to ‘wet’ types.

Because relatively large motors and groups of motors are started direct-on-line, the consequent voltage dip is important because of its effect on the system as a whole and, in particular, on lights, contactors and voltage operated relays. Stipulations are:

(1) A limit of 15% voltage dip at the generator terminals and a recovery to within 3% of rated voltage within 1.5 s, when the generator is subjected to a suddenly applied symmetrical load of 60% rated current at a power factor between zero and 0.4 lagging; the recovery may be increased to 4% within 5 s for emergency generators.

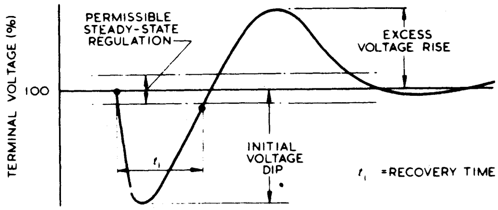

Figure 46.1 A typical voltage response

(2) A limit of 20% excess voltage following initial recovery.
(3) Under steady-state conditions the system, which may include an automatic voltage regulator, must be maintained within 2½% rated bus-bar voltage (3½% for emergency sets). The conditions are shown in *Figure 46.1*.

These requirements are for normal installations. Special conditions apply if the impact load exceeds 60%, or if the deck machinery consists of groups of multi-speed cargo winches liable to be switched simultaneously, or in any other special conditions.

It is common practice in modern ships to use self-excited compounded a.c. generators, or brushless machines with a.c. exciters and shaft mounted rectifiers (*Figure 46.2*). In order not to nullify short-circuit protective gear, such generators must maintain adequate voltage under short-circuit fault conditions. BS 2949:1960 specifies a current of at least three times rated value for 2 s unless provision is made for a shorter duration without impairing safety.

46.7.1 A.c. generators

Self-excited self-regulating a.c. generators are now available in all sizes for marine service, with excitation obtained from a three-phase exciter through semiconductor rectifiers. The principles are the same whether a slip-ring or a brushless form is applied. Voltage and current transformers connected to the generator output feed field excitation through a three-phase rectifier to give a compounding effect. A typical arrangement (*Figure 46.3*) combines compounding with closed-loop control: the effect on the excitation due to the compounding is supplemented by a fine control, the response of which is determined by the divergence of the generator voltage from a pre-set reference. A transient dip of generator voltage during the first period following a

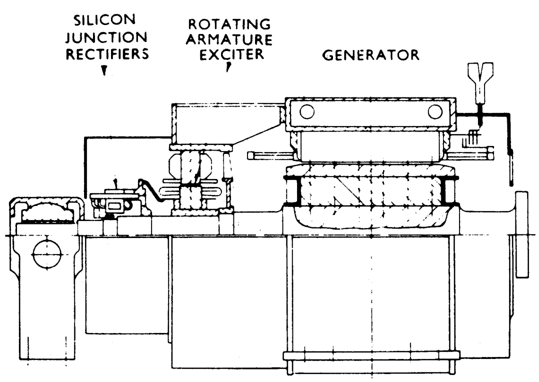

Figure 46.2 Cross-section of a brushless a.c. generator

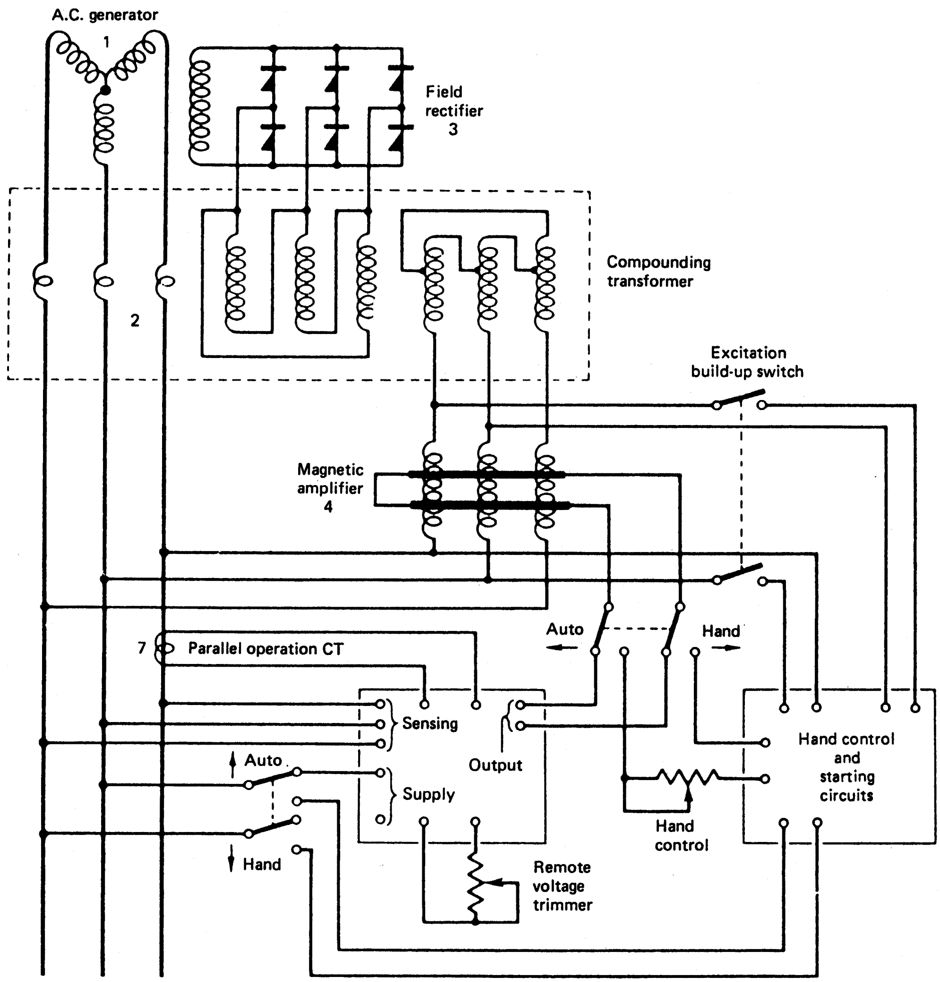

Figure 46.3 Schematic diagram of a static-excited a.c. generator

disturbance is inevitable, but no further change due to armature reaction occurs, because the excitation is rapidly corrected by field forcing through the action of the series windings of transformer 2.

Under short-circuit conditions saturation of the static excitation components limits the excitation to about 1.5 times full-load value, and the sustained short-circuit current is about three times rated value. Variations in field resistance are swamped by the series impedance of the magnetic amplifier. The circuit self-compensates for speed changes, as the amplifier current rises as the frequency falls. The automatic control circuit incorporates a Zener diode which controls a silicon transistor driving a thyristor. The three-phase rectifier is connected to the generator main field through slip-rings.

An example of a brushless system is given in *Figure 46.4*. Excitation is provided partly by saturable current transformers and partly by a three-phase linear inductor, all of small rating and easily accommodated on the switchboard. There is sufficient magnetic remanence in the a.c. exciter to ensure starting. By means of the automatic voltage regulator (a.v.r.) a steady voltage regulation of ±1% is obtained with high-speed response, typically within 0.5 s.

Governors on prime-movers are required to automatically maintain rated speed within a momentary maximum variation of 10% and a maximum steady state variation, i.e droop not exceeding 5%. These figures are to be met during tests whereby a fully loaded generator is subjected to a step 50% load reduction for a short period before full load is restored.

46.7.2 Voltage build up

In *Figure 46.3* the no-load terminal voltage is applied to magnetic amplifier 4; its current lags this voltage by nearly a quarter-period, passes through the compounding current transformer 2 and the field rectifer, and supplies the no-load excitation. When the generator is on load, the load current passes through the series coils of current transformer 2; the secondary current is then the phasor sum of the inductor current and a current proportional to the load current. By correct proportioning the static excitation is appropriate for all normal loads, even at low lagging power factors.

With brushless generators two rectifiers in parallel are provided in each phase of the rotating element to provide

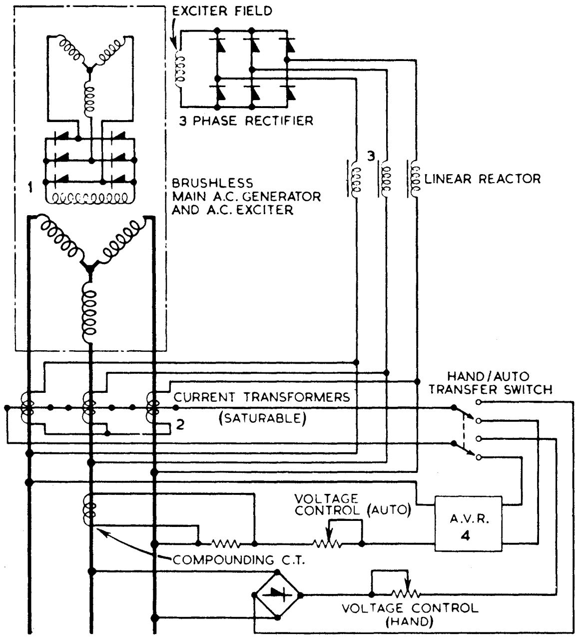

Figure 46.4 Schematic diagram of a brushless a.c. generator. C.T., current transformer; A.V.R., automatic voltage regulator

back-up should one fail. The commonest diode failure is a short circuit, so that each diode must be fused. A failed doide produces an unbalance and a ripple in the exciter field current. This can be used to detect failure.

46.7.3 Reverse-power protection

Loss of power from the prime-mover may be accidental or intentional. If the generator was left connected in parallel with other generators, it would act as a motor and continue rotating, with possible damage to the prime-mover. With d.c. generators this is taken care of with a reverse-current tripping relay, but with a.c. a reverse-power relay is necessary. To prevent inadvertent operation of reverse-power relays due to power surges, particularly when synchronising, a time-delay feature is incorporated. With diesel engines a fairly coarse setting of the order of 10–15% of full power is suitable, but steam turbines absorb very little power when motored and a fine setting of 2½–3% is necessary.

The alternative to reverse-power relay protection is to provide electrical interlocks or contacts which will respond to predetermined occurrences, such as failure of lubrication, closing of fuel or steam admission valve, operation of overspeed governor or excessive back pressure.

46.7.4 Single phasing

A common cause of motor burn-out is single-phasing, which can arise from broken or faulty connections or, more commonly, the blowing of one of the three-phase fuses. For this reason the IEE Regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for Their Implementation 1990, stipulate that matching cartridge fuses be used. In addition, overload relays with alarms and indication of motor failure to start must be fitted. This is particularly important if automatic starts are employed or if the machinery spaces are operated unmanned.

Undervoltage releases do not provide protection. Should the open circuit occur on the motor side of the circuit-breaker, the coil will continue to be fed from the supply, and if the open circuit is on the supply side, the coil will be fed by voltage induced in the motor.

A three-phase motor will not restart with an open-phase connection: out of sight and sound it may remain stalled, and if the overload protection is set too high or with too long a time delay, the motor may burn out. Pilot lights across one phase will give a false indication if the fault is on another phase. The remedy is to set overload protective devices closely, with suitable time lags, or to adopt some form of single-phase protection.

46.8 Switchgear

46.8.1 D.c. switchgear

Open switchboards have all essential switchgear exposed on the front. Some owners prefer dead-front construction. For the open type all parts, front and back, are readily accessible for maintenance, an important consideration when it is remembered that these operations have to be performed on a live board.

Regulations state that for each d.c. generator installed which does not run in parallel, a double-pole circuit-breaker or a fuse for each pole and a double-pole switch is required. For generators that run in parallel in a two-wire-insulated system a double-pole circuit-breaker is required for each machine. With compound generators the equaliser switch is required to be interlocked with the circuit-breaker of each machine so that it is made before the circuit-breaker can be closed and not opened until the circuit-breaker is opened.

Regulations require preferential tripping in large installations so that non-essential loads can be automatically switched off when the generators become overloaded. This can be done in either one stage in a simple installation or in two or three stages in larger systems. A typical arrangement is shown in *Figure 46.5*.

46.8.2 A.c. switchgear

Because of the greater risk of shock in a.c. systems, the open construction is not permitted and switchboards must be 'dead-front'. In the usual construction the switchboard is divided into cubicles. Circuit-breakers can be withdrawn and isolated from the bus-bars for maintenance and adjustment. Access doors are interlocked to prevent access to live parts. A similar construction is used for control gear.

Preferential tripping as described for d.c. systems is also required. Instrumentation must include a synchroscope (see *Figure 46.6*). Automatic synchronising is now becoming necessary in installations comprising prime movers which start automatically, and SOLAS and its protocols require automatic start-up and circuit-breaker closure within 45 s to ensure continuity of supply with unmanned installations.

Circuit-breakers are required to comply with the requirements of BS 4752 (replaced by BSEN 60947:1990). Air-breakers and miniature circuit-breakers are common at 440 V; high fault levels have led to the introduction of current-limiting breakers. At 3.3 kV and above, vacuum

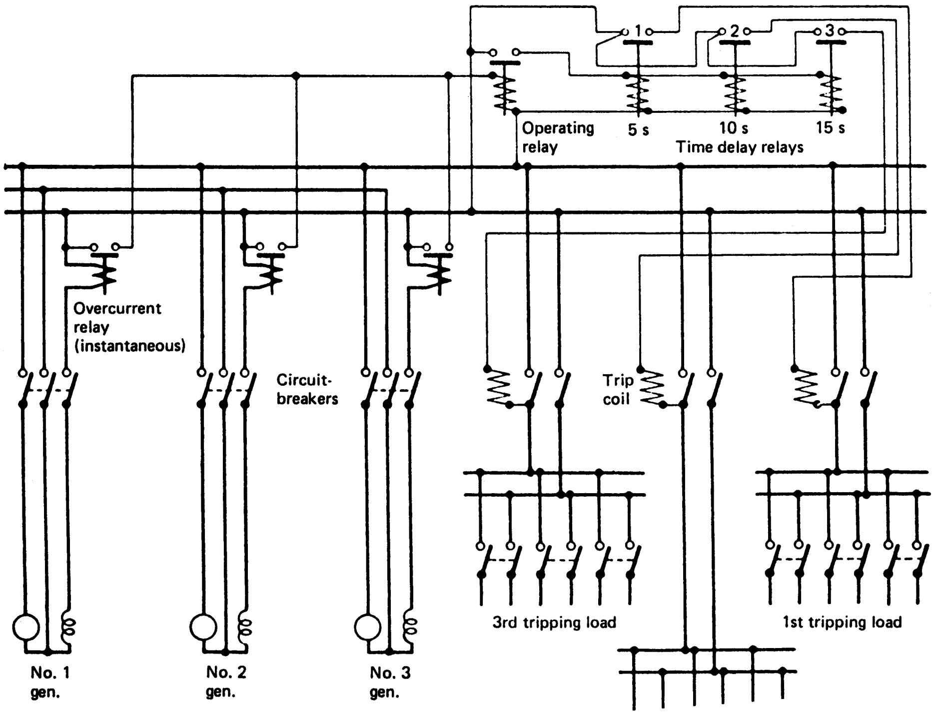

Figure 46.5 Diagram of typical preferential tripping circuits

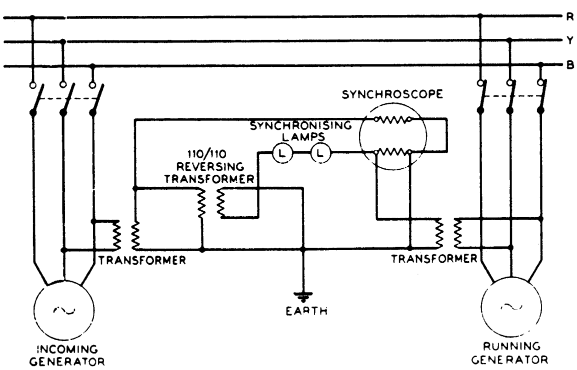

Figure 46.6 Schematic diagram of a synchroscope and synchronising lamps for a 'lamps bright' system

contactors are often used; active consideration is given to SF_6.

46.9 Cables

EPRCSP, PVC and XLPE, all with metallic sheath and PVC overall, are most common, being flame retardant as required by SOLAS. MICC and silicone rubber withstand high temperatures and have appropriate applications.

Cables which are required to be flame proof, for example those in tankers and gas carriers, are required to retain insulating properties after severe fire damage. The regulations governing these types of cable are covered by IEC 331 and by BS 6387:1991.

46.10 Emergency power

SOLAS and its protocols have extended for all ships the services to be supplied; for cargo ships the period for which this power must be available is stated.

Passenger ships are to have emergency power from a generator or battery adequate for 36 h duration. With a generator there must be a transitional battery to supply specified services for 30 min to come into operation automatically.

Cargo ships have similar requirements for 18 h duration, but do not need a transitional battery if the emergency source can start and be connected automatically.

Mobile offshore installations are covered in the MODU Code.

Both nickel–cadmium and lead–acid batteries are used for emergency or stand-by services to vital circuits such as computer communication, fire detection, etc., without 'excessive volt drop', a term interpreted by the British authority as a drop, at the end of the specified emergency period, not exceeding 12½% of nominal system voltage. The voltage should be within the limits −10% to −12½% from the fully charged condition to that at the completion of the prescribed duty.

Battery installation, ventilation and maintenance correspond to the best practice ashore.

46.11 Steering gear

Electric steering can be either all-electric or electrohydraulic. Its function is to control the position of the rudder through an angle of 35° each side of the central position. Regulations require that the time taken to put the rudder from 35° on

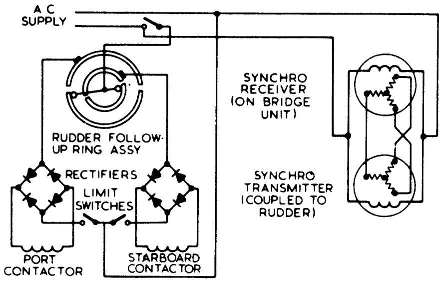

Figure 46.7 Schematic diagram of a rudder follow-up system and the synchro transmitter and receiver (Sperry system)

one side to 30° on the other is not to exceed 28 s at maximum service speed. The steering gear must be provided with running indicators, one on the bridge at the main steering position and one in the engine room. A usual arrangement is that one quarter-turn of the steering wheel corresponds to one degree of rudder movement. Automatic steering on a set course controlled by a gyro-compass can be superimposed on a power-operated system.

One such system is shown in *Figure 46.7*. Mounted in the bridge control unit is a follow-up ring assembly consisting of two pairs of silver rings mounted on insulating formers. Carbon brushes on the outer rings are connected to rectifiers which, in turn, are connected to contactor coils. Follow-up rollers make contact with the inner surfaces of the rings, one half-ring of each inner ring being connected to the complete outer ring. The carbon brushes are fixed, but the rings and the bracket carrying the inner contact rollers are free to rotate. The inner roller assembly is rotated by a synchro receiver; the contact rings by the pilot wheel when under hand control or by the gyro-compass transmitter when under automatic control. In this system the transmitter is geared to the rudder so that it adopts a corresponding angular position. When the rudder has reached the angle set by the pilot wheel (or by the compass), the rollers will have caught up with the gap in the ring and the contactors will open.

Electrohydraulic systems usually depend on a continuously running motor coupled to a variable-delivery pump supplying oil pressure to one or other of a pair of hydraulic cylinders. Operation from the bridge is by telemotor control, in which the rudder motion continues until its position coincides with that of the bridge setting.

All-electric systems depend either on a direct-coupled reversing motor or on Ward–Leonard control. In the latter the generator voltage may be controlled by a voltage divider or by field windings of opposite polarity. In push-button systems the rudder movement continues so long as the push-button is held closed.

Steering is a vital service. SOLAS now requires duplication of power supplies and control circuits, the latter to be supplied specifically from the associated power circuits. Alarms and transfer switching are to be sited on the navigating bridge. Large ships require steering power to be available, automatically within 45 s, from the emergency source on loss of main power.

46.12 Refrigerated cargo spaces

The system now commonly used consists of batteries of brine cooled pipes over which air is circulated by fans and distributed uniformly to all parts of the hold. The fans vary in size and number according to the holds, and a ship may require up to about 40 fans of 1–8 kW rating. Compressor motors up to about 200 kW at constant speed are commonly required. The fans are located in the holds and their lubrication presents a problem, as the ambient air temperature can vary between tropical conditions at the loading port and approximately −20°C when fully refrigerated.

Temperature control of the holds within narrow limits is essential for some cargoes (e.g. bananas), so that provision must be made for accurate and sensitive sensing and control at numerous points. Electrical thermometers have been specially developed to read to 0.1°C over a range of approximately −20°C to +15°C. A tolerance of ±0.1°C at the freezing point of water is attainable under working conditions.

Container ships with typical installed power of 6 MW, 450 V, 60 Hz and considerable instrumentation are now common. Up to 3000 containers of rating 3.5 kW may be supplied through flexible connections.

46.13 Lighting

46.13.1 General

For general lighting both tungsten and fluorescent lamps are used. For deck lighting halogen floodlights or high-pressure mercury lamps may be installed. Where colour rendering is not important, sodium lamps, which have high efficiency and long life, are suitable for high-level general lighting. The lighting load for large public rooms can be appreciable, and fluorescent lighting can reduce power and heat, which, in turn, assists air conditioning.

Under the Merchant Shipping Act, the Department of Trade requires artificial lighting in crew accommodation to be well diffused, avoiding glare and deep shadows. Bunk lights must be provided, and 25 W or 40 W tungsten or 15 W fluorescent lamps are considered satisfactory. In cold stores separate light fittings of robust construction, with a switch outside the compartment and a pilot light, are required.

For general lighting the level of lighting measured at a height of 0.85 m above floor level and midway between adjacent lamps, and between any lamp and a boundary of the space, is prescribed in precise terms. Good lighting in galleys is important, and brings faster working, fewer mistakes and accidents, and better hygiene.

Statutory regulations (when applicable) require emergency lighting supplied from the emergency source of power to be embodied in the lighting system. All boat stations, lifeboat launching gear and all public and crew areas, alleyways, service spaces, stairways and exits must be provided with emergency lighting.

Voltage variation affects the light flux output and life of both filament and fluorescent lamps.

46.13.2 Navigation lights

The requirements are prescribed in the International Regulations for Preventing Collisions at Sea 1972, as amended. All ships are to be provided with ‘steaming lights’, masthead, side, stern and anchor. Each navigation light should be provided with primary and alternative lanterns. Classification rules require that navigation lights shall be connected to a distribution board reserved solely for this service, and connected directly or through transformers to

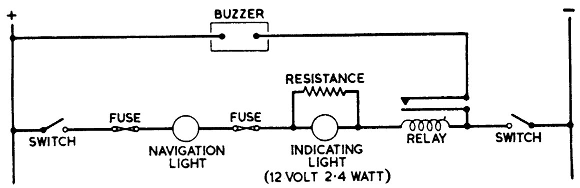

Figure 46.8 Schematic diagram of a typical navigation light indicator

the main or emergency switchboard. Each light must have aural and/or visual indication of failure. If only an aural device is fitted, it must be battery operated. If a visual signal is connected in series with the navigation light, there must be means to prevent extinction of the navigation light through failure of the signal lamp. Typical arrangements are shown in *Figure 46.8*. The volt drop across series connected indicators must not exceed 3% of the system voltage. The use of double-filament navigation lights is not permitted.

46.14 Heating

SOLAS prescribes that electric heaters, where used, must be fixed in position and must not have an element so exposed that clothing, curtains, etc., can be scorched or set on fire.

Except in ships employed solely in the tropics, crew accommodation has to be provided with a heating system of prescribed minimum performance. With certain exceptions a temperature of 19°C must be maintained in a ship regularly employed otherwise than as a 'home-trade ship', and 15°C in the case of any other ship, when the outside air temperature is −1\°C.

46.15 Watertight doors

Watertight doors, under certain conditions prescribed by regulations, have to be power operated and to conform to specific requirements, including testing at maker's works in the presence of a surveyor.

They may be either electrically or electrohydraulically operated and controlled, either in groups or individually from a central control position, usually the navigating bridge. In addition, hand operated gear must be provided which can be worked at each door or from a position above the bulkhead deck. At each control position an indicator must show whether the door is open or closed. An audible warning device situated near the door and operated by a time switch giving about 10 s notice functions before it starts to close.

The central control station has overriding features which decide whether the doors are to close; they can be opened locally but re-close automatically. They can also be closed locally independently of the central control.

An essential feature of the powering system is that it should exert an initial high effort to withdraw the door from the grip of door wedges which come into effect in the fully closed position. Thereafter this force diminishes and the rate of opening increases.

46.16 Ventilating fans

When trunking carries ventilating air to accommodation and cabins, any noise arising from fans or fan motors must be avoided. For this reason sleeve bearings are generally preferred. A variable speed or a choice of speed is usually necessary for control purposes.

Regulations require means to be provided for stopping fans from remote positions in the event of fire.

46.17 Radio interference and electromagnetic compatibility

Radio communication is vital and must as far as practicable be interference-free. 'Noise' may originate in the ship's electrical installation, in the rigging, from other radio frequency apparatus (e.g. public address systems) and from electromedical appliances. The radio installation can also cause interference with other electronic circuits; hence the concept of electromagnetic compatibility.

Suppression of unwanted noise is an economic problem to be shared by the supplier of the radio equipment, the shipbuilder, the electrical contractor and the manufacturers. Usually interference cannot be entirely eliminated, so permissible levels are prescribed. Interference can be alleviated by careful planning of radio installations and aerial systems, by applying certain techniques to the rigging, and by fitting suppression devices to electrical equipment and wiring. Interference arising from the electrical installation can be of two kinds—i.e. radiated and picked up by the aerial or conducted by cables entering the radio cabin. BS 1597:1985 deals with remedies generally considered necessary for the electrical installation and prescribes the permissible level of interfering emissions in the various wavebands. Precautions to be taken in the construction of the rigging and in the installation of cables are included.

This subject is detailed in an Appendix to the IEE Regulations for the Electrical and Electronic Equipment of Ships 1990.

46.18 Deck auxiliaries

Deck auxiliaries include cargo winches, cranes, capstans, warping winches, windlasses and hatch cover winches. For some classes of ship a variable speed for deck auxiliaries is still preferred, but, in general, two- or three-speed change-pole induction motors are suitable. For cranes a high-speed facility is needed for rapid return of the empty hook.

46.18.1 Variable speed

Where variable speed is essential in a.c. systems, slip-ring motors or Ward–Leonard control may be provided, the latter with a motor generator for each winch or for a group. In recent years there has been a trend to employ a.c. variable-speed drives. With d.c. systems, a variety of methods has been used: e.g. series resistance, Ward–Leonard, boost and buck, and lowering by dynamic braking or regeneration. Dynamic braking is generally achieved by means of diverters in shunt with the armature giving a potentiometer connection. In nearly all cases load discriminators may be necessary to control speed in relation to load, i.e. to permit of higher speeds with empty or lightly loaded hooks.

46.18.2 Deck auxiliary services

Some of the additional factors concerned with particular applications are given below.

46.18.2.1 Cargo winches

Emergency centrifugal brakes are fitted, where necessary to prevent excessive speeds when heavy loads are being lowered. Provision must also be made to prevent the load from running back in the event of a power failure. Light-hook speeds are 3–4½ times normal full-load speed.

Serious generator loading problems may be introduced where several winch motors with direct-on-line starting are in use. Large currents at low power factor cause generator and cable heating. *Table 46.1* gives empirical data for the effective current (in per-unit of the full-load current per winch) of a group of n winches ($n > 2$). Load-assessment curves are given in the IEE Regulations for the Electrical and Electronic Equipment of Ships.

46.18.2.2 Warping

Warping is frequently done with an additional barrel on care winches or windlasses. A flange prevents the hawser from running over the rim, and at the inner end of the frame a projection prevents it from becoming jammed between frame and warp end. If a foot-brake is fitted, its effect should be limited to the full-load torque of the winch, or torque-limiting relays should be fitted.

46.18.2.3 Capstans

Capstan barrels are normally mounted on a vertical shaft and the motor mounted below deck to leave the deck free.

46.18.2.4 Windlasses

Anchor windlasses are vital to the safety of the ship and have no stand-by. They are subject to classification and governmental requirements. The cable lifter is shaped to fit the links of the cable, and will normally accommodate four or five links around its circumference, although only two links are actually engaged at one time. The lifter can be declutched so that it runs freely for lowering, the speed being controlled electrically or by band brake. A slipping clutch is fitted to prevent excessive stress which could otherwise occur when heaving or when entering the anchor into the hawsepipe. A crawl speed is necessary to enable the anchor to be housed safely and to allow the motor to stall when it is fully home. It is also necessary while the anchor is still holding.

The overall efficiency of a windlass is about 60% and as much as 30% can be lost in friction unless, in accordance with modern practice, rollers are fitted. Windlasses can perform warping duties and extra control refinements are sometimes incorporated for these. They provide for a pull of about one-third of that of the cable lifters but at a greater speed. This speed is also required for recovering lines cast off from the quayside.

46.18.2.5 Mooring winches

Mooring winches are similar to warping winches except that one end of the line is fixed to the barrel.

The St Lawrence Seaway regulations require short-period stalling while docks are navigated, also constant tensioning against rising and falling tides or lock waters and during rapid loading or unloading.

46.19 Remote and automatic control systems

Since 1960 automation of ship's machinery spaces has increased considerably to the point where it is now generally recognised as an indispensable part of modern propulsion plant. In 1981 about 55% of the ships classed with Lloyd's Register of Shipping were designed to be operated with an unattended machinery space (UMS), and approaching 80% of the ships, including those with a UMS notation, had machinery spaces operated from a centralised control station.

Automation has also become indispensable in such areas as cargo handling, disposal by incineration of obnoxious waste, and pollution prevention. With high discharge rates, critical incinerator temperatures and specified limits of contamination, control systems are required to anticipate demand and give rapid response if catastrophes are to be avoided on board or at the terminal.

The proper functioning of control systems demands careful planning, since their viability may be governed by the nature of the ship's trading, the type of machinery to be controlled and the shipowner's manning and maintenance policies. A full specification is required of the extent of control facilities to be provided to ensure compatibility of controls with machinery, the marine environment and the operating personnel.

46.19.1 Operational modes of machinery spaces

Modern applications of control engineering systems permit two basic operational modes of the machinery space: (1) continuously attended, but with a high degree of remote and automatic controls to allow operation from a centralised control station; (2) periodically unattended machinery spaces so that engineers need not be tied to traditional watch-keeping routines and, for example, may leave the machinery space unattended during the night.

On vessels where centralised control is adopted, it is usual to incorporate all controls, alarms and instrumentation in an enclosed control room which is sound and vibration proofed and air conditioned. With the withdrawal of the engineer from the machinery space, it is essential that the controls and instrumentation provided be such that supervision of the machinery plant from the control room is as effective as it would be under direct supervision. The arrangements must give provision for corrective actions to

Table 46.1 Effective group current (in p.u. of the full-load current of n similar winch motors in a group, for $n > 2$) of winches

Part of system	*D.c. motors (series resistance)*	*A.c. cage motors*	*A.c. slip-ring motors*	*A.c. Ward–Leonard*
Cables and switchgear	$0.33n$	$3.3 + 0.3n$	$1.6 + 0.2n$	$1.2 + 0.15n$
Generators	$2.2 + 0.2n$	$5.0 + 0.4n$	$2.0 + 0.25n$	$2.2 + 0.2n$

be taken at the control station in the event of faults such as stopping of machinery, starting of stand-by machinery, adjustment of operating parameters, etc. These actions may be effected by either remote or automatic control.

With the advent of microprocessor-based control systems the concept of centralised control has been extended to incorporate techniques known as 'totally distributed control'. This enables all machinery within specified areas to be controlled and monitored by one integrated system. To implement this, individual microprocessor-based interface units are placed at various locations throughout the machinery space and are interconnected to the central control station by a data link.

Figure 46.9 shows diagrammatically a totally distributed control system. The outstations, interface units, have two functions: (1) to receive data from the various sensors, and (2) to output information to the control actuators. The system is arranged so that information is transmitted to the central station only as and when requested, or when a fault condition develops. If the data link between the central station and the outstation is broken, the outstation is capable of continuing operation.

In order to transmit information from the central station to the outstations, and vice versa, a multiplex system has to be used. This arrangement eliminates the need for interconnecting individual signals from each outstation to the central station. Multiplexing is a technique whereby each individual signal is given a specific address which can be transferred from one station to another along the cable in a very short time. The address is recognised only by the unit it is intended for, i.e. it will search many 'go-no go' gates until it finds the one 'go'. The information will then be used by the unit for action. *Figure 46.10* shows diagrammatically how multiplexing functions.

At the control station the complete operation of the system is organised; it consists of the central computers along with visual display units, keyboards, printers, analogue recorders, etc. In early distributed-control systems conventional analogue controllers were used at the outstations with the facility for the set points to be changed from the central station. However, as microprocessor systems have become more reliable, analogue controllers have been replaced by software generated digital control algorithms. Thus, the desired requirement for each control loop is retained in software rather than hardware. These systems are called direct digital control (DDC) systems. All the facilities that were available with the analogue controllers are built into these DDC systems.

46.19.2 Alarms and safeguards

For periodical unattended operation of a machinery space, all controls and safeguards necessary for centralised control are required, but safety actions must be automatic. In addition, it is necessary to extend the machinery space alarm system to the bridge and accommodation areas so that engineering personnel are made aware when a fault occurs. Control of propulsion must also be extended to the bridge to enable the navigating officers to carry out manoeuvres if the need arises. It is important, when an engineer responds to an alarm and enters the machinery space alone, that other personnel are aware of his well-being. It is usual to configure the alarm system so that the navigating officer is also made aware of a machinery fault, when it is being attended to and when it is corrected. *Figure 46.11* shows the functioning of an alarm system to meet these requirements.

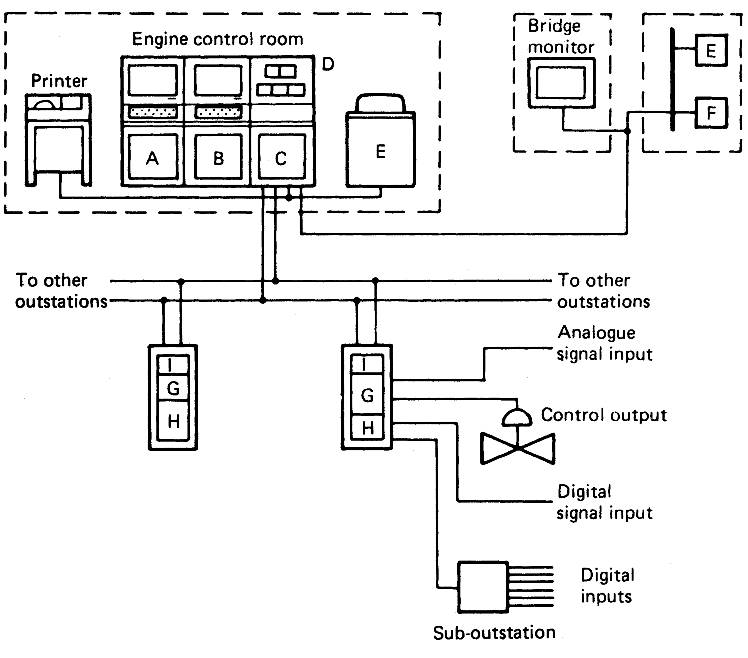

Figure 46.9 A totally distributed control system. A, Operator station alarm; B, operator station control; C, multiplexer and control unit; D, trend recorders; E, magnetic storage unit and general-purpose computer; F, extension alarm system; G, process interface analogue/control and alarms; H, process interface digital/alarms; I, multiplexer unit

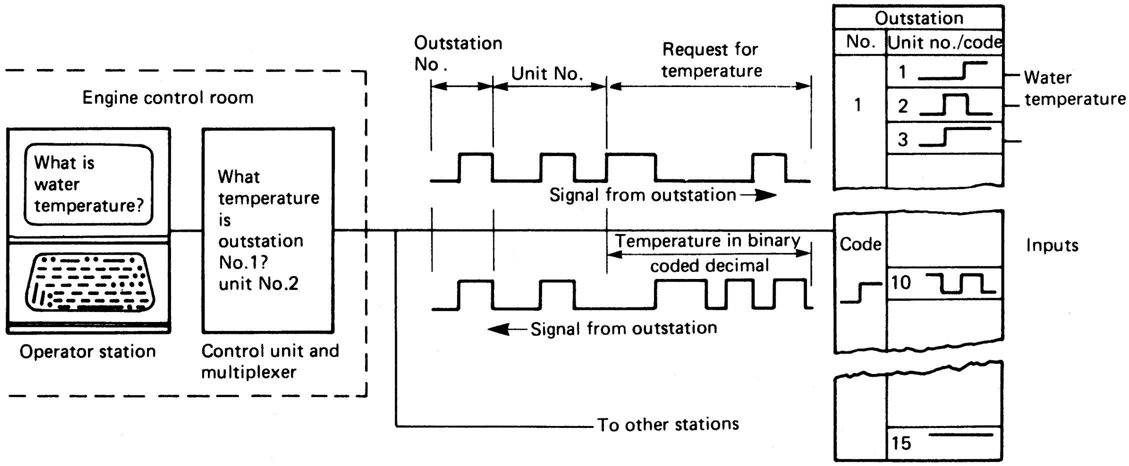

Figure 46.10 A totally distributed control system—form of signal on the data link

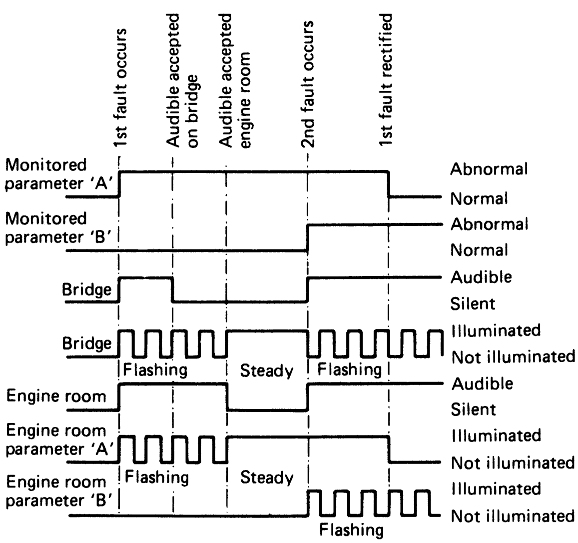

Figure 46.11 Functional diagram for an alarm system

46.19.3 Reliability

No matter how comprehensive the control and protection systems provided, they are of little value if the equipment used is not reliable. Experience has shown that many items of control equipment do not operate satisfactorily at sea. Control equipment, designed for use ashore, is all too often unsuitable or unreliable when used on board ship.

In order to improve reliability, the majority of classification societies have adopted and developed criteria to which equipment should be tested. This is known as 'type approval', a procedure whereby a prototype or a production unit is tested under conditions of environmental and mechanical stress that simulate severe shipboard operating conditions.

Basic minimum requirements specified by Lloyd's Register of Shipping include the following.

(1) *Visual inspection*: to ensure that workmanship is good and materials used are adequate for the duty of the equipment.
(2) *Performance tests*: to ensure that the manufacturer's specified limits of accuracy, repeatability, etc., are fulfilled.
(3) *Fluctuations in power supply*: voltage variations, steady, ±10% with simultaneous frequency variation of ±5%. Transient, ±20% voltage with ±10% frequency. For hydraulic and pneumatic systems supply pressure variations of ±20%.
(4) *Vibration tests*: testing in frequency range 1–13.2 Hz at ±1.0 mm displacement and 13.2–100 Hz at ±0.7 g. Endurance tests carried out at each major resonant frequency for 2 h.
(5) *Humidity*: 90–100% for 12 h at 55 ±2°C, then reduced to 20 ±5°C over a period of 1–3 h and remaining at the lower temperature for not less than 6 h. This test repeated over two full cycles.
(6) *Dry heat*: at manufacturer's stated maximum operating temperature if greater than 55°C for 16 h.
(7) *Inclination test*: at least $22\frac{1}{2}°$ each side of the vertical in one plane, repeated in a second plane at right angles to the first.
(8) In addition, for electrical equipment, high-voltage and insulation resistance tests are required.
(9) *General*: further requirements may include low-temperature and salt mist tests. As applicable, intrinsic safety certification may be called for.

46.20 Tankers

It is of vital importance to take account of bending stresses in the hull resulting from unequal buoyancy. These may arise from ballasting or from different grades of oil, or may occur during loading or discharging. A large number of valves control the filling and unloading of cargo tanks, and these must be operated in logical sequences. Trim and list must also be taken into account. There is obviously a fertile field for computer controlled centralised operation. Because of explosion risks, hydraulic power is favoured for valve operation. For instrumentation and control purposes, pneumatic and intrinsically safe electronic circuits are suitable, subject to classification approval.

46.21 Steam plant

Correct relationship between fuel supply, feed-water supply, temperatures, forced draught, engine load and sea-water temperatures depends on a large number of interdependent controls. Optimum efficiency is rarely, if ever, achieved without some form of automatic control. The essential factors are: (a) maintenance of steam pressure under varying loads by fuel control; and (b) optimum control of combustion air flow and fuel/air ratio.

46.22 Generators

Two or more generators are always provided, but for economy it is undesirable to run more sets than necessary for the prevailing load. Preferential tripping of non-essential loads has already been dealt with. This is only a temporary expedient and, to prevent overloading, systems are available for automatic starting, stopping and synchronising of sets according to demand. In confined waters it is necessary for safety reasons to have a margin in reserve, and it is therefore usual practice to have two sets on the board. An overriding provision should be included in automatic schemes.

Advances in technology have led in recent years to the introduction of micro-based systems for efficient power management. Escalating fuel costs and the need for reliable unmanned operation have stimulated this development.

46.23 Diesel engines

When bridge control of main propulsion engines is installed, it is necessary to make provision for a repeat start if the first sequence is not completed. After a set number of false starts (usually three) an alarm operates. If acceleration to the firing speed is not reached in about 3 s, a further period of about 4 s is allowed and the complete cycle is then repeated.

For auxiliary generator plant, standby sets can be prewarmed by continuous circulation of hot water from the main engine cooling system. It is usual to bring in another set before full load is reached. However, a short time delay is advisable to prevent starting on a spurious load demand.

46.24 Electric propulsion

The popularity of propelling ships using electric motors has varied considerably over the past 80 years, but electrical propulsion has always offered several advantages over traditional mechanical systems. These include, installation flexibility, high torque across the whole speed range, low vibration and noise, smooth variation of speed and reduced fuel consumption and maintenance (not always so in d.c. systems). It should be noted, however, that both the initial cost and size of an electrical system are generally greater than those of mechanical systems.

46.24.1 Methods of propulsion

The mechanical power produced by the electric motor may be transmitted to propel a vessel in a number of different ways:

(1) by direct coupling, or via a reduction gear box, to a conventional fixed pitch propeller (FPP) or to a controllable pitch propeller (CPP);
(2) by hydrojet thrusters;
(3) by an azimuthing or fixed ducted propeller assembly; or
(4) by a cycloidal propeller system.

The electric motor may be the sole means of propulsion, or it may be used in conjunction with a mechanical drive, as in some types of naval vessel. In these types of ship electric motors are used at low speed, often when the vessel is required to minimise radiated noise for sonar activity, and at high speed gas turbines are used to provide the boost power as required.

Steering of a vessel may also be achieved by the propulsion unit, as in the case of the azimuthing propeller assembly, but such systems must conform to specifications as laid down by Lloyds Register of Shipping's Rules and Regulations for the Classification of Ships.

46.24.2 Traditional electrical systems

46.24.2.1 D.c. generators, d.c. motors, fixed pitch propellers

In series-connected d.c. systems the generators and motors are all connected in series in one circuit. In the parallel-connected system all generators and motors are arranged in parallel. In both cases the speed and direction of rotation of the motors is changed by varying the generator and motor excitations, as shown in *Figure 46.12*.

Both parallel and series-type systems have been used widely in the past, particularly in ice breakers, but the build up of carbon dust from the commutator brush gear has always been a problem with d.c. systems. As the size of vessels has progressively increased, the popularity of this method of propulsion has declined, and there are only a few vessels still in service employing full d.c. propulsion systems.

46.24.2.2 A.c. generators, a.c. motors, variable-frequency supply

An a.c. generator, often driven by a steam turbine, supplies a synchronous motor. Speed control of the motor is achieved by varying the speed of the prime mover and hence the generator and motor frequency, as shown in *Figure 46.13*. Below 25% of normal speed, i.e. when manoeuvring is being carried out, it is usual to operate the propulsion motor as an induction machine, i.e. with the motor field removed. Precautions need to be taken during this manoeuvring period because high slip-ring voltages can be induced.

During the past two decades there has been a steady decline in the number of turbo-electric systems in operation, mainly because prime-mover limitations make it difficult to achieve high torques at low propeller speeds. The most notable ship still employing such a main propulsion system is the passenger ship *Canberra*, but low-power turbo-electric systems have seen some resurgence for bow thruster applications.

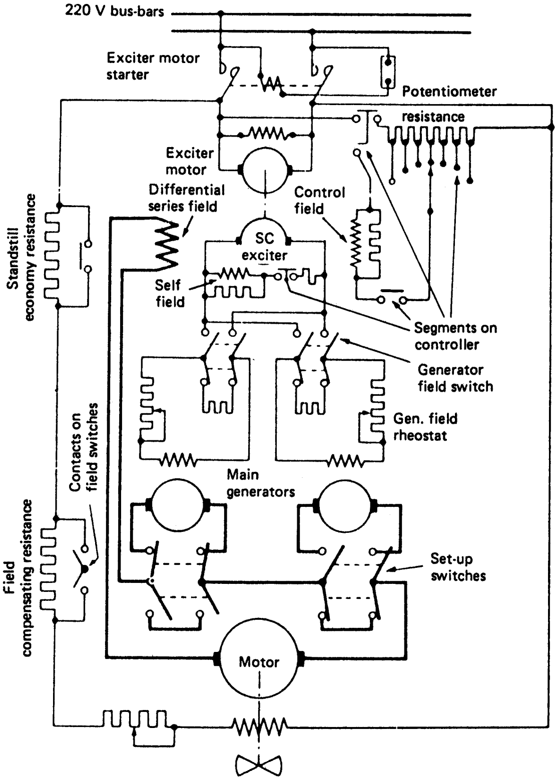

Figure 46.12 Diesel-electric d.c. system with modified Ward–Leonard control

46.24.3 Modern electrical systems

46.24.3.1 A.c. generators, d.c. motors, fixed-frequency generation and fixed pitch propeller (FPP)

The d.c. propulsion motor is normally supplied by a fully controlled bridge rectifier fed from the a.c. generator supply system, as shown in *Figure 46.14*. The speed of the motor is controlled by changing the firing angle of the silicon controlled rectifiers (thyristors), which in turn change the voltage supplied to the armature of the d.c. motor. Motor reversal is easily achieved by reversing the polarity of the field of the motor.

There is, however, an empirical limit to the size of d.c. motor that can be built, which depends on the product of speed and power:

$$1.5 \times 10^6 = \text{Power (kW)} \times \text{Speed (rev/min)} \Leftarrow$$

As an example, this limits the power to 10 MW at 40 rev/min. In vessels requiring propulsion powers greater than those obtainable with a single d.c. motor, the choice is really between multiple d.c. motors on the same shaft or a full a.c. system.

46.24.3.2 A.c. generators, fixed-speed a.c. motors, fixed-frequency generation

In fixed-speed systems a constant-speed a.c. motor is used in conjunction with a controllable pitch propeller, as shown in *Figure 46.15* for a North Sea support vessel. The motor may drive the propeller directly, such as in the system employed in the New Zealand ferry *Arahura*, or via a gearbox, an example of this being the *BP Iolair*. Both synchronous and induction motors are used in these types

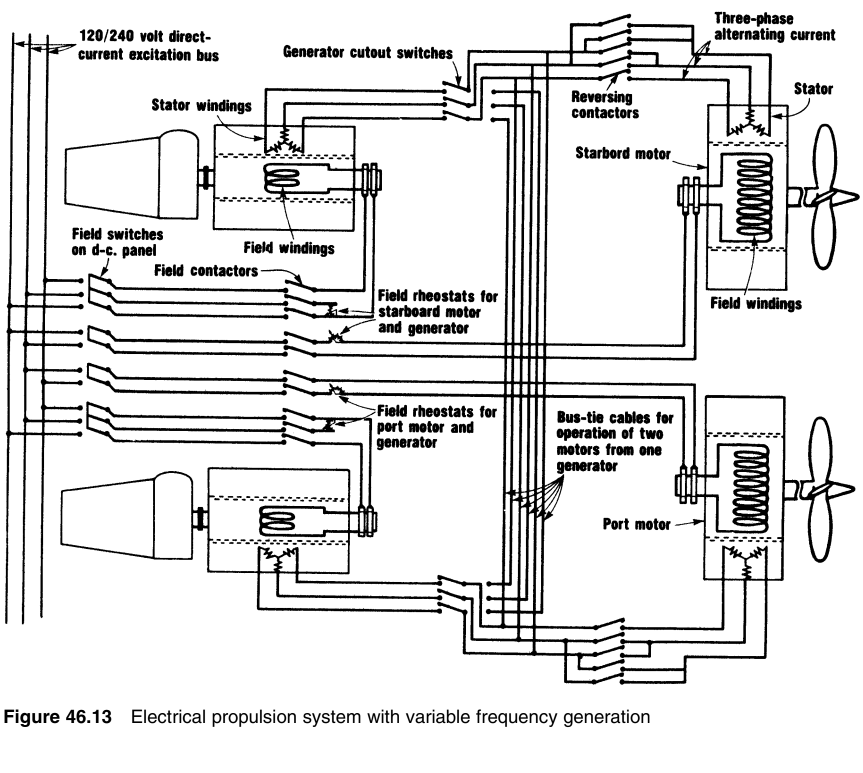

Figure 46.13 Electrical propulsion system with variable frequency generation

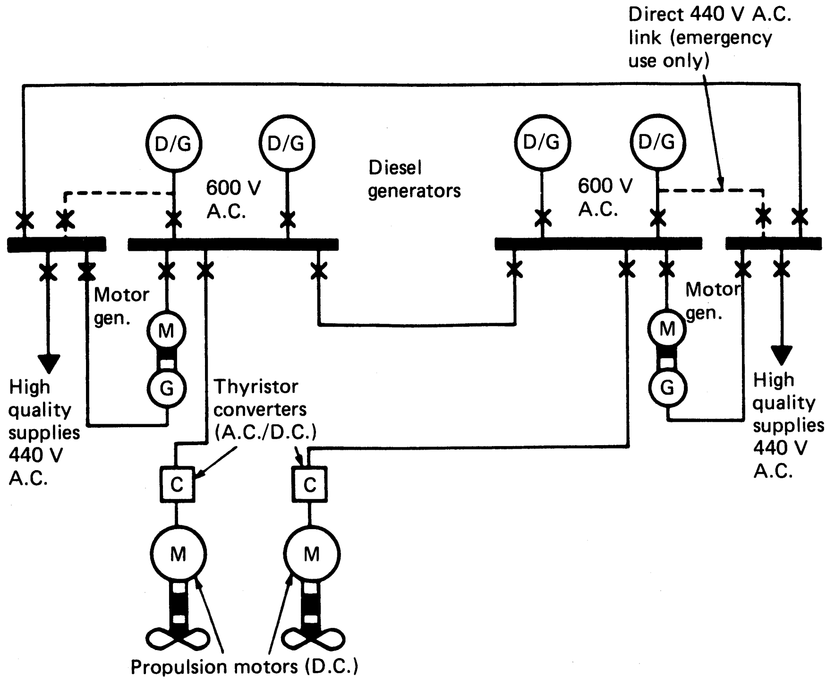

Figure 46.14 A.c. generators/d.c. motor configuration employing motor generator sets to ensure that harmonics generated by the fully controlled converter are not transmitted on to the 440 V a.c. bus-bars

of electric propulsion system, the motors being fed directly from the 50 or 60 Hz generator system or via transformers. Speed control of these vessels is achieved solely by the use of the controllable pitch propellor (CPP), so this type of system is employed in vessels that are operated extensively at high speed or in vessels that require dynamic positioning.

46.24.3.3 A.c. generators, variable-speed motors, fixed-frequency generation

In this type of system the speed of the a.c. motor is controlled by a frequency converter, and is generally used in conjunction with a fixed-pitch propeller, as shown for an ice-breaker in *Figure 46.16*. Shaft-speed variation is achieved by varying the supply frequency to the propulsion motor, since the motor speed is proportional to frequency/number of poles:

$$\text{Rev/min} = \frac{120 \times \text{Frequency (Hz)}}{\text{No. of poles}}$$

A synchronous motor is normally used in preference to an induction motor in many applications. This is because synchronous motors can be manufactured with larger air gaps to withstand arduous mechanical conditions. They can also be operated at unity power factor across the whole speed range, and generally have higher overall efficiencies. In addition, the synchronous motor has the highest power/weight ratio of any electrical machine. Induction motors, because of their reduced construction costs, tend to be used in low-power propulsion systems only.

There are two main types of static converter used to feed the synchronous machines with the variable frequencies they require, the cycloconverter and the autosynchronous inverter. Both are reversible and, if necessary, both systems can be designed to provide motor braking provided dynamic resistors are included.

Induction motors are generally fed using autocommutated or forced-commutated inverters, although cycloconverters have recently found favour in systems requiring power above 8 MW.

This type of electric drive has become the accepted system in many different types of vessel, including cruise liners and ice-breakers. The *Queen Elizabeth 2* employs a modified version of this system, and includes CPPs for manoeuvring at lower speeds, and an autosynchronous drive that is used for speed adjustment at higher speeds.

46.24.4 Voltage levels and harmonics

The choice of system voltage for an electric propulsion system is determined predominantly by the size of the propulsion plant and the short-circuit fault currents. Where the capacity of individual generating sets exceeds 2.5 MW, or the fault level under normal operation exceeds 50 MV-A, a high-voltage system is usually selected as specified in Part 6, Chapter 2.1 of the Rules and Regulations of the Classification of Ships. Standard marine high voltages now in use are:

50 Hz	*60 Hz*
3300 V	4160 V
6600 V	6000 V
	10 000 V

IEC 92:Part 304 also applies to the installation and performance of static converters using semiconductor

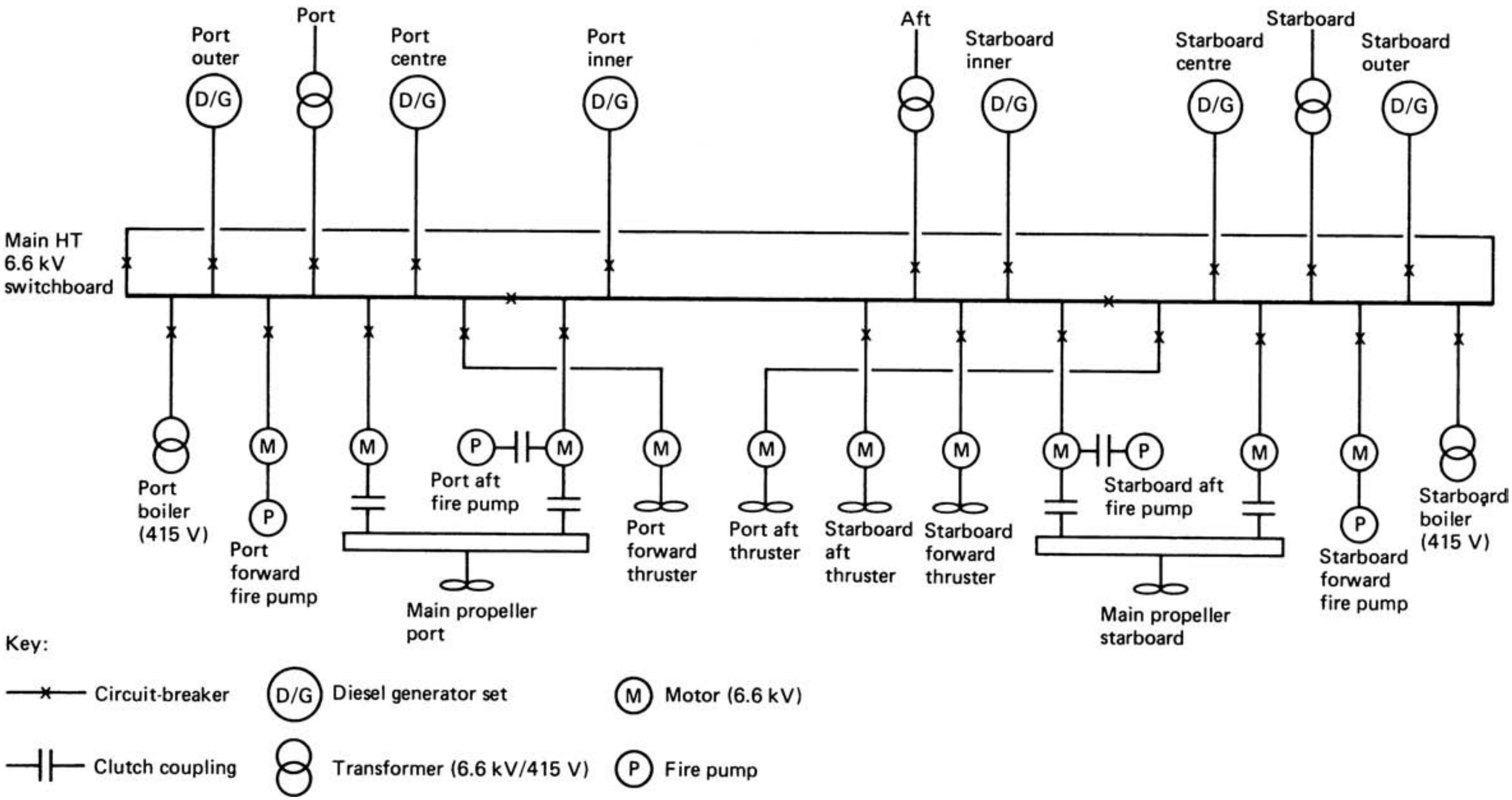

Figure 46.15 A.c. generators/a.c. motor configuration employed on a typical North Sea oil-field support vessel. Speed variation is achieved solely by the use of controllable-pitch propellers

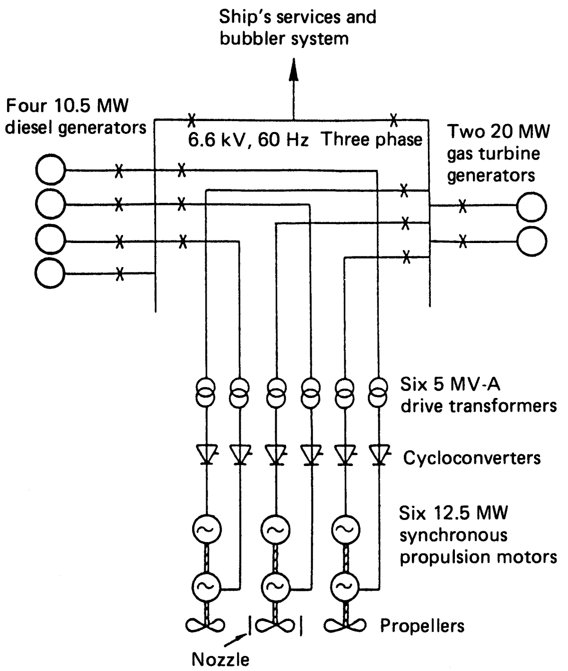

Figure 46.16 A.c. generators/a.c. motors employing cycloconverter variable-speed drives commonly found on ice-breakers

devices. In ships using converters, harmonic problems, such as electrical resonance, may occur in the electrical system. In some instances the problems can be quite severe, and the high power levels of the converters usually makes in-line filtering impractical. The recommendations for eliminating harmonic problems using motor generator sets, or low-power filters local to the equipment to be protected, is governed by the IEE Regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for their Implementation 1990.

46.24.5 Electric propulsion employing superconductivity

The development of niobium–titanium d.c. homopolar motors in the UK and USA during the 1960s demonstrated that high shaft torques could be produced with almost no motor power loss if the motor could be cooled using liquid helium. An electromagnetic thruster system has been developed in Japan. In this system superconducting coils are used in a linear motor configuration. An electric current is passed through sea-water and a propulsion thrust is generated without the use of rotating propellers. The disadvantage of superconducting systems is that large cooling plants are required to maintain the motors at the very low temperatures needed (−268.6°C). Recent research has been directed towards obtaining super-conductivity at ambient temperatures using ceramics rather than alloys but, although significant advances have been made, it is unlikely that super-conductivity will become a viable commercial option in the near future.

46.24.6 Electromagnetic slip couplings

In diesel-engined ships in which the propeller is driven through mechanical reduction gear, up to four engines per shaft can be coupled to the gear through slip couplings. It is necessary to protect the gears from torsional vibration transmitted by the engines, and the slip coupling serves both this purpose and that of a disconnecting clutch, enabling the numbers of engines in service to be altered without stopping the engines already operating. A typical four-engine arrangement is shown in *Figure 46.17*.

Manoeuvring can be carried out by having some engines running ahead and the others astern and selecting the direction required by switching.

A coupling can exert a starting torque from rest, with the engine at full speed, equal to full-load torque. The efficiency is high, the only losses being windage, excitation and the I^2R loss due to slip. Slip varies with speed and rating and is generally 1–2%.

46.24.7 Electromagnetic gearing

Elements of a speed reduction and reverse gear which can also act as an auxiliary a.c. generator, clutch and flexible coupling are shown in *Figure 46.18*. An inner rotor carries the input shaft, field windings and slip-rings. The outer rotor carries the electromagnetic coupling armature winding on the inner side which is connected, through a switching device, to the synchronous motor field windings on the outside, and two sets of slip-rings.

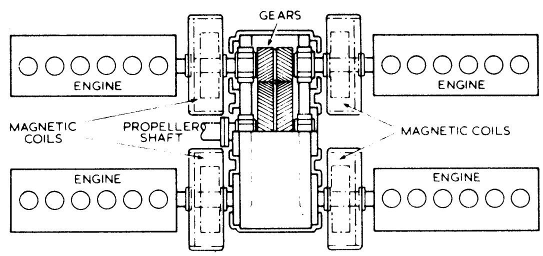

Figure 46.17 Typical four-engine coupling arrangement

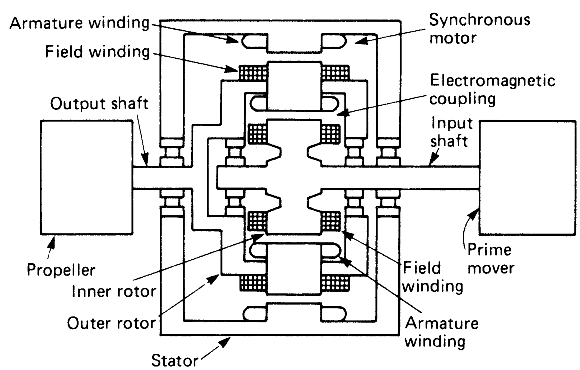

Figure 46.18 Versatile electromagnetic gear