FUNCTION 2: ELECTRICAL, ELECTRONIC AND CONTROL ENGINEERING AT THE MANAGEMENT LEVEL

Knowledge, understanding and proficiency	Total hours for each topic	Total hours for each subject area of Required performance
Competence: **2.1 MANAGEMENT OPERATION OF ELECTRICAL AND ELECTRONIC CONTROL EQUIPMENT** **Theoretical Knowledge**		
2.1.1 MARINE ELECTROTECHNOLOGY, ELECTRONICS, POWER ELECTRONICS, AUTOMATIC CONTROL ENGINEERING AND SAFETY DEVICES **1.** Marine electro technology **2.** Electronics, power electronics **3.** Automatic control engineering and safety devices	10 30 40	80
2.1.2 DESIGN FEATURES AND SYSTEM CONFIGURATION OF AUTOMATIC CONTROL EQUIPMENT AND SAFETY DEVICES FOR THE FOLLOWING: **1.** General requirements **2.** Main engine **3.** Generator and distribution system **4.** Steam boiler	2 20 2 2	26
2.1.3 DESIGN FEATURES AND SYSTEM CONFIGURATION OF OPERATIONAL CONTROL EQUIPMENT FOR ELECTRICAL MOTORS **1.** Three phase A.C. motor **2.** Three phase synchronous motors **3.** Effect of varying frequency and voltage of A.C. motors **4.** Motor control and protection **5.** Insulated gate bipolar transistor (IGBT) motor speed control **6.** Motor speed control by thyristors **7.** Three phase generators **8.** Three phase transformers **9.** Distribution **10.** Emergency power	6 4 4 3 4 2 7 3 4 3	40
2.1.4 DESIGN FEATURES OF HIGH-VOLTAGE INSTALLATIONS		

1. Design features of high-voltage installations **2.** Operational safety of high-voltages installations	20 2	22
2.1.5 FEATURES OF PNEUMATIC AND HIDRAULIC CONTROL EQUIPMENT **1.** Hydraulic control equipment **2.** Pneumatic control equipment	 5 5	 10
2.2 MANAGE TROUBLESHOOTING AND RESTORATION OF ELECTRICAL AND ELECTRONIC CONTROL EQUIPMENT TO OPERATING CONDITION Practical knowledge		
2.2.1 TROUBLESHOOTING OF ELECTRICAL AND ELECTRONIC CONTROL EQUIPMENT 1. Electrical safety 2. Test equipment 3. Interpretation of circuit symbol 4. Logical six step troubleshooting procedure 5. Generation 6. Prime mover electrical controls 7. Main air circuit breaker 8. Protection of generators 9. Electrical distribution systems 10. Motors 11. Electrical distribution systems 12. Calibrate and adjust transmitters and controllers 13. Control system fault finding	 2 12 12 8 6 3 3 4 2 4 4 3 3	66
2.2.2 FUNCTION TEST OF ELECTRICAL, ELECTRONIC CONTROL EQUIPMENT AND SAFETY DEVICES 1. Function test of electronic, electronic control equipment and safety devices	12	12
2.2.3 TROUBLESHOOTING OF MONITORING SYSTEMS 1. Test and calibration of sensors and transducers of monitoring systems	12	12
2.2.4 SOFTWARE VERSION CONTROL 1. Programmable logic controller (PLC) 2. Microcontrollers 3. Digital techniques	 6 6 8	20
Total for function 2: Electrical, Electronic and Control Engineering at the Management Level		**288 hours**

2.1 MANAGEMENT OPERATION OF ELECTRICAL AND ELECTRONIC CONTROL EQUIPMENT Theoretical Knowledge

2.1.1 MARINE ELECTROTECHNOLOGY, ELECTRONICS, POWER ELECTRONICS, AUTOMATIC CONTROL ENGINEERING AND SAFETY DEVICES

.1. Marine electrotecnology.

Apart from an Act of God, lighting, flood, earthquake and natural disaster, the causes of hazard and accident may be attributed to:

1. Calculated Risk: taken for a cause, or to prove self-reliance.
2. Uncalculated Risk: resulting from over-familiarity, lack of imagination and foresight.
3. Blind Risk: arising from ignorance, incompetence and culpable negligence.
4. Human Error: momentary aberration or misunderstanding.
5. Deliberate Irresponsibility: horseplay and vandalism.

All men, on occasion, are at fault in these respects; most can be conditioned by training and instruction to accept rules and develop the necessary reflexes to hazard and danger. Even so, absolute safety is an illusion, and the question in practical terms is: What is the acceptable risk? The simplest accident means injury and loss of time; the serious accident means permanent injury and loss of earning capacity; the lethal accident means bereavement and, perhaps, an adverse effect on the upbringing of children.

Before attempting any electrical work, there are some basic safety precautions you must bear in mind. The possible dangers arising from the misuse of electrical equipment are well known.

Electric shock and fire can cause loss of life and damage to equipment. Regulations exist to control the construction, installation, operation and maintenance of electrical equipment so that danger is eliminated as far as possible. Minimum acceptable standards of safety are issued by various bodies including national governments, international governmental conventions (e.g. SOLAS), national and international standards associations (e.g. BSS and IEC), learned societies (e.g. IEE), classification societies (e.g. Lloyds), etc. Where danger arises it is usually due to accident, neglect or some other contravention of the regulations.

Ships' staff must operate equipment in a safe manner and maintain it in a safe condition at all times. Failure to do so will cause danger with possible disastrous consequences. Ships' staff should keep in mind an essential list of DO's and DON'T'S when working with electrical equipment.

DO get to know the ship's electrical system and equipment. Study ships' diagrams to pinpoint the location of switches and protection devices supplying distribution boards and essential items of equipment. Write down this information in a note book. Note the normal indications on switchboard instruments so that abnormal operation can be quickly detected.

DO operate equipment according to manufacturer's recommendations.

DO maintain equipment according to manufacturer's recommendations or ship owners' maintenance procedures.

DO ensure that all guards, covers and doors are securely fitted and that all bolts and fixings are fitted and tight.

DO inform the Duty Engineer before shutting down equipment for maintenance.

DO switch off and lock off supplies, remove fuses, and display warning notices before removing covers of equipment for maintenance.

DO confirm that circuits are DEAD (by using a voltage tester) before touching conductors and terminals.

DON'T touch live conductors under any pretext.

DON'T touch rotating parts.

DON'T overload equipment.

DON'T neglect or abuse equipment.

You should think 'safety' at all times and so develop a safety conscious attitude. This may well save your life and the lives of others. Most accidents occur due to a momentary loss of concentration or attempts to short-circuit standard safety procedures. DO NOT let this happen to YOU.

Always secure completely after finishing a task, access covers and doors to electrical equipment.

.2. Electronics, power electronics

All equipment is subject to wear and tear, eventually reaching the end of its useful life when it must be replaced. As equipment nears the end of its life its condition can deteriorate to such an extent as to be a danger to personnel and other plant. The purpose of maintenance, therefore, is to extend the useful life by repair and/or replacement of defective parts and to maintain it in a safe and serviceable condition.

The marine environment is particularly arduous for electrical equipment due to the damp, salt laden atmosphere, extremes of temperature and constant vibration.

Shipboard equipment is in particular need of correct maintenance. The continuous operation of equipment on board ship demands high operating efficiency and optimum economy in order to keep down costs to maintain financial competitiveness.

Nearly all equipment NEEDS maintenance. An efficient maintenance engineer must get to know his plant. He must be able to check ships' drawings and diagrams and relate them to actual equipment. Equipment must be kept under continuous observation so that normal healthy operating conditions become known, and abnormal operation becomes quickly apparent. Faults can then be pin-pointed and corrected before a breakdown occurs. Maintenance can be classified as: Breakdown maintenance,

Planned maintenance and Condition monitoring.

Breakdown maintenance (corrective maintenance) is that in which equipment is regularly inspected and maintained according to a laid down timetable and set of procedures specifying the actual work to be done at particular times in order to prevent failure of equipment.

Condition monitoring (another form of preventive maintenance) is that in which equipment is regularly monitored and tested. When monitoring indicates that breakdown is imminent, the equipment is repaired or replaced and any other specified maintenance procedures carried out. Regular insulation testing and vibration testing are two forms of condition monitoring.

There are several disadvantages in breakdown maintenance:

1. A serious breakdown of equipment may cause sufficient down time to put the ship out of commission until it is repaired.
2. If several breakdowns occur simultaneously the available manpower on board ship may not be able to cope adequately, resulting in delays.
3. 3. Some items of equipment may need the specialist services of the manufacturer to carry out repairs which may cause further delays.

Planned maintenance is carried out at fixed regular intervals whether the equipment needs it or not and the aim is to prevent breakdown. This type of maintenance has the following advantages:

1. Fewer breakdowns and reduced down time produces higher levels of operating efficiency.
2. Maintenance is carried out at times favourable to the operation of the plant.
3. More effective labour utilisation because maintenance is carried out at times favourable to ships' staff.
4. Replacement equipment can be ordered in advance.
5. Equipment is maintained in a safe condition with reduced possible dangers.
6. Where specialist manufacturers' services are required these can be obtained at pre-planned and convenient times.
7. Replacement of short life components at scheduled times.

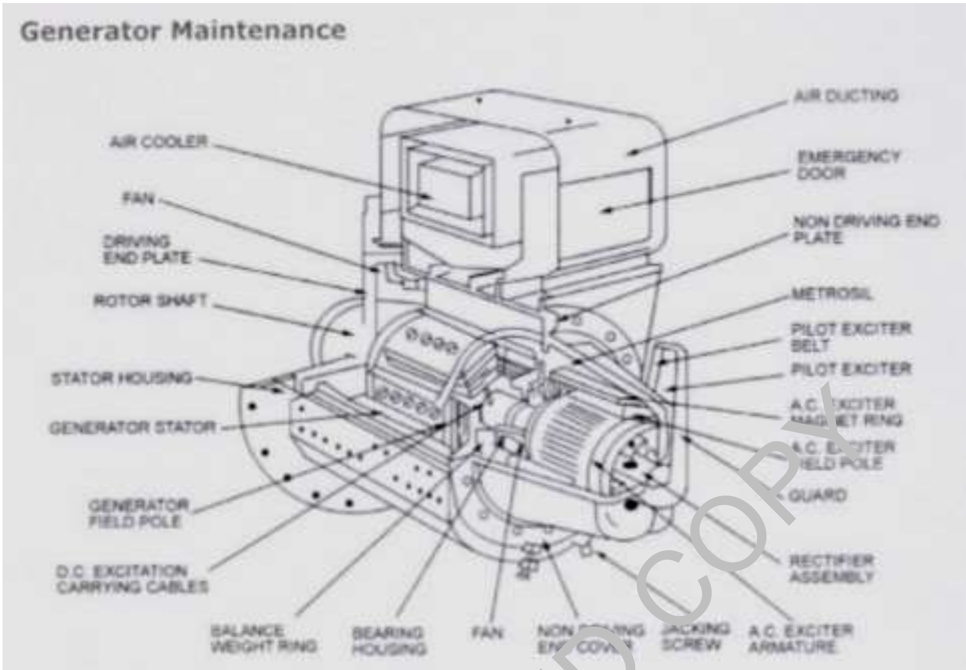
All electrical motor starting panels should be fitted with an hours ran meter, the reading being recorded on a monthly basis, the planned maintenance can be based on an hours ran intervals.

Condition monitoring is also carried out at fixed regular intervals. The aim is to forestall breakdown by predicting probable failure from the TREND shown by the monitoring results. The advantage of this type of maintenance is that Equipment is not subjected to unnecessary maintenance.

Equipment is regularly condition-monitored according to a monitoring schedule. Measurements are taken of insulation resistance, temperature and vibration (of motors).

Contacts and other parts subject to deterioration are inspected. All findings are recorded in an historical record file. No maintenance is carried out until findings are indicate that it is absolutely necessary. The equipment is then either replaced, repaired or subjected to a major overhaul as specified on a job card.

A records system is required. The recorded measurements of insulation resistance may show a falling trend indicating a progressive degradation of insulation. The equipment should be inspected and repaired before the insulation resistance falls to a dangerously low value. The recorded measurement of the vibration of a motor may follow a rising trend indicating progressive bearing deterioration. Bearings should be replaced before a final bearing failure occurs. Immediate repair of maintenance is probably not necessary but should be put in hand at the earliest convenient moment.



Regular inspection and correct maintenance of generators and their associated control gear is essential to prevent failure and inefficient operation.

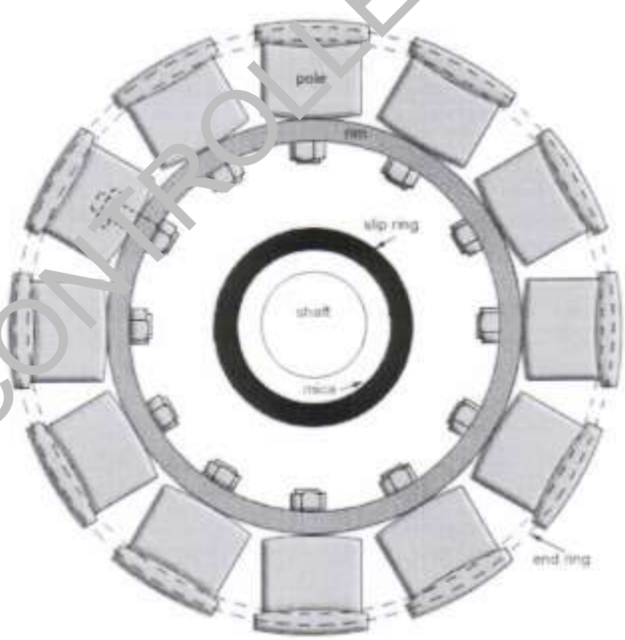
CAUTION: Always ensure that the generator prime mover is shut down and locked off before you being any maintenance. Also ensure that the generator circuits are disabled and generator electric heaters are isolated.

All wiring to the generator should be inspected for damage or frayed insulation and tightness of terminal connections. Particularly check for signs of oil and water contamination of cable insulation within terminal boxes.

Check that cooling air intake and exhaust openings are not blocked and are free of dirt and dust.

Inspect and clean the generator rotor and stator windings by removing dust with a dry lint-free cloth. Low pressure, dry compressed air may be used to dislodge heavier dirt but be careful not to drive the dirt deeper into the windings. An industrial type vacuum cleaner is very effective for removing dirt from the windings. Use a rubber of plastic coated nozzle on the vacuum cleaner tube to prevent abrasive damage to fragile winding insulation. Oil on the surface of winding insulation will reduce the insulation resistance and the surface of winding insulation will reduce the insulation resistance and shorten its life. The oily deposits can be removed by washing the windings with special degreasant liquids. Minor abrasions to winding insulation can be repaired, after cleaning, by the application of a suitable air drying varnish.

Rotor slip rings must be checked for even wear and that the carbon brushes have free movement in their boxes. Correct brush pressure can be checked using pull type spring balance and compared with the manufacturer's instructions. A 'pull' of around 2-3 lb or 1.-1.5 kg is usual. If the brushes become too short (below about 2 cm) the reduced spring pressure will cause sparking at the slip ring contact. Replace brushes with the correct type and 'bed' them to the curvature of the slip rings. This can be done by placing a thin strip of glass paper (not emery paper) over the slip ring with its cutting surface under the carbon brush. Pull the glass paper around the slip ring until the brush surface has the same contour as the ring. The last few passes of the glass paper should be made in the same direction as the normal rotor direction. Remove all traces of carbon dust with a vacuum cleaner. The air gap between the exciter armature and exciter field poles must be checked and logged, the gap should be the same for all poles, adjust if required.



Generator excitation transformers, AVR components and rotating diodes must be kept free of dirt, oil and dampness. A special contact grease is usually applied between the rotating diode connections to prevent electrolytic action occurring between dissimilar metals. Check such contacts for tightness but do not disturb them unnecessarily.

Measure the insulation of the stator and rotor windings to earth and between stator phases if the neutral point is available for disconnection at the terminal box.

Remember to disconnect/short out any electronic circuit components which may be damaged by a 500V insulation test . Consult the wiring diagrams and manufacturer's instructions before testing. Record the IR values and note that prevailing temperature and humidity. Compare with previous test results. A minimum IR value is usually taken to be IMΩ but a lower value may be acceptable to a surveyor based on 1kΩ/volt, e.g. 450kΩor 0.45MΩ for a 450K generator. However, it is the historical trend in the machine IR values which will give a better picture of the insulation condition.

Generators with very Low IR values (less than 0.5MΩ) should be given a thorough cleaning then dried out. If the IR has recovered to a reasonable value which has become steady during the drying period, its windings should be covered with high quality air-drying insulating varnish. Should the IR value remain low during a dry-out, the machine insulation needs to be completely re-impregnated or rewound (generally a shore job).

After maintenance, no-loan running checks should precede synchronising and loading.

On load, particularly check for excess temperature rise and load-sharing stability when running in parallel.

Finally, if a generator is to be left for a long time make sure that its windings are suitably heated to prevent internal condensation forming on its insulations. As with all electrical equipment – dirt, overheating and dampness are the enemy!

.3. Automatic control engineering and safety devices.

After a ship enters service it is exceptional for the main bus bars to be made dead.

Electrical supply of some sort is always needed, even if it consists only of lighting. It therefore follows that the bus bars are continuously alive practically throughout the life of the ship as, even in dry dock, a shore supply will usually be taken.

During the dry dock period the vessel should be "Blacked Out" for a period, with the shore supply disconnected, a spanner tightness check and inspection should be carried out on all switchboard bus bars.

This means that, as far as the main switchboard is concerned, routine maintenance work on circuit breakers and other fittings must be carried out with live bus bars and some thought should be given to this in the design and layout stage. In land practice necessary provision is sometimes made by using duplicate has been used in certain offshore installation.

On a simple bus bar system a limited solution can be achieved by using isolators to sectionalised the switchboard; splitting of the lighting feeders can also help. However, in large installations draw-out type switchgear undoubtedly offers the best solution.

Precautions must be observed not only to isolate the apparatus but to verify that it is isolated and to ensure that it cannot inadvertently be made alive. Where interlock circuits, pilot lights or control circuits are involved there is always a risk that although the main circuits may be isolated these auxiliary circuits may still be energised from a separate source. Fatalities have resulted from this cause. Where switches can be locked 'off', it must be seen that this safeguard is used and the keys are removed.

Where there are main fuses in the circuit, these might be removed as an additional precaution. Before commencing work it should be verified that the apparatus is actually dead by using a live-line detector. This test should be conducted not only between phases but also between phases and earth.

Portable handlamps used to facilitate the work should be fully insulated with nonmetallic guards, so that there is no risk of shock or short-circuit being caused should they inadvertently come into contact with live parts. When closing any switch by hand, whether in normal operations or when testing, it is a golden rule to do so in one clear positive movement without hesitation.

Overheating may be caused by loose connections, poor contact pressure (particularly at fuse contacts), or poor alignment of contacts. On air circuit breakers the condition and alignment of the contacts can be checked by removing the arch chutes to expose the contact assembly. On some high voltage designs the chutes tilt forward to provide access. This inspection should be made annually and the mechanism should be lubricated at the same time.

Copper contacts may be dressed by using a fine file or fin glass paper, but emery or carborundum paper should not be used. Silver or silver-plated contact seldom require attention; their black appearance is caused by oxidation, but the oxide is a good conductor. If cleaning is required metal polish may be used.

A slight smear of petroleum jelly, particularly on contacts which are frequently operated, not only helps to preserve good contact but also reduces mechanical abrasion. Excessive application must be avoided as this may cause burning and pitting of contacts.

Oil levels in dashpots should be checked. Particular care should be taken to use the correct grade of oil when topping up or replenishing, as proper functioning of the switchgear is entirely dependent on this.

Whenever the opportunity occurs, direct-acting overcurrent trips and relays should be tested by current injection (i.e. injection into the primary copperwork rather than the current transformer secondary circuits). Injection testing is performed to verify not only operation but also the time-current characteristics. This should be compared with the manufacturer's operating curves.

Emphasis must be placed on the need for cleanliness, not only for motors but for all electrical apparatus. Accumulations of dirt in machines has two effects. Firstly, dirt on the insulation may in time cause carbonisation of the deposit and of the surface of the insulation, and eventually a burn-out. This is particularly a problem on surfaces between exposed live parts of opposite polarity and between live parts and earthed metal where dirt forms a path of low resistance resulting in leakage currents. Secondly, the ventilating ducts may become clogged with dirt, thereby obstructing or restricting the free flow of ventilating air. The machine temperatures will increase and if the situation is not remedied insulation failure will ultimately occur. Machines should therefore be kept as clean as possible in service.

For all motors, cleanliness is next to godliness. A regular cleaning routine is required to remove harmful deposits of dust, dirt, grease and oil from both inside and outside the motor. The cleaning of the external surface is especially important for totally enclosed motors which run continuously. The hat generated in these motors is removed through the external surface. A thick layer of dust will reduce the heat dissipation and result in very high temperatures. Internal dust and dirt in open ventilated motors must be regularly removed by blowing or extraction and ventilation screens and ducts cleared out.

If motors are to be blown out, the air used must be absolutely dry and the pressure should not be more than 1.75 bar. If the pressure is higher than this it forces the dust into the winding insulation rather than removing it.

When blowing out a motor remember to cover up other machines in the area to protect them from flying dust. Suction cleaning is better than blowing out.

Contamination by oil and grease from motor bearings – often a cause of insulation failure. The application of grease to the bearings should be carried out on a planned schedule basis, therefore over greasing will be avoided. The insulation should be cleaned by brushing or spraying with one of the many proprietary brands of cleaning fluid which are available. Badly contaminated motors may require total immersion of the stator windings in cleaning fluid.

Broken or missing bearing covers must be repaired or replaced to prevent grease escaping.

When a motor has been dismantled for cleaning and overhaul it should be thoroughly inspected. In this way faults can be detected before they lead to breakdowns.

STATOR – on the stator windings look for damaged insulation caused by careless replacement of the rotor into the stator. Discoloured insulation is an indication that the winding has been overheating. The cause of overheating must be found and corrected before putting the motor back into service.

Carefully examine the stator core for signs of rubbing with the rotor caused by a worn bearing. Even slight rubbing of the rotor against the stator will generate enough heat to destroy the stator insulation. Renew bearings before putting back into service. Core plates which have been badly scored may cause a local hot spot to be generated when the motor is running. This is because the iron losses will increase in the damaged area.

After the motor has been put back into service with new bearings check the motor running temperature. After a short period of service dismantle the motor and check for discolouration at the core damage which will indicate local heating. If you suspect core hot spots then the motor core will need to be dismantled for the laminations to be cleaned and re-insulated – shore job.

The insulation resistance reading is the best indicating as to the presence of moisture in the motor windings. Breakdowns due to insulation failure usually result in an earth fault, short-circuited turns in a phase or phase-to-phase faults.

A problem can arise on small, 'three terminal' motors where the star or delta connection is made inside the motor. Only one end of each winding is available at the terminal block. Phase-to-phase insulation resistance cannot be checked. If a three terminal motor is to be rewound ask the repairer to convert it to a six terminal arrangement.

BEARINGS – Induction motors are fitted with ball and/or roller bearings. These bearings are tough and reliable and should give very little trouble provided they are properly fitted, kept absolutely clean and lubricated correctly. Many engineers argue that if a bearing seems to be operating correctly it should not be tampered with. It is not possible to predict with any degree of certainty the unexpired life of bearings that have already run for some time. Also, inspection may not show damage to raceways and rolling elements in areas hidden from view.

The best policy is to renew the bearings as part of a planned maintenance programme.

If this is not possible because of cost or a shortage of replacements, then bearings should be removed, cleaned and inspected for signs of damage before a decision to refit or renew is taken. Before opening up a bearing make sure that the complete area around the housing is clean and dry.

Bearing manufacturers recommend that bearings should be removed from the shaft as seldom as possible. But cleaning and inspection is best done with the bearing off the shaft. If the correct size of wedges or pullers is used, then removal should not cause any damage.

Bearings should be cleaned by immersion in a solvent such a clean white spirit or clean paraffin, the thoroughly dried in a jet of clean, dry compressed air. Bearings should not be spun by the air jet because skidding can damage the following elements and raceways. Once dry, the baring must be lightly oiled. Any traces of metal particles, such as brass, indicate cage wear and the bearing must be discarded. If there is no evidence of metal particles, carefully examine the raceways and rolling elements for signs of wear or damage. Hold the inner race in one hand ad slowly turn the outer race. If there is any sticking or unevenness in the rotation re-wash the bearing and rotate it in the cleaning fluid. If the sticking persist the bearing must be rejected. Similarly, bearing with visible signs or corrosion, overheating or damage, and those with a noticeable degree of roughness in rotation should also be discarded.

When fitting a bearing to a shaft, first clean the shaft and apply a thin film of light oil.

Set the bearing square on the shaft and, with a tubular drift, force the bearing against the shaft shoulder. The drift should bear on the inner race as close to the shaft as possible. Large bearings can be heated for 10-15 minutes in clean mineral oil up to

80°C to facilitate.

Lubricate the bearings with the correct type and quantity of grease as recommended by the manufacturer. Fill the bearing about one third to one half full with grease. Over greasing causes churning and friction which results in heating, oxidation of the grease and possible leakage through the seals. Because of the high ambient temperature and excessive vibration which marine motors endure, grease life can be short and fresh grease should be applied at regular intervals. Unless the bearing housing has a vent hole to allow excess grease to escape, it will be necessary to clean out the baring housing before charging with fresh grease.

Because of the vibration on ships, bearings can be damaged when the motor is not running. The shafts of stationary motors should be periodically rotated a quarter turn to minimise vibration damage to the bearings.

Fan motors in refrigerated compartments require special consideration. Not only must they operate at freezing temperatures but they must also run at tropical temperatures when cooling down cargo spaces in tropical waters. This represents a very wide range of operating temperature and accordingly requires special greases.

ROTOR – As you will have gathered, maintenance of cage-rotor induction motors tends to mainly involve the stator windings and bearings. Cage-rotors require little or no special care in normal service. Inspect for signs of damage and overheating in the cage winding and laminated core. Make sure that all core ventilating ducts are clean and clear. If an internal fan is fitted it must be in good condition if it is to provide adequate cooling.

If a cage rotor motor has been flooded with sea water, the insulation resistance can drop down to zero MΩ. The main problem is to restore the insulation value of the stator winding to a high value. This is achieved in three stages:

(i) Cleaning

(ii) Drying

(iii) Re-varnishing

Salt contamination can be removed by washing with clean, fresh water. Any grease or oil on the windings has to be removed using a degreasant liquid such as Armaclean.

Dry the stator windings with low power electric heaters or lamps with plenty of ventilation to allow the dampness to escape. Alternatively, the windings can be heated by current injection from a welding set or from a special injection transformer. Be sure to keep the injected current level well below the motor's full load rating.

With the windings clean and dry, and if the IR test remains high over a few hours, apply a couple of coats of good quality air-drying insulating varnish.

2.1.2 DESIGN FEATURES AND SYSTEM CONFIGURATION OF AUTOMATIC CONTROL EQUIPMENT AND SAFETY DEVICES FOR THE FOLLOWING:

1. General requirements

All moving contacts used in control gear have what is known as 'wipe' or followthrough; that is to say, if the fixed part were to be removed the moving part would follow on. In addition, particularly in the case of the contactors, a rolling or sliding action to remove any oxide which may have formed, and thus ensure a good metal-tometal contact; and secondly to provide that the point at which the contacts make and break and where roughening due to arcing occurs is away from the running position.

Contacts that make and break infrequently may never need more than an occasional cleaning but those which operate frequently, such as lifts, winches, windlasses and capstans, may become so worn that not only is the contact bad but the wipe is lost, causing reduction of contact pressure, and overheating will occur. They must therefore be examined periodically on a planned maintenance basis and renewed in good time.

Provided the contact pressure is ample, a rough contact surface may have a lower contact resistance than one in smooth new condition, so the file should be used sparingly and only on badly burned and pitted contacts. A think film of oil smeared on with an oily rag helps to reduce mechanical wear, but excess of oil or grease encourages burning and pitting. Mechanical wear on drum-type contacts can be considerably reduced by judicious greasing.

Silver-faced contacts and carbon contacts should not be lubricated. Copper contacts that have been closed for long periods tend to develop an oxide film which may cause overheating. When opportunity permits these contacts should be opened and operated several times to clean the contact surfaces.

Magnet faces should be kept clean and free from grease or oil, and rust should be removed carefully with fine emery, making sure that metal particles are carefully moved and never deposited on contacts or insulation. See that the moving parts are free and without undue wear at pivots, and that magnets are bedding properly. The faces of a.c. magnets should on no account be filed.

Hence starter and other motor control gear should be regularly inspected to check and maintain the following items:

(a) Enclosure – Check for accumulations of dirt and rust. Any corroded parts must be cleaned and repainted. Examine the starter fixing bolts and its earth bonding connection – particularly where high vibration is present, e.g. in the steering flat and the foc'sle.

(b) Contactors and relays – check for any signs of overheating and loose connections.

Remove any dust and grease from insulating components to prevent voltage breakdown by surface tracking. Ensure that the magnet armature of contactors moves freely. Remove any dirt or rust from magnet faces which may prevent correct closing.

(c) Contacts – Examine for excessive pitting and roughness due to burning. Copper contacts may be smoothes using a fine file and copper oxide, which acts as a high resistance, can be removed using glass-paper. DO NOT file silver alloy contacts or remove silver oxide as it acts as a good conductor. A thin smear of electrical contact lubrication helps to prolong the life of all contacts. When contacts have to be replaced, always replace both fixed and moving contacts in pairs.

(d) Connections – Examine all power and control connections for tightness and signs of overheating. Check flexible leads for fraying and brittleness.

(e) Overcurrent relays – Check for proper size (relate to motor full-load current).

Inspect for dirt, grease and corrosion and for freedom of movement. A thorough OCR performance test can only be carried out by calibrated current injection.

(f) Control operation – Watch the sequence of operation during a normal start-up, control and shut-down of the motor. Particularly look for excessive contact sparking.

Remember to check operation of emergency stop and auto restart functions.

.2 Main Engine

The performance of electric lamps will deteriorate with time. Eventually they fail and the lamps must be replaced. Simple lamp replacement becomes the obvious maintenance task. When a light fails to light when switched on it is natural to suspect lamp failure. If this does not solve the problem, checks on the lamp equipment and power supply must follow. An incandescent tube may be checked (out of circuit) for low-ohm continuity using a multimeter. If the lamp appears intact then the fault must lie in the supply or its connections. Voltage and continuity checks of the supply, fuse/MCB and ballast circuit must be applied. Remember that a single earth fault on an insulated two-wire lighting supply will not blow a fuse. However, a similar earth fault on an earth supply system (as often used for 110V deck sockets for portable tools and hand lamps) will blow a fuse.

Remember it is good practice to replace both fuses after clearing a fault which has ruptured only one of them.
When replacing a lamp, ensure that the circuit is dead while removing the old lamp and inserting the new one. The glass bulb or tube of an old and corroded fitting may break loose from its end-cap while attempting to remove the lamp. If the supply is still connected, it is relatively easy to cause an accidental short-circuit during the removal process and the corresponding arc flash may cause blindness, burns and fire.

Always replace a lamp with the correct size, voltage and power rating for the fitting it is housed in. Overheating and fire can easily result by using a higher power incandescent lamp than the fitting was designed for. Check the lampholder wire connections behind the lampholder for signs of overheating (hard, brittle insulation on the wires) and replace if necessary.

Take care when disposing of lamps, particularly discharge tubes, which should be broken (outdoors) into a container (e.g. a strong plastic bag) to avoid handling the debris.

Remember that in a fluorescent lamp circuit the capacitor may remain charged for a while after switch off unless fitted with a discharge resistor. Play safe, discharge the capacitor with a screwdriver blade before touching its terminals.

Cleaning of the lamp glass and reflectors is essential for safety and necessary to maintain the fitting's luminous efficiency. Particular care should be paid to the maintenance of the watertight integrity of exposed light fittings on deck at its flanged joints and cable gland entry. Similarly, a regular inspection of all portable cargo light fittings, together with their flexible cables and supply plugs, should be undertaken.

The design of electrical equipment for hazardous areas is rather special. Maintenance of such apparatus must not, in any way, cause its operation to be less safe than in its original certified state. This most important point means that the maintenance must be carried out by a competent person. 'Lash-ups', refitting with wrong sized components (e.g. lamps) failing to employ the correct number of cover bolts etc., is absolutely forbidden. The inspection and maintenance of Ex'd' (flameproof) enclosures for lights, switches, junction boxes, push-boxes, etc., required meticulous care. This following example gives a guide to the inspection and maintenance points as applied to a flameproof light:

1. Corrosion

This will reduce the enclosure strength. To ascertain the extent of corrosion, remove dirt, loose paint and surface corrosion with a wire brush. If only the paintwork is deteriorating, the enclosure should be repainted to prevent further corrosion.

2. Bolts

Make sure that there are no missing bolts. This is particularly important on flameproof lights because a missing bolt will invalidate the certification. Replacement bolts must be of equivalent strength as originals (usually high tensile steel).

3. Mountings

Ensure that all mountings are secure. Corrosion and vibration are severe on ships and can cause premature failure.

4. Flamepaths

Examine the flamepath for signs of corrosion or pitting. If the flamepath needs cleaning, this should be done with a non-metallic scraper and/or a suitable noncorrosive cleaning fluid.

5. Cement

Examine the cement used around lamp glass assemblies both inside and outside. If the cement is eroded, softened or damaged in any way, advice should be sought from the manufacturer regarding repair. If deterioration of the cement has occurred, a complete new lamp glass assembly should be fitted.

6. Lamp glass

Check lamp glass; if cracked or broken a complete new lamp glass assembly should be fitted. Clean the lamp glass.
When re-assembling an EX'd' enclosure you must ensure that the following points are covered:

(a) Lightly grease all flamepaths and threaded components with an approved form of non-setting silicone grease. Care must be taken to ensure that blind tapped holes are free from accumulated dirt or excessive grease which can prevent the correct closure of flamepaths, or cause damage to the tapped components. Fit new lamp of the correct rating.

(b) Ensure bolts are not over-tightened as this can distort flamepaths, cause excessive stress on the lamp glasses or distort weather proofing gaskets, if fitted, allowing the ingress of liquids and dusts.

(c) Check the lights are installed in accordance with the requirements of the installation, particularly the classification of the area if it is hazardous and that the correct rating of lamp is fitted.

(d) Remove any build-up of dust on the lights, this can cause overheating as well as acting as a corrosive agent.
Before attempting any maintenance work on the EX'd' equipment check for any particular inspection and overhaul instructions given by the manufacturer.

.2 Generator and distribution system

Nearly everyone has experienced an electric shock at some time. At best it is an unpleasant experience, at worst it is fatal. Anyone who has access to live electrical equipment must be fully aware of first aid and safety procedures related to electric shock as described in relevant safety acts. Copies of these safety procedures should be displayed on board ship.
The nervous system of the human body forms an electrical network which is monitored by a ripple at about 100 Hz of amplitude 4mA. Exposure to excessive current from some external source produces effects that range from serious to lethal.
In all cases the damage is done by current (or current*time), and is consequently a function of voltage and path resistance. The effects of total current in the frequency range 5 – 200 Hz are roughly as follows:
1-5 mA: discernible;
5-12 mA: painful;

13-15mA: threshold of involuntary muscle contractor ('let-go' value) after which it is physically impossible to release grasp;
20-50mA: severe pain and loss of consciousness, although heart and lungs continue to function; if contact is short the effects may not be serious;
50-75mA: tetany (paralysis) with no pulse nor respiration; when flow of blood to the brain ceases (usually within 5 minutes) damage is irreparable;
100-1500mA: ventricular fibrillation (disturbance to the co-ordinate action of the main blood pumping chambers), destroying the heart's natural rhythm, with almost instantaneous death;
1500mA upward: contraction of heart muscles but not necessarily fibrillation; respiratory system may or may not be paralysed.
The 'let-go' current is greater than 13-15mA for d.c. and for frequencies below 5Hz and above 500 Hz.
Electric shock is due to the flow of current through your body. This is often from hand to hand or from hand to foot. A chock current as low as 15mA ac or dc may be fatal.
Obviously the size of shock current is related to the applied voltage and your body resistance. The body electrical resistance is markedly non linear, and is affected by the moisture on and the physical state (thick hard or thin tender) of the skin. The actual internal paths may be several and are often unpredictable. The current effects listed above may occur even if the current passes between two fingers of the same and or two points on the same leg. In general, however, currents from hand to hand, head to foot or hand to foot involve the heart and the respiratory system, and possibly to brain.
Typically, the total resistance between hands is around 2kΩ but it is dependent upon the contact area, the resistance of which may be 30kΩ per cm^2 when dry, or 1 kΩ per cm^2 when damp. The resistance of the internal paths is a few hundred ohms.
The voltage that may cause death is not capable of specification. It could be as low as 100V with the skin wet and the contact area large.
Voltages of about 60V and below are regarded as reasonably safe for portable hand tools. This is why special step-down isolating transformers are used with portable hand tools and hand lamps. These transformers supply the tool or lamp at 110V ac but because the secondary winding is centre-tapped to earth, maximum shock voltage to earth is 55V.

The victim must first be detached from live metal, by switching off the supply or by aid of dry non-conducting material (wood, dry clothing, rubber gloves), to roll the body aside or to brush aside a flexible conductor. As soon as this has been accomplished it is essential to begin some resuscitation.

Electric shock if often accompanied by falling, which may cause additional physical injury and require firs aid action. If the shock victim is unconscious, resuscitation must take priority over first aid methods. Check the resuscitation techniques displayed on the electric shock posters displayed on board.

If the heart still beats, but the breathing has stopped, artificial respiration should be applied, the most effective method being mouth-to-mouth. The dashing of cold water on the face may sometimes cause the victim to gasp and start breathing, upon which artificial respiration must be started. Promptly applied and continued, first aid is successful in about 75 percent of apparent death from electric shock, but it may have to be maintained for as long as 8 hours.

Delay in applying first aid may prove fatal and, even when the patient recovers, may result in permanent injury. Accidental shock may have serious consequences if resuscitation is delayed, or if abandoned too soon.

Throughout protracted artificial respiration the patient must be kept warm. His other injuries (burns, fractures etc) must be treated as soon as possible thereafter.

Protective devices such as circuit breakers, fuses, reverse relays, and current-sensitive relays are installed on switchboards to provide protection against faults in the electrical distribution system. These devices are applied so as to isolate any fault with the least possible portion of the system being interrupted; the arrangement should be such that the generator circuit breaker is the last to open under fault conditions. Each protective device (circuit breaker) must have an interrupting rating adequate to safety interrupt the maximum fault current obtainable at the point of application.

Generator and bus bar breakers and breakers feeding combined loads in a selective system are of the open-frame type and have long-time and short-time trips.

Instantaneous trips may be used in those cases where the circuit breakers have shorttime rating below the interrupting rating, provided they do not defeat selectivity.

Breakers feeding individual loads in the system should be of the moulded-case or open-frame type with the only requirement being that the continuous and interrupting ratings are adequate for the application.

When three or more generators are to operate in parallel, the generator circuit breakers should have instantaneous trips which are set at a value in excess of the maximum fault current obtainable from an individual generator.

Fuse selection is based on systems characteristics (voltage and current) and speed response (standard or time-delay) required at the point of application. All fuses should be of the non-renewable cartridge type and capable of interrupting the available fault current.

Reverse power relays are provided to prevent a generator from operating as a motor when paralleled with another generator. This relay trips its associated generator breaker when power flows from the generator to the line. Usually the relay is set to initiate generator breaker tripping within 10 seconds when reverse power is approximately 5 percent of the generator rating

It is sometimes necessary to employ current-sensitive relays for tripping circuit breakers at a predetermined current. This becomes of special importance when arranging for selectivity between the emergency generator and main switchboard bus bar breaker during feed-back operation. Under normal conditions (with the emergency switchboard energised from the main switchboard), the bus bar breaker is coordinated with the main generator breaker, and has a relatively high trip value. During feedback operation it is necessary to trip the bus bar breaker should the combined load (both main and emergency) on the emergency generator approach a value likely to exceed the emergency generator rating. This is required so as to provide for continuity of emergency supply to emergency loads.

The tripping scheme would normally consist of current transformers and currentsensitive relays properly co-ordinated and arranged to monitor the emergency generator total current and act on a shunt trip of the main-emergency bus bar breaker.

The trip circuit would be electrically interlocked so as not to be effective at any time other than when operating under a feed back condition.

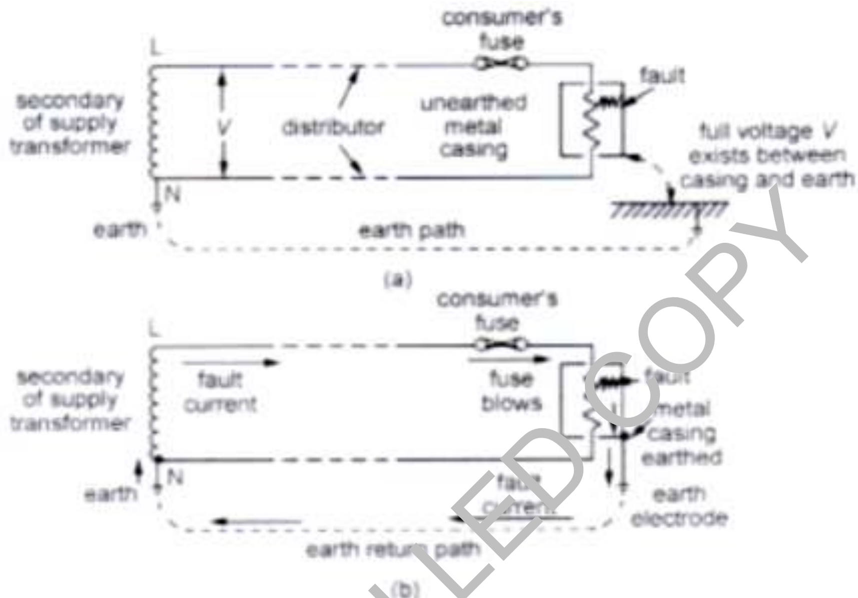
To avoid interrupting vital circuits as a result of over-load tripping the generator circuit breakers, non-vital loads may be arranged for automatic tripping when the total load on any generator or bus bra circuit exceeds a predetermined value. Usually, the loads to be tripped are connected to a common bus or buses; tripping the breaker feeding the bus thus disconnects all loads commonly connected.

In lieu of the foregoing, non-vital loads may be sequentially tripped via a multiplecontact timing relay. The contacts are arranged to close serially at predetermined intervals, and the closing of each contact trips one or more circuit breakers serving on vital loads until the overload is reduced to an acceptable value. With the overload cleared, the relay contacts open and the timing relay resets.

The circuit breakers to be tripped must have either a shunt or undervoltage trip device, undervoltage being preferred because of its fail-safe characteristic. Current transformers of the proper rating are required for each generator or bus tie circuit to be monitored, and a current-sensitive relay is required for each breaker or group of breakers to be tripped. The relay may be instantaneous or time-delayed so as to not initiate tripping on momentary overloads.

The simplest is the transformer as an earth fault on the circuit serving one winding cannot proceed further than that circuit due to the air gap of the transformer.

The figure below shows a circuit consisting of an appliance being fed through the local distribution system from a transformer. One point of the distribution transformer secondary is connected to earth. The live conductor is protected by a fuse. Suppose a fault occurs in the equipment causing the metal case to be connected to the live conductor.

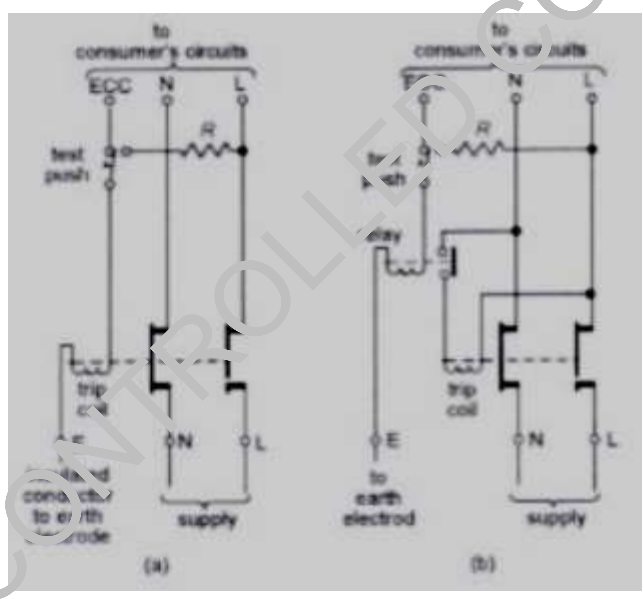


In (a) the metal casing is unearthed. The fault will cause it to have a potential above the earth the same as the live conductor, that is, full mains voltage V. A person standing on an earthed deck or touching an earthed part of the ship will receive a severe and possibly fatal shock if he also touches the equipment casing. Thus unearthed metal associated with an electrical installation is a source of danger. All such metal must be earthed to comply with I.E.E. Regulations and with Classification Society Regulations.

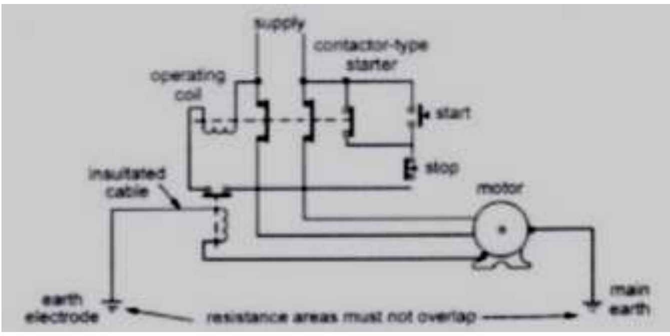
(b) shows the path of the fault current when the casing is earthed. The earth return patch should be of low impedance so that the whole of the earth fault circuit, consisting of the transformer winding, the live conductor, earth-continuity conductor, earthing lead, and earth return, has a low impedance. This current should be large enough to blow the fuse and protect the circuit.

Where the fuse rating is 100A or over, the circuit must be protected by an earthleakage circuit breaker or trip. The operating coil of the trip is connected in the earthcontinuity conductor circuit. Even a high-impedance earth fault will cause a small current to flow in the earth-continuity conductor and this will be sufficient to trip the circuit. These earth-leakage circuit breakers are set to trip with currents as small 40-50 mA. An earth fault causes metal casing and the associated earth-continuity conductor to have their potential raised above earth and produce the fault current. It is a requirement that the earth-leakage circuit breaker shall protect the circuit so that no part of the earth-continuity conductor can have its voltage raised by a fault more than 40 V above earth.

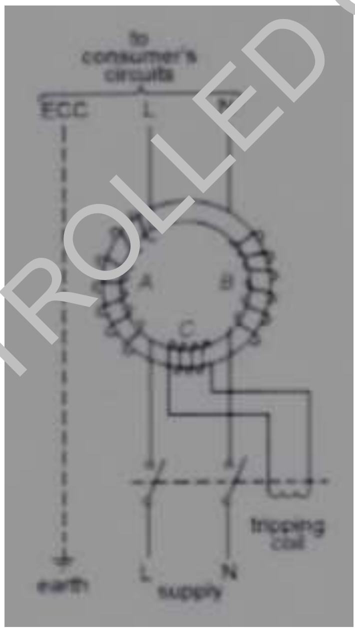
Typical arrangements of voltage-operated earth-leakage circuit breakers are shown below. In (a), the trip coil opens the contacts when the earth fault current flows. The current may have to be fairly large to give this direct tripping. A more sensitive circuit is shown at (b) where only a very small fault current is sufficient to operate the relay which closes contacts so that the tripping coil is connected directly across the supply to given a more definite action. In both cases, a test push places an artificial earth fault on to the circuit through the high resistance R so that a check can be made of the operation of the circuit breaker. After tripping, the breaker has to be reclosed manually. To safeguard against the trip coil being by-passed, the lead between the earth-leakage circuit breaker and the earth electrode must be insulated.



The shutdown of a large installation can be avoided by protecting individual appliancesagainst earth leakage. A motor, for example, can be protected by having an earthleakage relay connected to open the operating coil circuit of a push-button contactortype starter. The tripping circuit is in parallel with the main earthing circuit as shown below. It is essential that the resistance areas of the two electrodes do not overlap.
(The resistance of earth from an electrode increases with distance from the electrode until a point is reached when the resistance becomes constant. This area round an electrode in which the earth resistance varies is called the resistance area of the electrode and it can be a few metres or up to 7 of 8m or more.



Another form of earth-leakage circuit breaker is the current-operated type shown below. This consists of a current-balance transformer which has three windings, A, B and C, on a ring core. Windings A and B carry the line and neutral load currents, respectively, which will be equal in a healthy circuits.



They are wound in opposition so that the total magnetic flux is zero and no current is induced in the third coil, C. If a fault occurs between line and earth, then the current in the neutral will be less than the current in the live conductor. The balance between A and B will be upset and the resultant magnetic flux will induce a current in coil C. This is connected to the tripping coil of the earth-leakage circuit breaker which it will open.

As well as reducing the operating voltage of the tool to 110V or less all the metal parts which can be touched by the operator must be covered with plastic.

Welding

The arcs and sparks produced by arc welding and cutting make the process appear more dangerous than it is. There are comparatively few reported electrical accidents.

Undoubtedly the operators experience occasional electric shocks but at the low voltages employed for most types of welding shocks are not a serious hazard. In confined, conductive and/or wet locations, however, an open circuit voltage of 80 V ac can be lethal and there are occasional electrocutions. Operators are also prone to minor burn injuries from contact with hot metal and 'arch eye' from ultra violet radiation. The accidents are almost wholly confined to manual welding where an operator holds an electrode holder or torch.

The most common process is AC manual arc welding where flux coated, stick electrodes are used and the power source is a transformer with an inductive control to vary the reactance and control the welding current from about 50 to 600 amps. The standard open circuit voltage is 80 V and on load it falls to some 20 V to 40 V depending on the current load.

The non-electrical safety precautions comprise protective clothing for the operator to prevent burn injuries from arc sputter and the UV and infra red radiation produced by the arc. A visor is used to protect his face with an aperture fitted with a filter glass through which he observed the arc. It is usually necessary to provide extract ventilation to remove fume and opaque or filter screens, arranged around the operator, to protect other people in the vicinity from UV radiation.

To avoid indirect electric shocks the power source metal work and the workpiece should be earthed. Earthing the latter is also some safeguard should an interwinding fault cause the welding circuit to become 'live' at mains voltage. It is not advisable to save the cost of the welding earth cable by earthing the welding circuit at the power source at this practice can lead to damage from stray welding currents. Electrode holders should be insulated to prevent contact with 'live' parts as far as possible. There are two types of electrode holder specified in BS 639 'A and B'. Type 'A; is less versatile than type 'B' but somewhat safer as no 'live' parts are accessible to the standard test finger and when the electrode is fitted its non-coated end does not protrude from the electrode holder head. To avoid direct electric shocks operators should not change electrode with bare hands unless the power source is switched off.

Equipment that suffers from interference are classed as susceptible, and various arrangements can be employed to reduce this susceptibility. The reduction process is termed electromagnetic hardening and is complementary to the measures to control interference and the use of suppressors.

The susceptibility of equipment to interference depends on the number and nature of sensitive circuits employed and the amount of energy involved in those circuits.

Circuits that use only small amounts of energy are the most sensitive, e.g. aerial input circuits to radio receivers.

Almost every type of electrical apparatus is potentially capable of giving rise to interference under the right conditions, and even certain non-electrical equipment may also cause trouble owing to the generation of static electrical charges. Typical examples of the latter are seawater-lubricated rubber or plastic bearings, especially if they are fluted. In these cases minute electrical charges produced by the rotation of the shaft on the rubbing face of the bearing will give rise to a crackling noise in any adjacent radio set of the portable type.

Interference results from any sudden interruption or change of electrical current, such as surged from switches, control gear, motor starters, etc., or it can arise from steadystate conditions which in themselves are a series of current interruptions or reversals.

Examples of this type of disturbance vary from the familiar fluorescent tube (even if operating on d.c.) to thyristor control gear, and motors and generators of all kinds.
Erratic connections can also cause an enormous amount of trouble because by their very nature the trouble is intermittent and consequently difficult to trace. Equipments likely to cause interference and those likely to suffer from interference should be kept as far apart as possible, and this includes their connecting cables and all associated circuits. It is, or course, impracticable to give much separation in the average ship and the question then arises, how much?
An answer can be given only in general terms, e.g. that the closer together equipments are, the more likely they are to be incompatible. Screening can be used instead of separation, but it is difficult to assign any figure of merit as the variables are too numerous. In fact some experts even content that a screen on a radio room is unnecessary; the money saved can be put to a much better use by the provision of more effective local screening for sensitive equipment and the use of various forms of double and superscreened cable.
Precautions may be considered under three headings:

1. Spacing/screening
2. Suppressors
3. Cabling

1. Spacing/Screening

Receiving equipments and transmitting equipments of all sorts should be separated from each other and, where separation cannot be obtained, screening should be adopted.
This means that radio receivers and transmitters should be constructed so that their cases form complete electromagnetic screens with properly screened connectors to receive their respective aerial feeders and other interconnections.

2. Suppressors

Ideally, all equipment in a ship should be suppressed to the standards laid down in BS 1597, but there may be occasions when this standard is inadequate or only suppressed equipment is available. In such cases external suppressors must be fitted.
There are many types of suppressor available commercially and they should be selected for their suitability for marine conditions and of course for the voltage current on which they will be used. Suppressors may be simply capacitors or combinations of capacitors and chokes and the values normally used vary between 0.001 and 2.0. F while the chokes are usually 0.5-1.0 mH.
In the majority of cases suppressors are sited in the power supply lines to equipments and serve to prevent the conduction of interference energy along the lines. Such suppressors should be installed as close as possible to the equipment being protected; preferably not more than 150 mm away. The frame of the suppressor must be bonded efficiently to the case of the relevant equipment and should not be separately connected to earth.

3. Cabling

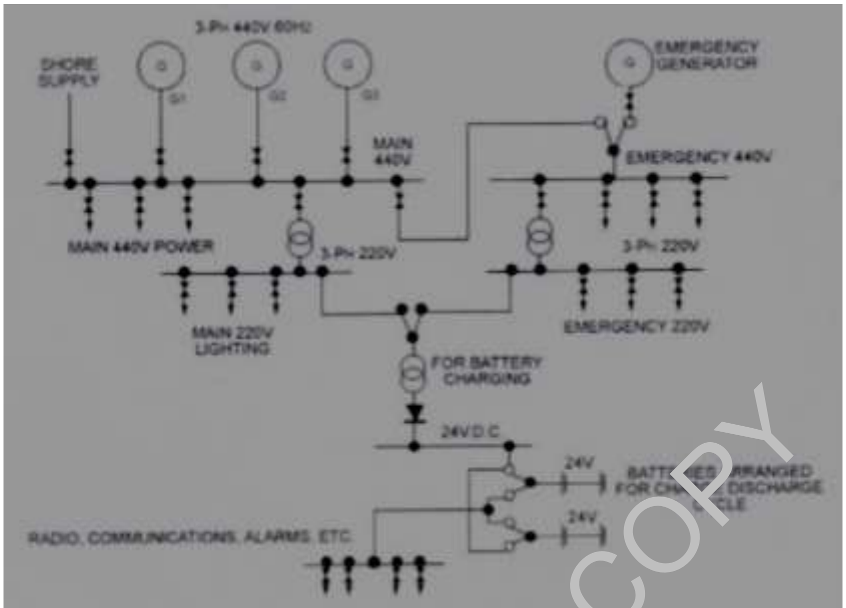
Cables should be separated into two groups:

1. Cables connected to sensitive parts of equipments such as amplifier inputs, aerial inputs to radio receivers, etc.
2. Cables connected on non-sensitive parts of equipments such as power supplies.

Cables in group 1 should not be bunches with those in group 2 and the two groups should be separated by the maximum possible distance.
Single core cables should be avoided; 'feed' and 'return' conductors should be contiguous or better still twisted together. The use of lead-sheathed cables as a means of controlling interference and to obtain compatibility is not recommended. The disadvantage of cost, weight and adequate sheath bonding outweigh any interference control advantage. However, in employing the grouping and segregation principles use should be made of any inherent screening offered by the ship's structural material such as ventilation trunking, bulkheads or even metallic cable trays. Such conducting materials should be interposed between groups of sensitive and non-sensitive cables. Meticulous maintenance of equipment and cabling is essential to preserve electromagnetic compatibility standards and the following points should be considered:

1. Replace all metallic covers carefully using all the fasteners provided.
2. Ensure good connections between cable screens and their terminating connectors.
3. Ensure that all bonding and earthing arrangements are clean and tight.
4. Do not install temporary wiring in such a way that separation rules are violated.
5. Avoid loose connections/contacts of any sort.

An emergency electrical power system must be provided on board so that in the event of an emergency involving a total power failure, a supply will still be available for emergency lighting, alarms, communications, watertight doors and other services necessary to maintain safety and to permit safe evacuation of the ship by lifeboats.
Regulations require that the emergency power source be a generator, or batteries, or both. The emergency power source must be self-contained and not dependent upon any other engine room power supply. A battery when fully charged is obviously selfcontained.
An emergency generator must have an IC engine as prime mover and have its own fuel supply tank, starting equipment and switchboard in the near vicinity.
The emergency power source must come into action following a total electrical power failure. Emergency batteries can be arranged to 'switch in' immediately a power failure occurs. Emergency generators can be hand cranked, but are usually automatically started by air or a battery to ensure immediate run-up following a power failure.
Although regulations may permit a battery to be the sole source of emergency power, in practice a suitable battery may be too large and hence a diesel driven generator is usually installed with its own small starting battery or air-start supply. Other small batteries may also be installed to supply control and communication equipment. On passenger ships, regulations require that the primary emergency power supply be provide by a diesel driven generator, but an emergency battery must also be installed to supply emergency lighting for a short-period-typically a minimum of 3 hours. This emergency battery is to ensure that a total blackout cannot occur between the moment of power failure and the moment of connection of the emergency generator – passengers may panic during a blackout, you are not expected to panic.
A typical ship's distribution system is shown below. The system incorporates emergency power supplies.



There is no ‘standard’ arrangement, all ships differing in some respect. It will be seen that both the auxiliary and the emergency services are supplied by the main service generators during normal operating conditions. In the event of an emergency, only the emergency services are supplied by the emergency generator. The emergency power system must be ready and available at all times. Such reliability requires special care and maintenance. At regular intervals it must be tested to confirm that it does operate correctly. The testing is normally carried out during the weekly emergency fire and boat drill practice sessions. The ship is not shut down but the emergency power sources are energised and connected to supply the emergency services for the period of the practice session.

The regulations governing the emergency source of power are detailed in the 1972 SOLAS Convention, in IEE Regulations for the Electrical and Electronic Equipment of Ships and in the regulations of the Classification Societies such as Lloyds, Det Norske Veritas, etc.

.4 Steam boiler

The power rating of an emergency generator is determined by the size and the role of the ship. On some small vessels a few kW will suffice for emergency lighting only. Larger and more complicated vessels, e.g. LPG carriers, passenger liners, etc., may require hundred of kW for emergency lighting, re-starting of the main engine auxiliaries, and to supply fire-fighting.

An emergency generator is connected to its own emergency switchboard and they are usually located together in a compartment above the water-line, e.g. on the boat deck.

In normal operation the emergency board is supplied from the main board by a cable called the ‘bus-tie’. It is not normally possible to synchronise the emergency and main generators. Special interlocks in the control circuits of the circuit breakers, at each end of the bus-tie, prevent parallel running.

Starting of the emergency generator prime mover is often automatic. The run-up is initiated by an electrical relay which monitors the normal mains power supply. Falling mains frequency or voltage causes the ‘start-up’ relay to operate the generator starting equipment. The prime mover

may be electrically cranked from its own 24V battery and starter motor or air started from its won air reservoir fitted local to the generator engine. A manual start-up may be initiated by push buttons in the main control room and in the emergency generator room.
Small generator prime movers can usually be hand cranked with a starting handle.
Correct functioning of the auto start equipment is obviously vital to the production of emergency power. Regular, weekly testing of the emergency generator should include simulation of the loss of normal power. The start-up equipment may provide a push button to interrupt the normal voltage supply to the panel which then triggers the start sequence. 'Loss' of main power supply can easily be simulated by pulling a fuse into the auto start panel which supplies the under-voltage or under-frequency relay.
Emergency generators should be regularly checked and run up to speed for short test runs to comply with safety regulations. These no-load running checks should, when practicable, be supplemented occasionally by a proper load test. This requires the disconnection of normal mains power while the emergency generator is loaded up to near its rated value. Only a proper load test will prove the performance of the generator and its prime move, together with its circuit-breaker operation.
A properly maintained storage battery will instantly supply electric power when required. This feature makes a battery the key element in the provision of essential and emergency power supplies on board ships.

Essential routine power supplies, e.g. for radio equipment, telephone exchange, fire detection, general alarm circuits etc., are often supplied from two sets of batteries worked on a regular charge/discharge cycle.
Emergency battery supplies e.g. for emergency generator start-up and emergency lighting are used in a 'standby' role to give power when the main supply fails.
Ships' batteries are usually rated at a nominal voltage of 24V dc. In some cases a battery system of 110V or 220V may be used where a large amount of emergency lighting its vital or where a large amount of emergency lighting is vital or where a battery is the only source of emergency power.
The two main types of rechargeable battery cell are (a) Lead Acid and (b) Alkaline. The nominal cell voltages of each type are 2V for lead acid and 1.2V for alkaline. Hence, qw lead acid cells or 20 alkaline cells must be connected in series to produce a nominal 24V. More cells may be connected in parallel to increase the battery capacity which is rated in Ampere hours (Ah). Ship's battery capacity is usually rated in terms of its discharge at the 10 hour rate. A 350Ah battery would be expected to provide 35A for
10 hours. However, the battery will generally have a lower capacity at a shorter discharge rate. The manufacturer's discharge curves must be checked for such details.
After a 10 hour discharge a lead acid cell voltage will have fallen to 1.73V. (The equivalent figure for an alkaline cell is 1.14V).
Battery installations for both types of battery are similar in that the battery room should be well ventilates, clean and dry. Both types generate hydrogen gas during charging so smoking and naked flames must be prohibited in the vicinity of the batteries. Steelwork and decks adjacent to lead acid batteries should be covered with acid-resisting paint and alkali resisting paint used near Ni-cad cells.
Battery maintenance includes keeping the cell tops clean and dry, checking the tightness of terminal nuts and applying a smear of petroleum jelly to such connections to prevent corrosion.

Be most careful when handling the battery electrolyte (e.g. when using a hydrometer to check its specific gravity). Use protective rubber gloves and eye goggles when handling electrolyte. Insulated spanners should be available for use on cell connections to prevent accidental short-circuiting of battery terminals. Such a short-circuit across the terminals of just one cell of a battery will cause a blinding flash with the probability of the cell being seriously damaged.

The state of charge held by a lead acid battery is best indicated by a check on the electrolyte specific gravity (SG), using a hydrometer. A fully charge lead acid cell has an

SG of about 1.27-1.285 (often written as 1270-1285) which falls to about 1.1 (or 1100) when fully discharged. The cell voltage also falls during discharge and its value can also be used as an indication of the state of charge.

The state of charge of an alkaline battery cannot be determined from its SG value. The electrolyte density does not change during charge/discharge cycles but gradually falls during the lifetime of the battery. New alkaline cells have an SG of around 1190. When this falls to about 1145 (which may taken 5-10 years depending on the duty cycle) the electrolyte must be completely renewed or the battery replaced. Discharge of alkaline cells should be discontinued when the cell voltage has fallen to about 1.1 V.

Battery charging equipment uses a transformer/rectifier arrangement to supply the required dc voltage to the cells. The size of voltage depends on the battery type (lead acid or alkaline) and the mode of charging, e.g. charge/discharge cycle, boost charge, trickler or float charge. Check manufacturer's instructions for details of charging voltages. Do not allow electrolyte temperatures to exceed about 45°C during charging.

A lead acid cell will gas freely when fully charged but an alkaline cell gases throughout the charging period. The only indication of a fully charged alkaline cell is when its voltage remains at a steady maximum value of about 1.6 – 1.8 V.

Generally, alkaline cells are more robust, mechanically and electrically, then lead acid cells. Nickel cadmium cells will hold their charge for long periods without recharging so are ideal for standby duties. Also they thrive on a 'float charge' to provide a reliable emergency supply when the main power fails.

For all rechargeable batteries it is essential to replace lost water (during gassing and by normal evaporation) with the addition of distilled water to the correct level above the plates. Exposure of the cell plates to air will rapidly reduce the life of the battery. The batteries should be maintained, inspected and checked on a regular basis. A battery log should be kept, the log will be asked for and inspected by the class surveyor and ship inspectors.

2.1.3 DESIGN FEATURES AND SYSTEM CONFIGURATION OF OPERATIONAL CONTROL EQUIPMENT FOR ELECTRICAL MOTORS

1. Three phase A.C. motor

In a three-phase power supply system, three conductors each carry an alternating current (of the same frequency) but the phase of the voltage on each conductor is displaced from each of the other conductors by 120 degrees. (One third of a 360 degree "cycle".) Hence, the voltage on any conductor reaches its peak at one third of a cycle after one of the other conductors and one third of a cycle before the third conductor. Using the voltage on one conductor as the reference, the peak voltage on the other two conductors is delayed by one third and two thirds of one cycle respectively. This phase delay gives constant power transfer over each cycle. It also makes it possible to produce a rotating magnetic field in an electric motor.

With a three phase supply, at any instant, the potential of any phase is exactly equal to and the opposite of the combination (sum) of the other two phases. This means that – if the load on the three phases is "balanced" - the return path for the current in any phase conductor is the other two phase conductors.

Hence, the sum of the currents in the three conductors is always zero and the current in each conductor is equal to and in the opposite direction as the sum of the currents in the other two. Thus, each conductor acts as the return path for the currents from the other two.

While a single phase AC power supply requires two conductors (Go and Return), a three phase supply can transmit three times the power by using only one extra conductor. This means that a 50% increase in transmission cost yields a 200% increase in the power transmitted.

Three-phase systems may also utilise a fourth wire, particularly in low-voltage distribution. This is the neutral wire. The neutral allows three separate single-phase supplies to be provided at a constant voltage and is commonly used for supplying groups of domestic properties which are each single-phase loads. The connections are arranged so that, as far as possible in each group, equal power is drawn from each phase. Further up the supply chain in high-voltage distribution the currents are usually well balanced and it is therefore normal to omit the neutral conductor.

Three-phase supplies have properties that make them very desirable in electric power distribution systems:

- The phase currents tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to reduce the size of the neutral conductor because it carries little to no current; all the phase conductors carry the same current and so can be the same size, for a balanced load.
- Power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations.
- Three-phase systems can produce a rotating magnetic field with a specified direction and constant magnitude, which simplifies the design of electric motors.

Most household loads are single-phase. In North American residences, three-phase power might feed a multiple-unit apartment block, but the household loads are connected only as single phase. In lower-density areas, only a single phase might be used for distribution. Some large European appliances may be powered by three-phase power, such as electric stoves and clothes dryers.

Wiring for the three phases is typically identified by color codes which vary by country. Connection of the phases in the right order is required to ensure the intended direction of rotation of three-phase motors. For example, pumps and fans may not work in reverse. Maintaining the identity of phases is required if there is any possibility two sources can be connected at the same time; a direct interconnection between two different phases is a short-circuit

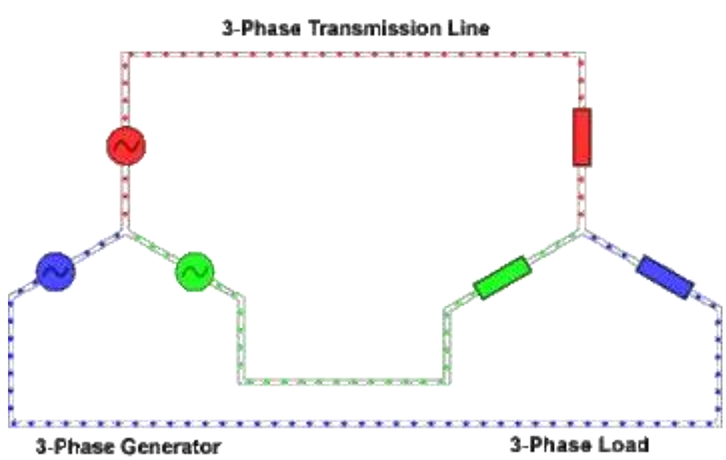
Generation and distribution

At the power station, an electrical generator converts mechanical power into a set of three AC electric currents, one from each coil (or winding) of the generator. The windings are arranged such that the currents vary sinusoidally at the same frequency but with the peaks and troughs of their wave forms offset to provide three complementary currents with a phase separation of one-third cycle (120° or $2\pi/3$ radians). The generator frequency is typically 50 or 60 Hz, varying by country.

At the power station, transformers change the voltage from generators to a level suitable for transmission minimizing losses.

After further voltage conversions in the transmission network, the voltage is finally transformed to the standard utilization before power is supplied to customers.

Most automotive alternators generate three phase AC and rectify it to DC with a diode bridge.



Three-wire and four-wire circuits

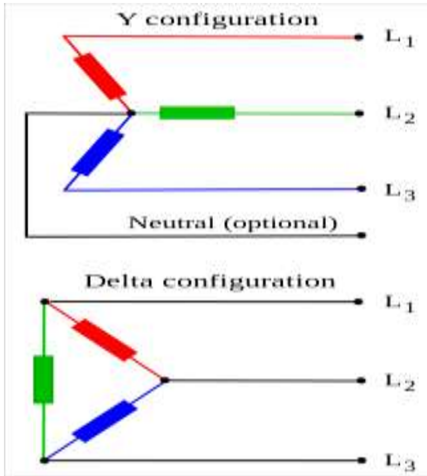
There are two basic three-phase configurations: delta and wye (star). As shown on the left, a delta configuration requires only 3 wires for transmission but a wye (star) configuration may utilise a fourth wire. The fourth wire, if present, is provided as a Neutral and is normally Grounded. The '3-wire' and '4-wire' designations do not count the ground wire used above many transmission lines which is solely for fault protection and does not carry current under non-fault conditions.

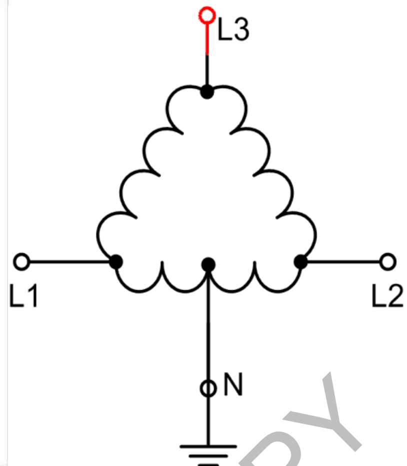
A four-wire system with symmetrical voltages between phase and neutral is obtained when the neutral is connected to the "common star point" of all supply windings. In such a system, all three phases will have the same magnitude of voltage relative to the Neutral. Other non-symmetrical systems have been used.

The four-wire wye system is used when ground referenced voltages or the flexibility of more voltage selections are required. Faults on one phase to ground will cause a protection event (fuse or breaker open) locally and not involve other phases or other connected equipment. An example of application is a local distribution in Europe (and elsewhere), where each customer is fed from one phase and the neutral. When a group of customers sharing the neutral draw unequal currents, the common neutral wire carries the currents resulting from these imbalances. Electrical engineers try to design the system so the loads are balanced as much as possible. By distributing a large number of houses over all three phases, on average a nearly balanced load is seen at the point of supply.

In North America, a high-leg delta supply is sometimes used, where one winding of a delta connected transformer feeding the load is center-tapped and that center tap is grounded and connected as a Neutral, as shown on the right. This setup produces three different voltages. If the voltage between the center tap (neutral) and each of the two adjacent phases is 120 V (100%), the voltage across any two phases is 240 V (200%) and the Neutral to "high leg" voltage is ≈ 208 V (173%).

The reason for providing the delta connected supply is usually to power large motors requiring a rotating field. However, the premises concerned will also require the "normal" North American 120 V supplies, two of which are derived (180 degrees "out of phase") between the "Neutral" and either of the center tapped phase points.





2. Three phase synchronous motors

Principle of Operation Synchronous Motor

Synchronous motor is a doubly excited machine i.e two electrical inputs are provided to it. It's stator winding which consists of a 3 phase winding is provided with 3 phase supply and rotor is provided with DC supply. The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux. The rotor carrying DC supply also produces a constant flux. Considering the frequency to be 50 Hz, from the above relation we can see that the 3 phase rotating flux rotates about 3000 revolution in 1 min or 50 revolutions in 1 sec. At a particular instant rotor and stator poles might be of same polarity (N-N or S-S) causing repulsive force on rotor and the very next second it will be N-S causing attractive force. But due to inertia of the rotor, it is unable to rotate in any direction due to attractive or repulsive force and remain in standstill condition. Hence it is not self starting.

To overcome this inertia, rotor is initially fed some mechanical input which rotates it in same direction as magnetic field to a speed very close to synchronous speed. After some time magnetic locking occurs and the synchronous motor rotates in synchronism with the frequency.

Methods of Starting of Synchronous Motor

Synchronous motors are mechanically coupled with another motor. It could be either 3 phase induction motor or DC shunt motor. DC excitation is not fed initially. It is rotated at speed very close to its synchronous speed and after that DC excitation is given. After some time when magnetic locking takes place supply to the external motor is cut off.

Damper winding: In case, synchronous motor is of salient pole type, additional winding is placed in rotor pole face. Initially when rotor is standstill, relative speed between damper winding and rotating air gap flux in large and an emf is induced in it which produces the required starting torque. As speed approaches synchronous speed, emf and torque is reduced and finally when magnetic locking takes place, torque also reduces to zero. Hence in this case synchronous is first run as three phase induction motor using additional winding and finally it is synchronized with the frequency.

Application of Synchronous Motor

Synchronous motor having no load connected to its shaft is used for power factor improvement. Owing to its characteristics to behave at any electrical power factor, it is used in power system in situations where static capacitors are expensive.

Synchronous motor finds application where operating speed is less (around 500 rpm) and high power is required. For power requirement from 35 kW to 2500 KW, the size, weight and cost of the corresponding three phase induction motor is very high. Hence these motors are preferably used. Ex- Reciprocating pump, compressor, rolling mills etc.

3. Effect of varying frequency and voltage of A.C. motors

Effects of Variation of Voltage and Frequency Upon the Performance of Induction Motors:

a. Induction motors are at times operated on circuits of voltage or frequency other than those for which the motors are rated. Under such conditions, the performance of the motor will vary from the rating. The following is a brief statement of some operating results caused by small variations of voltage and frequency and is indicative of the general changes produced by such variations in operating conditions.
b. With a 10 percent increase or decrease in voltage from that given on the nameplate, the heating at rated horsepower load may increase. Such operation for extended periods of time may accelerate the deterioration of the insulation system.
c. In a motor of normal characteristics at full rated horsepower load, a 10 percent increase of voltage above that given on the nameplate would usually result in a decided lowering in power factor. A 10 percent decrease of voltage below that given on the nameplate would usually give an increase in power factor.
d. The locked-rotor and breakdown torque will be proportional to the square of the voltage applied.
e. An increase of 10 percent in voltage will result in a decrease of slip of about 17 percent, while a reduction of 10 percent will increase the slip about 21 percent. Thus, if the slip at rated voltage were 5 percent, it would be increased to 6.05 percent if the voltage were reduced 10 percent.

f. A frequency higher than the rated frequency usually improves the power factor but decreases locked-rotor torque and increases the speed and friction and windage loss. At a frequency lower than the rated frequency, the speed is decreased, locked-rotor torque is increased, and power factor is decreased. For certain kinds of motor load, such as in textile mills, close frequency regulation is essential.

g. If variation in both voltage and frequency occur simultaneously, the effect will be superimposed. Thus, if the voltage is high and the frequency low, the locked-rotor torque will be greatly increased, but the power factor will be decreased and the temperature rise increased with normal load.

h. The foregoing facts apply particularly to general-purpose motors. They may not always be true in connection with special-purpose motors, built for a particular purpose, or as applied to very small motors.

4. Motor control and protection

Types of motor controllers

Motor controllers can be manually, remotely or automatically operated. They may include only the means for starting and stopping the motor or they may include other functions.

An electric motor controller can be classified by the type of motor it is to drive such as permanent magnet, servo, series, separately excited, and alternating current.

A motor controller is connected to a power source such as a battery pack or power supply, and control circuitry in the form of analog or digital input signals.

- Motor starters

A small motor can be started by simply plugging it into an electrical receptacle or by using a switch or circuit breaker. A larger motor requires a specialized switching unit called a motor starter or motor contactor. When energized, a direct on line (DOL) starter immediately connects the motor terminals directly to the power supply. Reduced-voltage, star-delta or soft starters connects the motor to the power supply through a voltage reduction device and increases the applied voltage gradually or in steps. In smaller sizes a motor starter is a manually operated switch; larger motors, or those requiring remote or automatic control, use magnetic contactors. Very large motors running on medium voltage power supplies (thousands of volts) may use power circuit breakers as switching elements.

A direct on line (DOL) or across the line starter applies the full line voltage to the motor terminals, the starters or cubicle locations, can usually be found on an ELO drawing. This is the simplest type of motor starter. A DOL motor starter also contain protection devices, and in some cases, condition monitoring. Smaller sizes of direct on-line starters are manually operated; larger sizes use an electromechanical contactor (relay) to switch the motor circuit. Solid-state direct on line starters also exist.

A direct on line starter can be used if the high inrush current of the motor does not cause excessive voltage drop in the supply circuit. The maximum size of a motor allowed on a direct on line starter may be limited by the supply utility for this reason. For example, a utility may require rural customers to use reduced-voltage starters for motors larger than 10 kW.

DOL starting is sometimes used to start small water pumps, compressors, fans and conveyor belts. In the case of an asynchronous motor, such as the 3-phase squirrel-cage motor, the motor will draw a high starting current until it has run up to full speed. This starting current is typically 6-7 times greater than the full load current. To reduce the inrush current, larger motors will have reduced-voltage starters or variable speed drives in order to minimise voltage dips to the power supply.

A reversing starter can connect the motor for rotation in either direction. Such a starter contains two DOL circuits—one for clockwise operation and the other for counter-clockwise operation, with mechanical and electrical interlocks to prevent simultaneous closure. For three phase motors, this is achieved by transposing any two phases. Single phase AC motors and direct-current motors require additional devices for reversing rotation.

- Reduced voltage starters

Two or more contactors may be used to provide reduced voltage starting of a motor. By using an autotransformer or a series inductance, a lower voltage is present at the motor terminals, reducing starting torque and inrush current. Once the motor has come up to some fraction of its full-load speed, the starter switches to full voltage at the motor terminals. Since the autotransformer or series reactor only carries the heavy motor starting current for a few seconds, the devices can be much smaller compared to continuously rated equipment. The transition between reduced and full voltage may be based on elapsed time, or triggered when a current sensor shows the motor current has begun to reduce. An autotransformer starter was patented in 1908.

- Adjustable-speed drives

An adjustable-speed drive (ASD) or variable-speed drive (VSD) is an interconnected combination of equipment that provides a means of driving and adjusting the operating speed of a mechanical load. An electrical adjustable-speed drive consists of an electric motor and a speed controller or power converter plus auxiliary devices and equipment. In common usage, the term “drive” is often applied to just the controller.

- Intelligent controllers

An Intelligent Motor Controller (IMC) uses a microprocessor to control power electronic devices used for motor control. IMCs monitor the load on a motor and accordingly match motor torque to motor load. This is accomplished by reducing the voltage to the AC terminals and at the same time lowering current and kvar. This can provide a measure of energy efficiency improvement for motors that run under light load for a large part of the time, resulting in less heat, noise, and vibrations generated by the motor.

- Overload relays

A starter will contain protective devices for the motor. At a minimum this would include a thermal overload relay. The thermal overload is designed to open the starting circuit and thus cut the power to the motor in the event of the motor drawing too much current from the supply for an extended time. The overload relay has a normally closed contact which opens due to heat generated by excessive current flowing through the circuit. Thermal overloads have a small heating device that increases in temperature as the motor running current increases.

There are two types of thermal overload relay. In one type, a bi-metallic strip located close to a heater deflects as the heater temperature rises until it mechanically causes the device to trip and open the circuit, cutting power to the motor should it become overloaded. A thermal overload will accommodate the brief high starting current of a motor while accurately protecting it from a running current overload. The heater coil and the action of the bi-metallic strip introduce a time delay that affords the motor time to start and settle into normal running current without the thermal overload tripping. Thermal overloads can be manually or automatically resettable depending on their application and have an adjuster that allows them to be accurately set to the motor run current.

A second type of thermal overload relay uses a eutectic alloy, like a solder, to retain a spring-loaded contact. When too much current passes through the heating element for too long a time, the alloy melts and the spring releases the contact, opening the control circuit and shutting down the motor. Since eutectic alloy elements are not adjustable, they are resistant to casual tampering but require changing the heater coil element to match the motor rated current.

Electronic digital overload relays containing a microprocessor may also be used, especially for high-value motors. These devices model the heating of the motor windings by monitoring the motor current. They can also include metering and communication functions.

- Loss of voltage protection

Starters using magnetic contactors usually derive the power supply for the contactor coil from the same source as the motor supply. An auxiliary contact from the contactor is used to maintain the contactor coil energized after the start command for the motor has been released. If a momentary loss of supply voltage occurs, the contactor will open and not close again until a new start command is given. This prevents restarting of the motor after a power failure. This connection also provides a small degree of protection against low power supply voltage and loss of a phase. However since contactor coils will hold the circuit closed with as little as 80% of normal voltage applied to the coil, this is not a primary means of protecting motors from low voltage operation.

- Servo controllers

Servo controllers are a wide category of motor control. Common features are:

- ✓ precise closed loop position control
- ✓ fast acceleration rates
- ✓ precise speed control Servo motors may be made from several motor types, the most common being:
    - o brushed DC motor
    - o brushless DC motors
    - o AC servo motors

Servo controllers use position feedback to close the control loop. This is commonly implemented with encoders, resolvers, and Hall effect sensors to directly measure the rotor's position.

Other position feedback methods measure the back EMF in the undriven coils to infer the rotor position, or detect the Kick-Back voltage transient (spike) that is generated whenever the power to a coil is instantaneously switched off. These are therefore often called "sensorless" control methods.

A servo may be controlled using pulse-width modulation (PWM). How long the pulse remains high (typically between 1 and 2 milliseconds) determines where the motor will try to position itself. Another control method is pulse and direction.

- Stepper motor controllers

A stepper, or stepping, motor is a synchronous, brushless, high pole count, polyphase motor. Control is usually, but not exclusively, done open loop, i.e. the rotor position is assumed to follow a controlled rotating field. Because of this, precise positioning with steppers is simpler and cheaper than closed loop controls.

Modern stepper controllers drive the motor with much higher voltages than the motor nameplate rated voltage, and limit current through chopping. The usual setup is to have a positioning controller, known as an indexer, sending step and direction pulses to a separate higher voltage drive circuit which is responsible for commutation and current limiting.

Silicon controlled rectifiers

Thyristor is a four layer, three junction p-n-p-n semiconductor switching device. It has three terminals; anode, cathode and gate. The four layers of alternate p-type and n-type semiconductors forming three junctions J1, J2, and J3. The terminal connected to outer p region is called Anode (A), the terminal connected to outer n region is called cathode (C) and that connected to inner p region is called gate (G).For large current applications, thyristors need better cooling which is achieved to a great extent by mounting them onto heat sinks.

Thyristor turn on

The thyristor is turned on by increasing the anode current. This can be accomplished in the following ways.

Thermals

If the temperature of a thyristor is high, there is an increase in the number of electron-hole pairs, which increases the leakage currents. This increase in currents causes $\alpha 1$ and $\alpha 2$ to increase. Due to regenerative action $(\alpha 1 + \alpha 2)$ may tend to unity and thyristor may be turned on.

Light

If light is allowed to strike the junctions of a thyristor, the electron-hole pairs increase; and the thyristor may be turned on. The light-activated thyristors are turned on by allowing light to strike silicon wafers.

High voltage

If the forward anode –to-cathode voltage is greater than the forward breakdown voltage VBO, sufficient leakage current flows to initiate regenerative turn on. This type of turn-on may be destructive and should be avoided.

Gate current

If a thyristor is forward biased, the injection of gate current by applying a positive gate voltage between the gate and the cathode terminals turns on the thyristor. As the gate current is increased, the forward blocking voltage is decreased.

5. Three phase generators

There are several types of 3 phase power generators. These can vary from a utility power station, to a prime source power generator to portable diesel (and other fuels) 3 phase generator, to 3 phase generators which run on 1 phase power (some models of phase converters). At a utility power station, an electrical generator converts mechanical power into a set of alternating electric currents (AC), one from each electromagnetic coil or winding of the power generator. The currents are sinusoidal functions of time, all at the same frequency but with different phases. In a 3 phase system the phases are spaced equally, giving a phase separation of 120°. The frequency is typically 50 Hz in Europe and 60 Hz in the US.

- Industrial Standby / Towable 3 Phase Power Generators

Industrial and towable 3 phase generators are designed and engineered for optimum performance and superior reliability. From the ultra quiet sound attenuated enclosures (64-71 dba) to the state-of-the-art electronics and controls, these 3 phase generator units are engineered to meet the most rugged conditions. Place the unit at the job site, connect the 3 phase load and start it up. These full-featured standby 3 phase generator units are specially suited for all industrial, commercial and rental applications. Generators can also be used with an automatic transfer switch for standby 3 phase applications.

- 3 Phase Power Generators Power Output

Generators voltage output ranges from hundreds of volts to 30,000 volts. This can be from small portable 3 phase generators, 3 phase generating rotary converters, or utility power stations. At the power station, transformers step-up this voltage to one more suitable for transmission.

- Popular Generators Fuel Includes Propane & Diesel Generators

3 phase power generators can be purchased to run on a variety of fuel types including two of the most popular: propane and diesel generators. Because of the common availability of propane, natural gas and diesel fuel, there are also a wide variety of generators built specifically to use these fuel types.

- 3 Phase Power Distribution and Transmission

After numerous further conversions in the transmission and distribution network the 3 phase power is finally transformed to the standard mains voltage (the voltage of "house" or "household" current in American English). The power may already have been split into single phase at this point or it may still be 3 phase. Where the step-down is 3 phase, the output of this transformer is usually star connected with the standard mains voltage (120V in North America and 230V in Europe) being the phase-neutral voltage. Another system commonly seen in the USA is to have a delta connected secondary on the step down transformer with a center tap on one of the windings supplying the ground and neutral. This allows for 240V 3 phase as well as three different single phase voltages (120V between two of the phases and the neutral, 208V between the third phase (sometimes known as a wild leg) and neutral and 240V between any two phases) to be made available from the same supply.

- 3 Phase Loads

The most common class of 3 phase load is the 3 phase electric motor. A 3 phase induction motor has a simple design, inherently high starting torque, and high efficiency. Such motors are applied in industry for 3 phase pumps, fans, blowers, compressors, conveyor drives, and many other types of motor-driven equipment. A 3 phase motor is more compact and less costly than a 1-phase motor of the same voltage class and rating; also 1-phase AC motors above 10 HP (7.5 kW) are not as efficient and thus not usually manufactured. Large air conditioning equipment (for example, most York air conditioning units above 2.5 tons (8.8 kW) cooling capacity) use 3 phase motors for reasons of economy and efficiency. Read more about 3 phase power loads here.

- 3 Phase Loads from 3 Phase Power Generated on 1 Phase Power

There are many places and instances where 1 phase power is all that is available, or where the power company wants to charge tens, or even hundreds of thousands of dollars to install and supply 3 phase power. When this is the case a quality 3 phase generating phase converter can be run on 1 phase to power 3 phase equipment of any type.

6. Three phase transformers

Electrical generation on board ship is typically at 3-phase a.c./ M0 V, 60 Hz, while fixed lighting and other low power loads are supplied with 220 V a.c. single-phase from very efficient (typically > 90%) static transformer units. Ships with HV generation require 3-phase transformers to supply the LV engine-room and accommodation subswitchboards e.g. using 6600/440V units.

The principle of operation of a single-phase transformer is simple. An applied a.c. voltage V_1 to the primary winding sets up an alternating magnetic flux in the laminated steel core.

The flux induces an emf in the secondary whose size is fixed by the ratio of primary and secondary turns in the pair of phase windings (N1 and N2) to give:

$V_1/V_2 = N_1/N_2$

The secondary voltage V_2 is available to drive current through a load.
It is the load connected to the secondary that sets the size and power factor angle of the load current I_2. This is matched on the primary side from:

$V_1/V_2 = I_2/I_1$

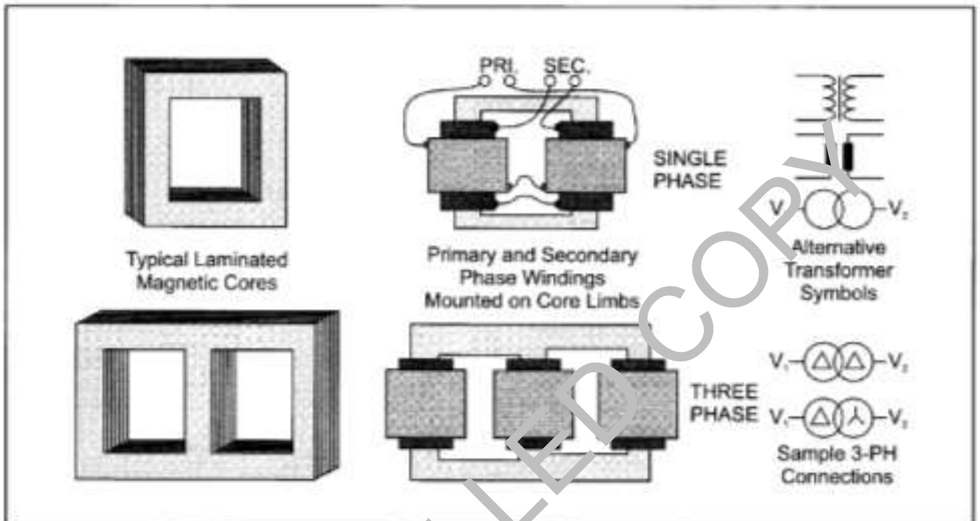
Transformers are rated in apparent power (VA or kVA) units.

The transformers are generally air cooled, being mounted in sheet steel enclosures which are often located adjacent to the main switchboard. Alternatively, they may be fitted within the switchboard so transformer enclosures are not required.

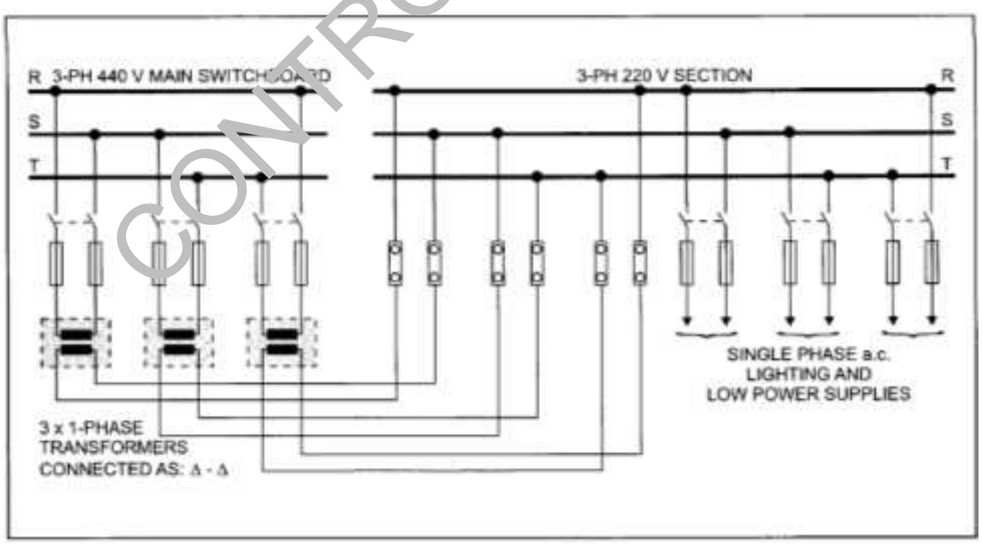
Three-phase 440/220 V lighting transformers are usually composed of three separate single-phase units interconnected to form a 3-phase arrangement.
This enables easy replacement of a single-phase unit if it develops a fault.
The alternative is to use a single 3-phase unit with all windings mounted on a common magnetic core. This type has to be completely isolated in the event of a fault on one phase only.
Transformers for use on 3-phase insulated systems are generally interconnected in a delta-delta circuit configuration using copper links between the phase windings.

If a fault develops on one phase of such an arrangement, the faulty unit can be disconnected (via the links) creating an open-delta or "V" connection and a 3-phase supply will still be available, although at a reduced power capacity. This is obviously a useful safeguard. In some cases, a spare 4th transformer is available to replace the faulty unit.

Transformers for use on 3-phase HV/LV earthed systems ashore are generally connected delta-star to provide a 3-phase,



Transformer arrangements



Delta-delta transformer connection

4-wire LV supply, e.g. a 6600/400 V ratio gives a secondary line voltage of 400 V plus a line-neutral phase voltage of $400\sqrt{3} = 230\ V$. An earth fault occurring on a such neutral-earthed system will immediately operate the protective fuse or circuit-breaker. This interruption of supply leads to rapid identification of the faulty circuit.

Transformers are static items of equipment which are usually very reliable and trouble-free. However, like all electrical equipment, transformers must be subjected to the usual maintenance checks.

At regular specified intervals, transformers must be disconnected, covers removed and all accumulated dust and deposits removed by a vacuum cleaner and suitable brushes. Windings must be inspected for any signs of damage or over-heating. Winding continuity resistance values are measured, recorded

and compared with each other for balance. Any differences in continuity readings will-indicate winding faults such as short-circuited turns. The insulation resistance of all windings must be measured both with respect to earth and to the other phase windings. The cause of any low insulation resistance reading must be investigated and rectified.

Cable connections must be checked for tightness. Covers must be securely replaced and the transformers re-commissioned.

All test results and observations should then be recorded for future reference.

7. Distribution

Distribution Circuit Breakers

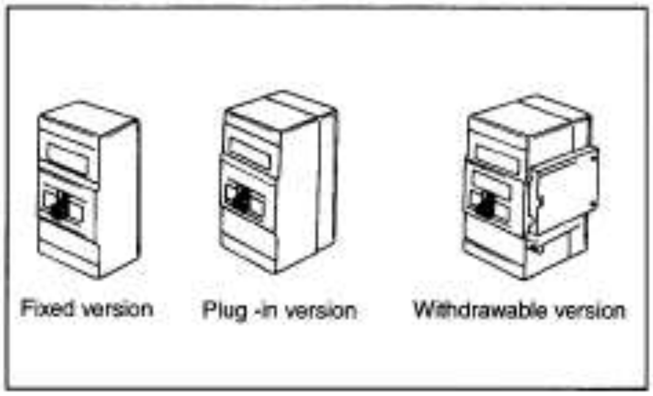
The function of any circuit-breaker is to safely make onto and break open the prospectiaes hort-circuit fault current expected at that point in the circuit. The main contacts must open rapidly while the resulting arc is transferred to special arcing contacts above the main contacts. Arc chutes with arc-splitters quickly stretch and cool the arc until it snaps. The CB is open when the arc is quenched.

Feeder and distribution circuits are usually protected by the moulded-case (MCCB) type or the miniature (MCB) type of circuit-breakers.

MCCBs

These are small, compact air circuit breakers fitted in a moulded plastic case.

They have a lower normal current rating (50-1500 A) than main breakers and a lower breaking capacity.



They usually have an adjustable thermal overcurrent setting and an adjustable or fixed magnetic overcurrent trip for short-circuit protection built into the case. An under voltage trip coil may also be included within the case.

Operation to close is usually by a hand operated lever but motor-charged spring closing can also be fitted. MCCBs are reliable, trouble free and require negligible maintenance. If the breaker operates in the ON position for long periods it should be tripped and closed a few times to free the mechanism and clean the contacts. Terminals should be checked for tightness otherwise overheating damage will develop.

Circuit Protection

Many forms of electrical protection are available which are designed to protect the distribution system when a fault occurs.

Protection relays are used to monitor overcurrent, over/under voltage, over/ under frequency, earth leakage, unbalanced loading, over-temperature, reverse power (for generators) etc.

As most protection relays monitor current and/or voltage, we will limit our examination to ooercurrent and undervoltage protection together with an appreciation of protectiae discrimination.

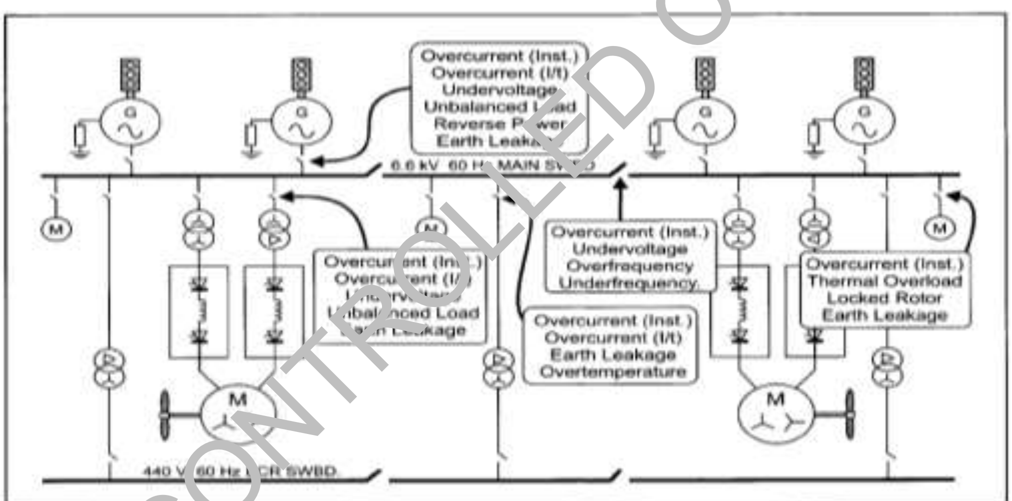
No matter how well designed and operated, there is always the possibility of faults developing on electrical equipment.

Faults can develop due to natural wear and tear, incorrect operation, accidental damage and by neglect.

The breakdown of essential equipment may endanger the ship, but probably the most serious hazard is FIRE. Overcurrent (I^2R resistive heating effect) in cables and equipment will cause overheating and possibly fire.

The size of conductor used in cables and equipment is such that with rated full load current flowing, the heat developed does not raise the temperature beyond about 80'C (i.e. 35'C rise above an ambient of 45ºC).

A copper conductor can withstand very high temperatures (melts at 1083ºC), but its insulation (generally organic materials such as cotton or plastic compounds) cannot withstand temperatures much in excess of 100ºC. At higher temperatures the insulation suffers irreversible chemical changes, loses its insulation properties and becomes burnt out. Short-circuit and overload currents must, therefore, be detected and rapidly cleared before damage occurs.



HV protection scheme

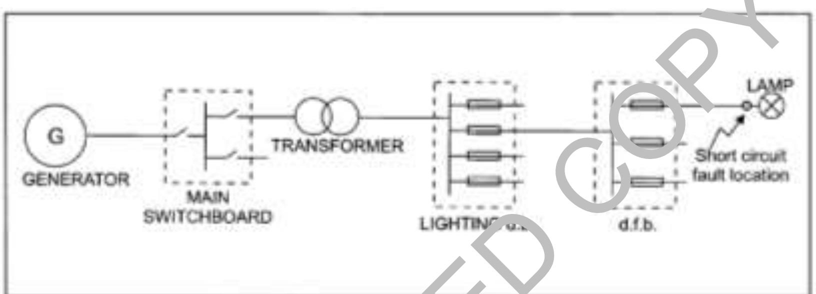
The protection scheme consists of circuitbreakers, fuses, contactors, overcurrent and undervoltage relays. A circuitbreaker, fuse or contactor interrupts the fault current. An overcurrent relay detects the fault current and initiates the trip action.

The circuit-breaker or fuse must be capable of safely and rapidly interrupting a short-circuit current. They must be mechanically strong enough to withstand the thermal and magnetic forces produced by the fault current.

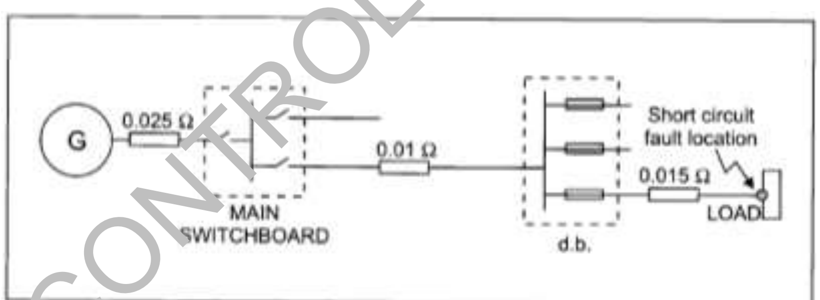
The size (strength) of the circuit-breaker or fuse is specified by its breaking capacity which is the maximum fault current it can safely interrupt.

For example, an MCCB may be continuously rated at 440 V with a rated current 600 A. Its breaking capacity may be 12.5 MVA which means it can safely interrupt a fault current of 1.6,400 A (from $\frac{12.5x10^6}{\sqrt{3}.440} = 16{,}400\ A$).

The prospective fault current level at a point in a circuit is the current that arises due to a short - circuit at that point. The size of this short-circuit fault current is determined by the total impedance of generators, cables and transformers in the circuit between the generator and the fault. This total impedance is generally very small so the maximum fault current (called the prospective fault current) can be very large.



Short-circuit fault location



Fault circuit

Note that the fault level increases, the nearer the fault occurs to the generator.

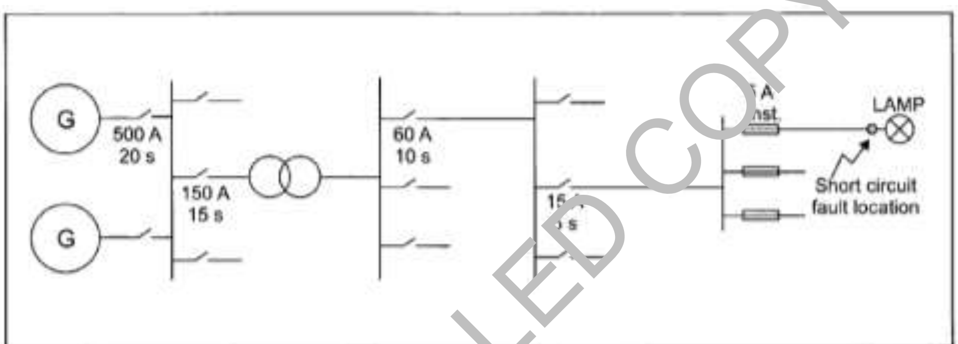
The circuit-breaker or fuse must have a breaking-current capacity in excess of the prospective fault current level expected at the point at which it is fitted.

If less, the circuit breaker (or fuse) is liable to explode and cause fire.

The ability of a protection system to disconnect only the faulted circuits and to maintain the electrical supplies to healthy circuits is called protective discrimination.

Discrimination is achieved by coordinating the current ratings and- time settings of the fuses and overcurrent relays used between the generator and the load as shown. The protective devices nearest the load having the lowest current rating and shortest operating time. Those nearest the generator having the highest current rating and longest operating time.

If a short-circuit fault occurs in the lampholder, the fault current will be large enough to operate all protection devices from the generators to the fault. However, the 5 A fuse protecting the lamp circuit has the lowest current rating and shortest operating time in the system so will be the quickest to operate. This action will clear the fault and leave all other healthy circuits still connected.



Protective discrimination scheme

In the case of fuses, it is generally accepted that discrimination will be achieved if consecutive fuses have a ratio of about 2:1. The shipbuilder specifies the current ratings of fuses, together with the current and time settings of relays, in the protection scheme.

It is important that the original settings are maintained to achieve correct discrimination.

- Overcurrent Protection

The general term "overcurrent" applies to a relatively small increase over the full load current (FLC) rating (e.g. due to mechanical overloading of a motor) rather than the massive current increase caused by a short-circuit fault.

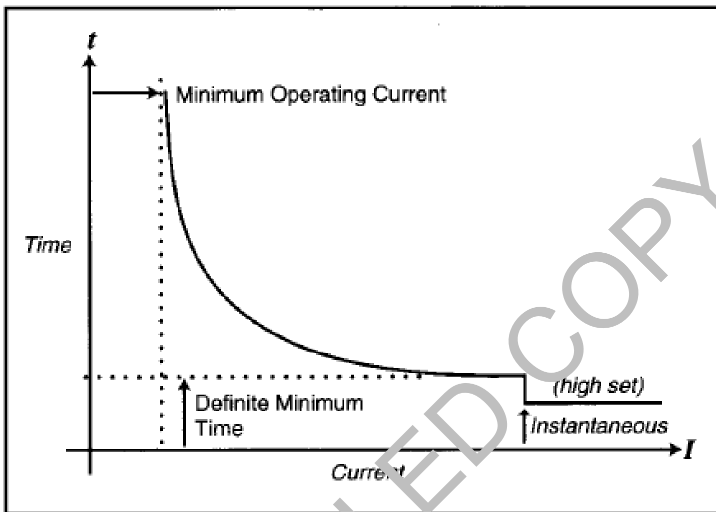
Generally, an overcurrent, supplied from a CT, is detected by a relay with an appropriate time-delay to match the protected circuit.

Short-circuit faults in LV distribution circuits are mainly detected and cleared almost instantaneoitslybfyu ses, MCCBs or MCBs.

Main supply feeders are usually protected against short-circuits by circuit breakers with instantaneous magnetic trip action.

Overcurrent relay types:

- Magnetic
- Thermal
- Electronic



Inverse current time (I/t) curve

All relay types have an inverse current time characteristic called OCIT (overcurrent inverse time), i.e. the bigger the current the faster it will operate. The basic inverse I/t curve would tend towards zero time for the highest currents. To make the relay action more precise at very high fault currents the action is arranged to operate at a definite minimum time which is fixed by the design. This type is called an OCIDMT (overcurrent inverse and definite minimum time) relay action.

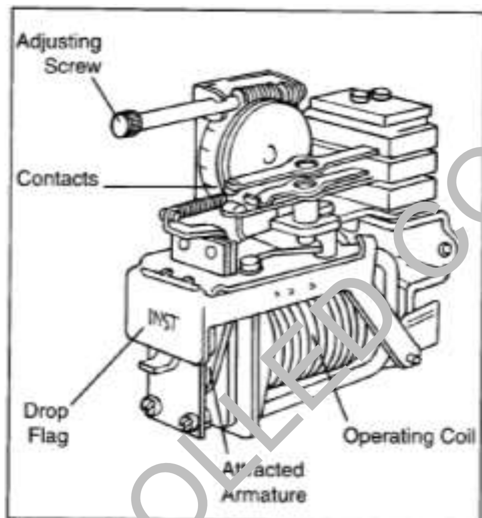
The OCIDMT can also be combined with an instantaneous (high set) trip to give the fastest action aginst extremely high currents due to I short circuit fault.

A magnetic relay, directly converts the current into an electromagnetic force to operate a trip switch. One type is the attracted armature action similar in construction to a, simple signalling relay but with an adjustment for the current setting.

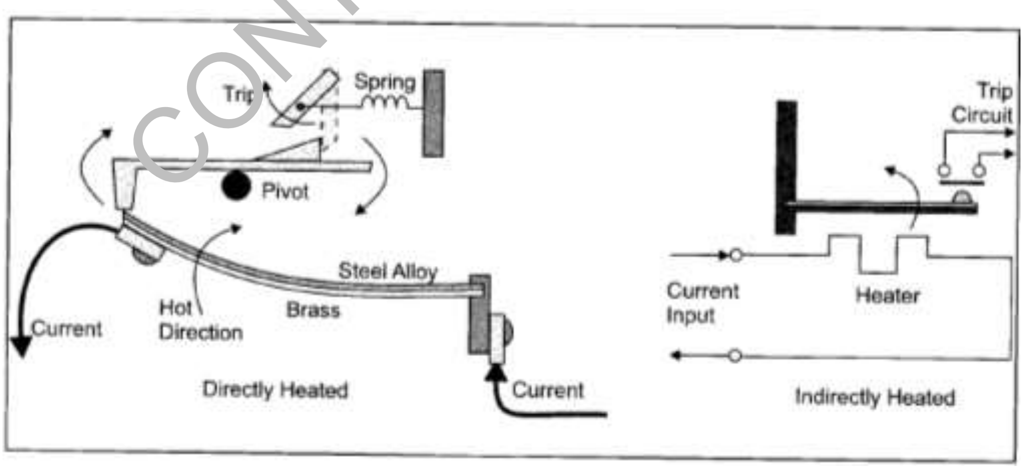
The time of operation is fixed at a definite minimum time which is usually less than 0.2 seconds. This is regarded as instantaneous i.e. with no deliberate time-delay.

To obtain a magnetic inverse-time action, e.g. for motor overload protection, an induction disc movement is usually employed. This construction is similar to a kWh energy meter used in a house but the disc movement is constrained by a spring so is not allowed to actually rotate. The disc travel is very small but sufficient to operate a set of trip switch contacts. Both current and time settings are adjustable. A combined relay including an attracted armature element and induction disc element will give an instantaneous action (high set current) and an inverse/time characteristic.

Thermal relay which utilises the bending action of a bimetallic bar (one per phase) to open a normally closed (NC) contact which then trips a contactor or circuit-breaker.



Magnetic overcurrent relay (instantaneous action)



Bimetallic thermal relay action

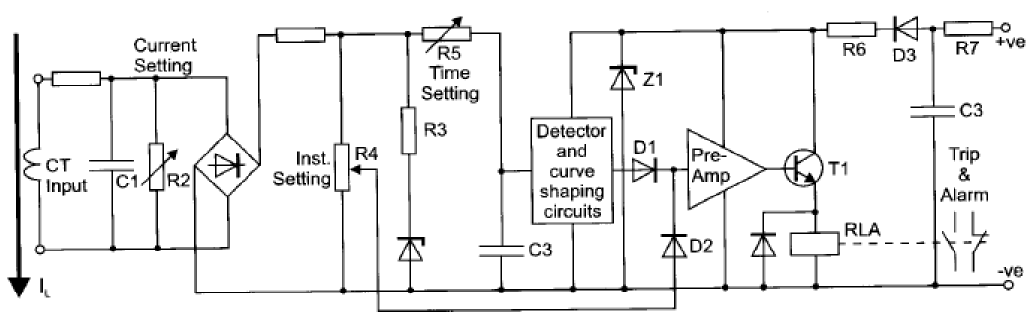
A small circuit current will be allowed to flow directly through the bimetallic strip but larger currents will be directed through a heater coil surrounding the strip. The three bimetal strips in a three phase relay, all bend in the same direction with balanced overcurrents to cause a trip. A mechanical bell-crank trip arrangement can also operate with unbalanced (differential) currents. This is particularly effective with a single-phasing motor fault. In this case, two of the bimetal strips bend further in the normal direction with increased line current, while the other cools down allowing this strip to move relatively backward s (differential action).

The time taken to heat the bimetal strip to cause sufficient bending fixes the required time to trip. Resetting the relay can only be achieved after the strip has cooled down back to the ambient temperature. The inverse I/t overcurrent characteristic of a thermal relay is very useful for the indirect temperature protection of motors. Its thermal time delay is, however, far too long for a short-circuit fault so back-up instantaneous protection must also be used in the form fuses or a circuit breaker.

An electronic overcurrent relay usually converts the measured current into a proportional voltage. This is then compared with a set voltage level within the monitoring unit which may be digital or analogue. In an analogue unit the time delay is obtained by the time taken to charge up a capacitor. This type of relay has separate adjustments for overcurrent and time settings together with an instantaneous trip. The electronic amplifiers within the relay require a low voltage d.c. power supply, e.g.24 V d.c. derived from a 110 V a.c. auxiliary supply.

Here, the input from a line current transformer (CT) is rectified to produce a d.c. voltage which is proportional to the line current. This voltage charges capacitor C2 at a rate set in conjunction with potentiometer R5 which determines the inverse-time characteristic for the relay. When this capacitor voltage exceeds the predetermined level (set by R2) the detector circuit drives Power transistor T2 to operate the output electromagnetic relay RLA which switches trip and alarm contacts in the external circuits.

An instantaneous trip operation is obtained by applying the output of the bridge rectifier directly of the amplifier with a voltage set by R4. Hence, for higher values of fault current, the inverse-time delay circuit is by-passed.



Electronic overcurrent relay circuit

Both the magnetic and electronic relays can be designed to give an almost instantaneous trip (typically less than 0.05 seconds or 50 ms) to clear a short circuit fault.

Thermal relays are commonly fitted in moulded case circuit breakers(MCCBs) and in miniature circuit-breakers (MCBs) to give a “long time" thermal overcurrent trip in addition to a magnetic action for an instantaneous trip with a short-circuit fault.

Overcurrent protection relays in large power circuits are generally driven by current transformers (CTs).

The CT secondary usually has a 5 A or 1A rating for full load current in its primary winding.

All overcurrent relays can be tested by injecting calibrated test currents into them to check their current trip levels and time delay settings.

Primary injection is where a calibrated test current is fed through the normal load circuit. This requires a large current injection test set. The test set is essentially a transformer and controller rather like a welding set, i.e. it gives a low voltage - high current output.

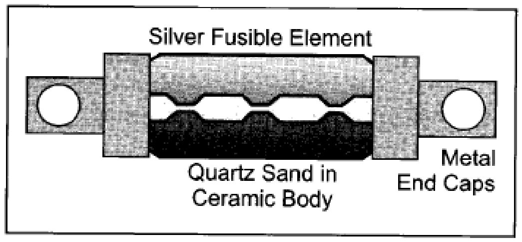
Small secondary injection currents (5-50 A) are fed current directly into the overcurrent relay usually via a special test plug/socket wired into the relay.

Secondary injection does not prove the CT performance (as it is disconnected during the test) but is the usual method for testing an overcurrent relay.

The setting up of an overcurrent relay is obviously critical to its protective duty so is carried out in strict accordance with the manufacturer's instructions. Such setting up is done during new ship trials and at subsequent periodic surveys.

- Fuse Protection

A fuse is the most common type of protection against a short-circuit fault in LV distribution circuits, motor circuits and for portable appliances. It is relatively simple, inexpensive and reliable. As re-wireable fuses tend to be less reliable than the cartridge type and are open to abuse (fitting the wrong size of fuse wire), they are not recommended for marine practice. HRC (high rupturing capacity e.g. 80 kA) cartridge- type fuse links are normally used.



HRC fuse construction

A disadvantage of a fuse is its insensitivity to small overcurrents. An HRC fuse will blow at currents as low as 25% overload, but only after about 4 hours.

The advantage- of a fuse is its very high speed of operation (a few milliseconds) at high short-circuit fault current - faster than a circuit-breaker.

Fuses are fitted in circuits to give protection against short circuits. Protection against relatively small overcurrents (e.g. due to shaft overloading on a motor) is provided where necessary by an overcurrent relay (OCR).

A starter overcurrent relay protects the motor against relatively small overcurrents.

The fuse links provide back-up protection for the supply cables and generators against a short-circuit fault.

Motor fuses are typically rated at 2-3 times the motor full load current in order to withstand the large starting current surge (up to 6 times full load) of the motor. The motor manufacturer will specify the correct rating of fuse link for a particular motor rating. Hence a typical fuse designation for a motor circuit could be "32M63" which indicates a continuous rating of 32 A but a rating of 63 A for the brief starting period.

Important points to note concerning fuses are:

- In the event of a fuse blowing, the cause of the fault must be located and repaired before the fuse link is replaced.
- The replacement fuse link must be of the correct current rating, grade and type. Usually this means the replacement fuse link is identical to the blown fuse link.
- Replace all three fuses in a 3-phase supply even if only one is found blown after a fault. The others may be seriously weakened which makes them unreliable for future use.

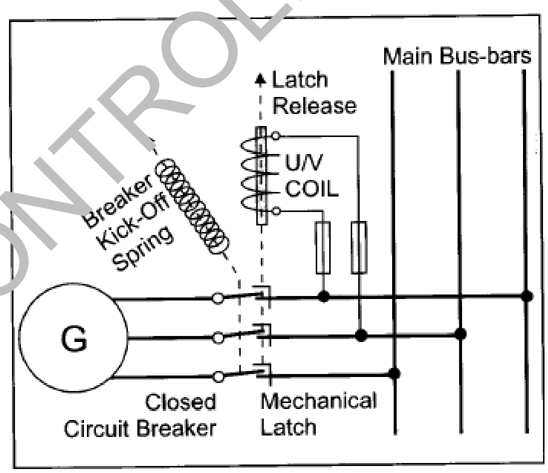
The reference symbols used on an HRC fuse link are devised by the particular manufacturer. They include the current rating, voltage, application (e.g. motor, transformer, diode, general use), physical size, and type of fixing arrangement.

- Undervoltage Protection

An undervoltage (U/V) release mechanism is fitted to all generator breakers and some main feeder circuit-breakers. Its main function is to trip the breaker when a severe voltage dip (around 50%) occurs. This is achieved by lifting the mechanical latch (which keeps the contacts closed) to allow the trip spring to function which opens the breaker contacts. The U/V release on a generator circuit-breaker also prevents it being closed when the generator voltage is very low or absent.

An undervoltage relay, which may be magnetic or electronic, also provides back-up protection to short-circuit protection. As an example, suppose during generator paralleling procedures, an attempt was made to close the wrong circuit breaker e.g. the breaker of a stopped and dead generator. If this circuit-breaker was closed, the dead generator would be the equivalent of a short-circuit fault on the bus-bars and cause a blackout.

The undervoltage relay prevents the closure of the circuit-breaker of the dead generator.



Under-voltage protection

Undervoltage protection is also required for motor starters. The starter contactor normally provides this protection as it drops out when the supply voltage is lost is drastically reduced. The starter circuit will not normally allow the motor to re-start when the voltage supply is restored except when special automatic re-starting facilities are provided.

Undervoltage protection can be electromagnetic or electronic.

Checking and calibration of generator undervoltage relays can only be done accurately by calibrated voltage injection. A known variable voltage is directly applied to the undervoltage relay to check:

- The voltage at which the relay pulls-in
- The voltage at which the relay drops-out

Generator U/V relays are usually slugged to allow a time-delay which prevents spurious tripping during transient voltage dips (typically 15%) caused by large motor starting currents.

8. Emergency power

An emergency power system is a standby generator which may include lighting, electric generators, fuel cells, uninterruptible power supplys and other apparatus, to provide backup power resources in a crisis or when regular systems fail.

They find uses in a wide variety of settings from residential homes to hospitals, scientific laboratories, data centers, telecommunication equipment and modern naval ships. Emergency power systems can rely on generators, deep cycle batteries, flywheel energy storage or hydrogen fuel cells. Finally, some homebrew emergency power systems use regular lead-acid car batteries

Operation in buildings

Mains power can be lost due to downed lines, malfunctions at a sub-station, inclement weather, planned blackouts or in extreme cases a grid-wide failure. In modern buildings, most emergency power systems have been and are still based on generators. Usually, these generators are Diesel engine driven, although smaller buildings may use a gasoline engine driven generator and larger ones a gas turbine. However, lately, more use is being made of deep cycle batteries and other technologies such as flywheel energy storage or fuel cells. These latter systems do not produce polluting gases, thereby allowing the placement to be done within the building. Also, as a second advantage, they do not require a separate shed to be built for fuel storage.

With regular generators, an automatic transfer switch is used to connect emergency power. One side is connected to both the normal power feed and the emergency power feed; and the other side is connected to the load designated as emergency. If no electricity comes in on the normal side, the transfer switch uses a solenoid to throw a triple pole, single throw switch. This switches the feed from normal to emergency power. The loss of normal power also triggers a battery operated starter system to start the generator, similar to using a car battery to start an engine. Once the transfer switch is switched and the generator starts, the building's emergency power comes back on (after going off when normal power was lost.)

Unlike emergency lights, emergency lighting is not a type of light fixture; it is a pattern of the building's normal lights that provides a path of lights to allow for safe exit, or lights up service areas such as mechanical rooms and electric rooms. Exit signs, Fire alarm systems (that are not on back up batteries) and the electric motor pumps for the fire sprinklers are almost always on emergency power. Other equipment on emergency power may include smoke isolation dampers, smoke evacuation fans, elevators, handicap doors and outlets in service areas. Hospitals use emergency power outlets to power life support systems and monitoring equipment. Some buildings may even use emergency power as part of normal operations, such as a theater using it to power show equipment because "the show must go on."

Electronic device protection

Computers, communication networks, and other modern electronic devices need not only power, but also a steady flow of it to continue to operate. If the source voltage drops significantly or drops out completely, these devices will fail, even if the power loss is only for a fraction of a second. Because of this, even a generator back-up does not provide protection because of the start-up time involved.

To achieve more comprehensive loss protection, extra equipment such as surge protectors, inverters, or sometimes a complete uninterruptible power supply (UPS) is used. UPS systems can be local (to one device or one power outlet) or may extend building-wide. A local UPS is a small box that fits under a desk or a telecom rack and powers a small number of devices. A building-wide UPS may take any of several different forms, depending on the application. It directly feeds a system of outlets designated as UPS feed and can power a large number of devices.

Since telephone exchanges use DC, the building's battery room is generally wired directly to the consuming equipment and floats continuously on the output of the rectifiers that normally supply DC rectified from utility power. When utility power fails, the battery carries the load without needing to switch. With this simple though somewhat expensive system, some exchanges have never lost power for a moment since the 1920s.

Structure and operation in utility stations

In recent years, large units of a utility power station are usually designed on a unit system basis in which the required devices, including the boiler, the turbine generator unit, and its power (step up) and unit (auxiliary) transformer are solidly connected as one unit. A less common set-up consists of two units grouped together with one common station auxiliary. As each turbine generator unit has its own attached unit auxiliary transformer, it is connected to the circuit automatically. For starting the unit, the auxiliaries are supplied with power by another unit (auxiliary) transformer or station auxiliary transformer. The period of switching from the first unit transformer to the next unit is designed for automatic, instantaneous operation in times when the emergency power system needs to kick in. It is imperative that the power to unit auxiliaries not fail during a station shutdown (an occurrence known as black-out when all regular units temporarily fail). Instead, during shutdowns the grid is expected to remain operational. When problems occur, it is usually due to reverse power relays and frequency-operated relays on grid lines due to severe grid disturbances. Under these circumstances, the emergency station supply must kick in to avoid damage to any equipment and to prevent hazardous situations such as the release of hydrogen gas from generators to the local environment.

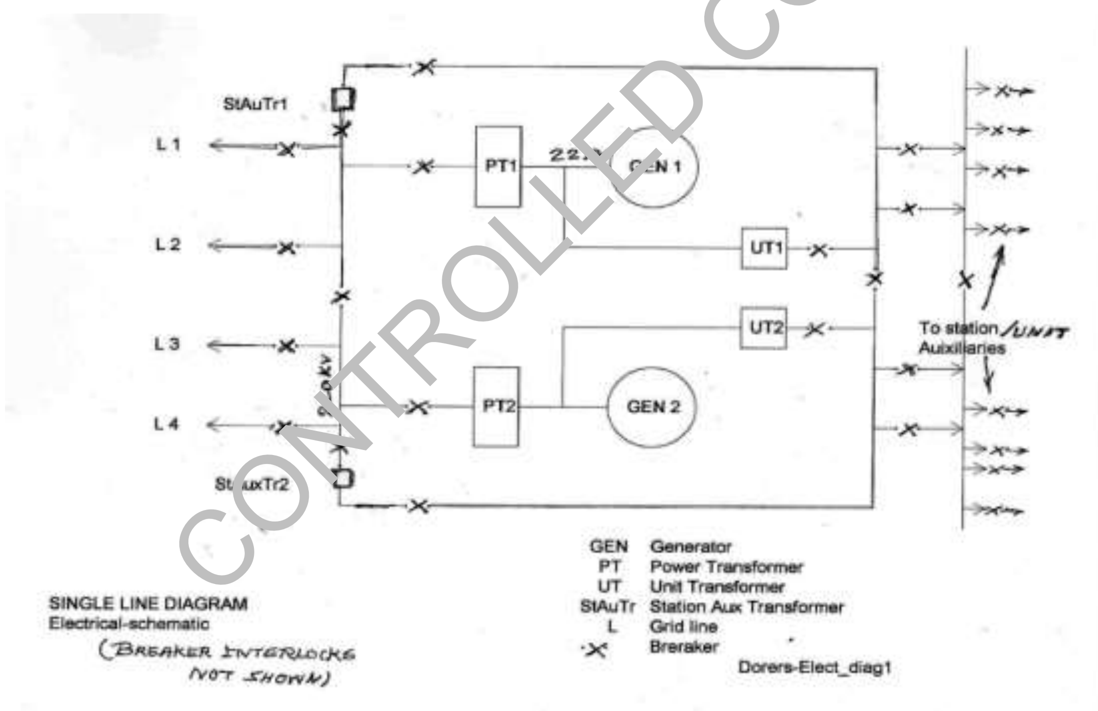


Diagram of a redundant power supply system.

Controlling the emergency power system

For a 208 VAC emergency supply system, a central battery system with automatic controls, located in the power station building itself, is used to avoid long electric supply wires. This central battery system consists of lead-acid battery cell units to make up a 12 or 24 VDC system as well as stand-by cells, each with its own battery charging unit. Also needed are a voltage sensing unit capable of receiving 208 VAC and an automatic system that is able to signal to and activate the emergency supply circuit in case of failure of 208 VAC station supply.

2.1.4 DESIGN FEATURES OF HIGH-VOLTAGE INSTALLATIONS

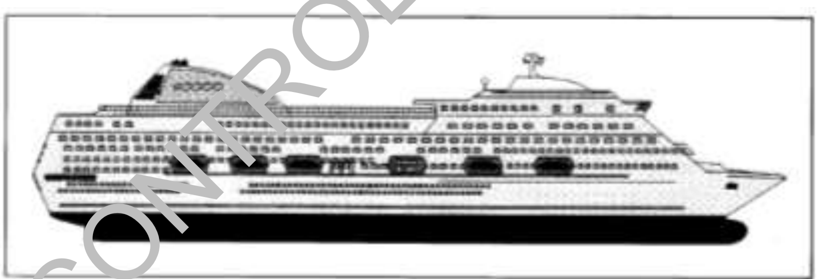
.1 Design features of high voltage installations

The earliest electric propulsion for ships was demonstrated in Russia in 1832 with a d.c. motor powered from a battery. In 1886 an electrically propelled vessel called the Volta crossed the English Channel. By 1888 the improvements to batteries and motors led to the first commercial applications in passenger launches on the River Thames in London.

As with road transport, electric river boats were soon eclipsed by the arrival of the internal combustion engine.

Electric propulsion for many new ships is now re-established as the popular choice where the motor thrust is governed by electronic switching under computer control.

The high power required for electric propulsion usually demands a high voltage (HV) power plant with its associated safety and testing procedures.



Passenger cruise ship with electric propulsion

Electric Propulsion Scheme

Electric propulsion of ships has a long but somewhat chequered history. There have been periods when it has enjoyed popularity, with a significant number of installations being undertaken, whilst at other times it has been virtually ignored as a drive system.

Passenger ships have always been the largest commercial vessels with electric propulsion and, by their nature, the most glamorous. This should not, however, obscure the fact that a very wide variety of vessels have been, and are, built with electric propulsion.

Early large passenger vessels employed the turboelectric system which involves the use of variable speed, and therefore variable frequency, turbo-generator sets for the supply of electric power to the propulsion motors directly coupled to the propeller shafts. Hence, the generator/motor system was acting as a speed reducing transmission system.

Electric power for auxiliary ship services required the use of separate constant frequency generator sets.

A system that has generating sets which can be used to provide power to both the propulsion system and ship services has obvious advantages, but this would have to be a fixed voltage and frequency system to satisfy the requirements of the ship service loads.

The provision of high power variable speed drives from a fixed voltage and frequency supply has always presented problems. Also, when the required propulsion power was beyond the capacity of a single d.c. motor there was the complication of multiple motors per shaft.

Developments in high power static converter equipment have-presented a very convenient means of providing variable speed a.c. and d.c. drives at the largest ratings likely to be required in a marine propulsion system.

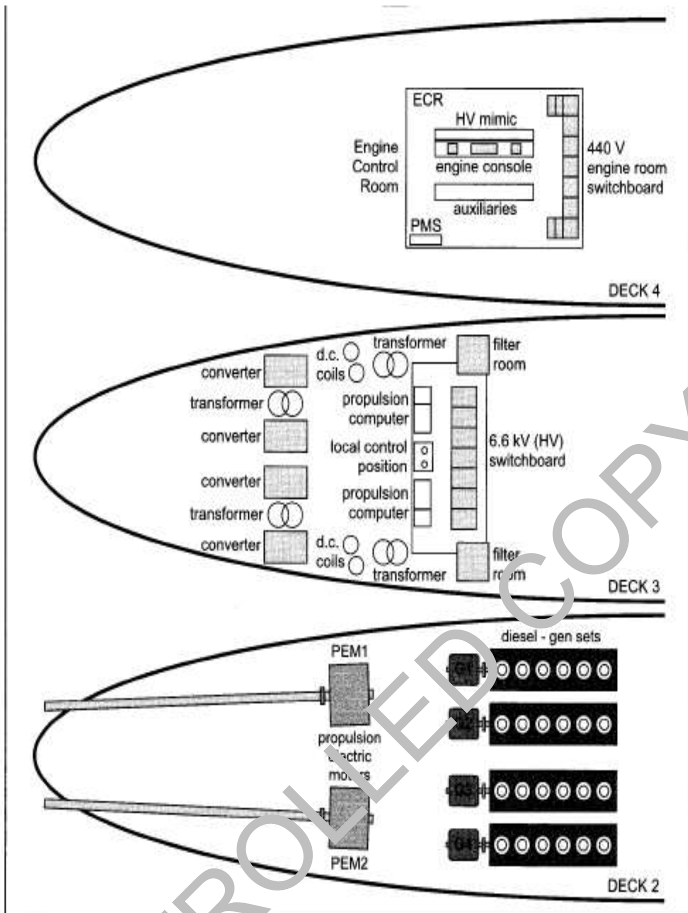
The electric propulsion of ships requires electric motors to drive the propellers and generator sets to supply the electric power. It may seem rather illogical to use electric generators, switchgear and motors between the prime-movers (e.g. diesel engines) and propeller when a gearbox or length of shaft could be all that is required.

There are obviously sound reasons why, for some installations, it is possible to justify the complication of electric propulsion and some of the reasons advanced are:

- Flexibility of layout
- Load diversity between ship service load and propulsion
- Economical part-load running
- Ease of control
- Low noise and vibration characteristics

Flexibility of layout

The advantage of an electric transmission is that the prime-movers, and their generators, are not constrained to have any particular relationship with the load as a cable run is a very versatile transmission medium. In a ship propulsion system it is possible to mount the diesel engines, gas turbines etc., in locations best suited for them and their associated services, so they can be remote from the propeller shaft.



Propulsion pant layout

Diesel generator sets in containers located on the vessel main deck have been used to provide propulsion power and some other vessels have had a 10 MW generator for ship propulsion duty mounted in a block at the stern of the vessel above the ro-ro deck. An example of an electric propulsion plant layout (for a large cruise ship).

Another example of the flexibility provided by an electric propulsion system is in a semi-submersible, with the generators on the main deck and the propulsion motors in the pontoons at the bottom of the support legs.

Load diversity

Certain types of vessels have a requirement for substantial amounts of electric power for ship services when the demands of the propulsion system are low. Tankers are one instance of this situation and any vessel with a substantial cargo discharging load also qualifies.

Passenger vessels have a substantial electrical load which, although relatively constant, does involve a significant size of generator plant. There are advantages in having a single central power generation facility which can service the propulsion and all other ship loads as required.

Economical part-load running

Again this is a concept that is best achieved when there is a central power generation system feeding propulsion and ship services, with passenger vessels being a good example.

It is likely that a typical installation would have between 4-8 diesel generator sets and with parallel operation of all the sets it becomes very easy to match the available generating capacity to the load demand. In a four engine installation for example, increasing the number of sets in operation from two that are fully loaded to three partially loaded will result in the three sets operating at a 67% load factor which is not ideal but also not a serious operating condition.

It is not necessary to operate generating sets at part-load to provide the spare capacity to be able to cater for the sudden loss of a set, because propulsion load reduction may be available instantaneously, and in- most vessels a short time reduction in propulsion power does not constitute a hazard.

The propulsion regulator will continuously monitor the present generator capability and any generator overload will immediately result in controlled power limitation to the propulsion motors. During manoeuvring, propulsion power requirements are below system capacity and failure of one generator is not likely to present a hazardous situation.

Ease of control

The widespread use of controllable pitch propellers (cpp) has meant that the control facilities that were so readily available with electric drives are no longer able to command the same premium.

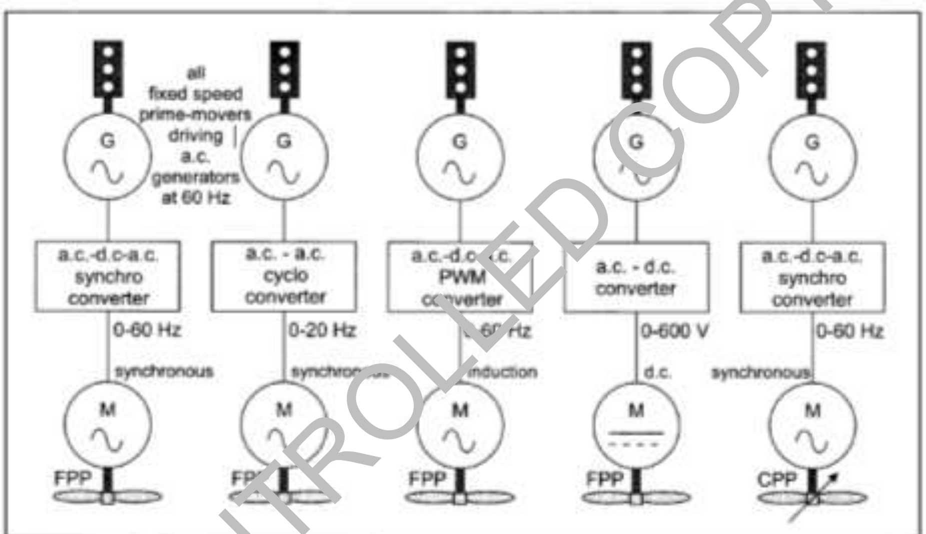
Electric drives are capable of the most exacting demands with regard to dynamic performance which, in general, exceed by a very wide margin anything that is required of a ship propulsion system.

Low noise

An electric motor is able to provide a drive with very low vibration characteristics and this is of importance in warships, oceanographic survey vessels and cruise ships where, for different reasons, a low noise signature is required.

With warships and survey vessels it is noise into the water which is the critical factor whilst with cruise ships it is structure borne noise and vibration to the passenger spaces that has to be minimised.

An overview of practical electric drive options.



Electric propulsion options

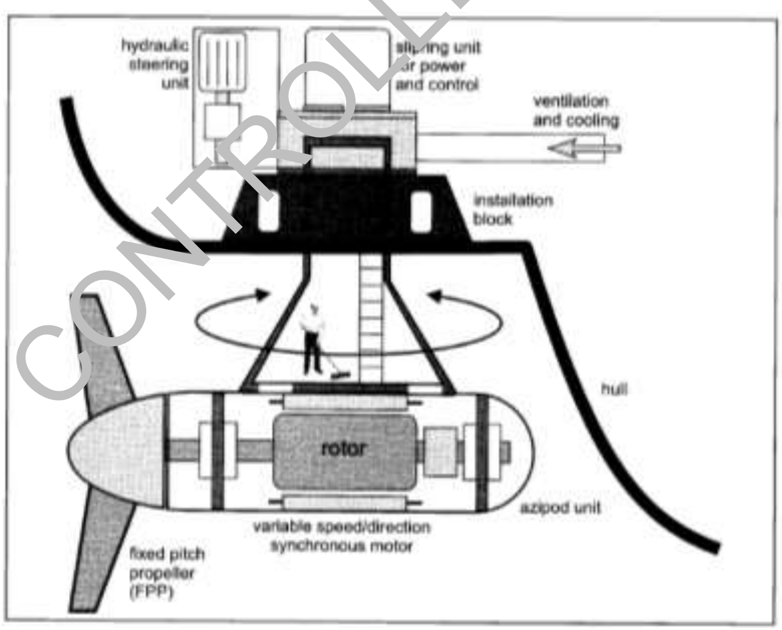
For very high power, the most favoured option is to use a pair of high efficiency, high voltage a.c. synchronous motors with fixed pitch propellers (FPP) driven at variable speed by frequency control from electronic converters. A few installations have the combination of controllable pitch propellers (CPP) and a variable speed motor. Low/medium power propulsion (1-5 MW) may be delivered by a.c. induction motors with variable frequency converters or by d.c. motors with variable voltage converters.

The prime-movers are conventionally constant speed diesel engines driving a.c. generators to give a fixed output frequency. Gas turbine driven prime-movers for the generators are likely to challenge the diesel option in the future.

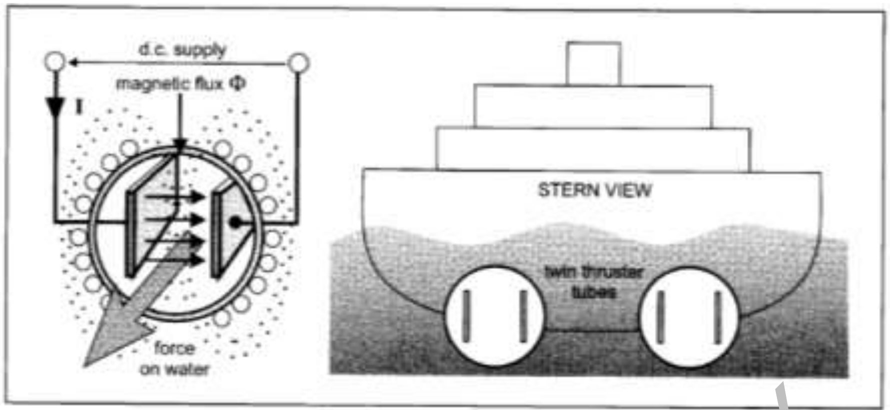
Conventionally, the propeller drive shaft is directly- driven- from the propulsion electric motor (PEM) from inside the ship. From experience obtained from smaller external drives, notably from ice-breakers, some very large propulsion motors are being fitted within rotating pods mounted outside of the ships hull. These are generally referred to as azipods, as the whole pod unit can be rotated through 360o to apply the thrust in any horizontal direction, i.e. in azimuth. This means that a conventional steering plate and stern side-thrusters are not required.

Ship manoeuvrability is significantly enhanced by using azipods and the external propulsion unit releases some internal space for more cargo/passengers while further reducing hull vibration.

Gradual progress in the science and application of superconductivity suggests that future generators and motors could be super-cooled to extremely low temperatures to cause electrical resistance to become zero. In this condition, the electrical power losses (I'R) are also zero so it is possible to drive extremely large currents (> 100,000 A) through very thin wire coils to create an exceptionally large magnetic field. The combination of a large current and a large magnetic field will produce a very large electromagnetic force as $F \infty \phi .I$. One way of applying such a direct force into the water for ship propulsion (a long-term ongoing experiment in Japan).



Azipod drive unit



Linear electric propulsion

A large d.c. current is driven between metal plates mounted in a open tube below the hull. The conductor for this current is the sea water. Coils of wire at a superconducting temperature (e.g - 269" C cooled by helium) are fitted around the propulsion tube to create a magnetic field 90º to the current flow.

The combination of current and magnetic field produces a direct mechanical force on the conductor (water) to create a linear thrust without the need for a rotating propeller. By dividing port and starboard thrust tubes into short sections along the hull, the size and location of thrust can be distributed so that conventional steering and side thrusters are not required. This is a very interesting experiment into the direct application of electromagnetic force for ship propulsion.

Review of Motor Operation

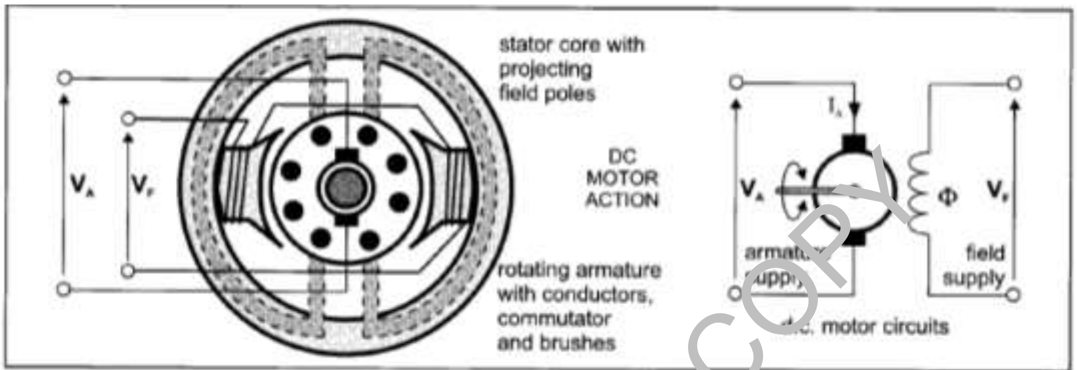
Electric motors may be of the for ship propulsion duty d.c. or a.c. type. The a.c. versions may be the induction or synchronous models. The following is a brief review of the basic action and control possibilities for the various types.

- **d.c. motors**

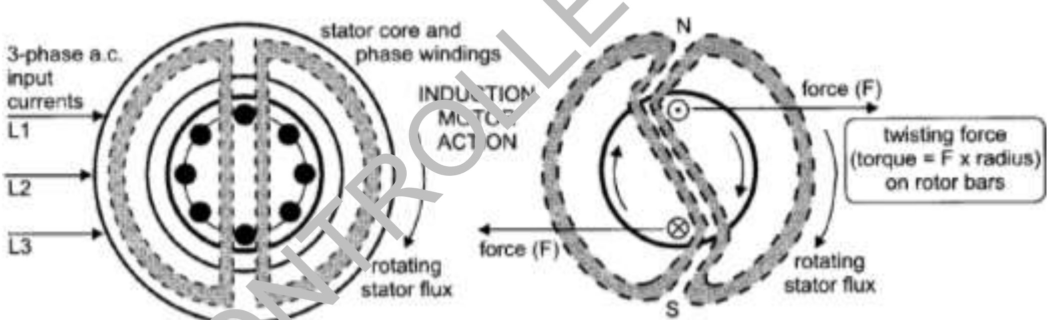
The d.c. motor drive is still used where very high torque and/or precise speed control is acquired. Traction drives such as electric trains, submarines and offshore drilling rigs use d.c. motors. The torque is governed by: $T \alpha \phi . I_A$ and the speed is due to: $n \alpha V/\phi$ where ϕ is the magnetic field flux and I_A is the armature current.

As the armature current and field flux can be independently controlled, the d.c. motor is able to provide very useful torque/speed characteristics for power drives.

The major drawback of a d.c. motor is that the necessary switching of the armature current is achieved by a mechanical "commutator" on the rotating shaft. Apart from the maintenance required for the commutator and its carbon brushes, the applied voltage for the armature is limited to about 750 V d.c. Many regional "Metro" train systems run at 1500 V d.c. where two d.c. motors are connected in series across the supply voltage.



d.c. motor circuit



Induction motor action

- a.c. motors

*induction type

The most common motor drive is a three phase a.c. induction motor with a cage-rotor because it is extremely robust as-there are no electrical connections to the rotor.

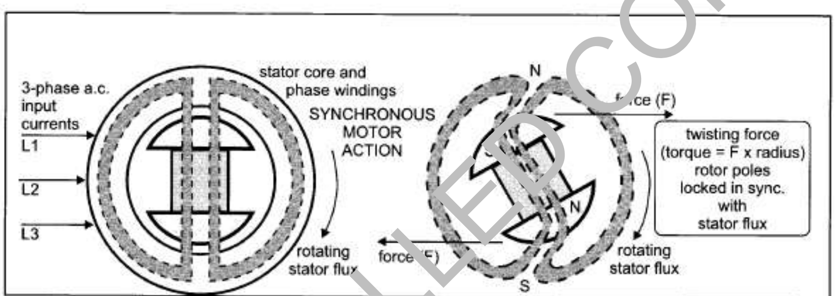
Three time-displaced supply currents to the three stator windings produce a rotating magnetic field which induces currents into the cage winding on the rotor. The interaction of stator flux ϕ and rotor current I_R produces a torque on the shaft from $T \alpha \phi . I_R . \cos\theta$ where θ is the phase angle between ϕ and I_R. To be able to induce currents into the rotor, its running speed must be slightly lower than that of the stator rotating field. This difference is called the slip speed and ranges between about 1-5% over the load range for a standard induction motor.

The speed n_s (synchronous speed) of the rotating flux produced by the stator is fixed by the number of winding pole-pairs "p" and the supply frequency "f" as: $n_s = f/P$ (rev/s).

- synchronous type

This is a three phase motor that produces a magnetic field rotating at a speed of $n_s = f/p$ (rev/s) just like the induction motor type.

The rotor has a set of magnetic poles with d.c. excitation which locks in synchronism with the stator rotating flux.



Synchronous motor action

This means that the shaft is always running at the synchronous speed set by the supply frequency.

To start the motor from standstill can be a problem - it is either:

- Pulsed forward at a very low frequency with the rotor poles excited, or
- Dragged up to slip speed as an induction motor with an embedded cage rotor then locked into synchronism by energising the d.c. rotor field.

For normal running, the operating power factor of a synchronous motor can be lagging or leading as this is determined by the size of the d.c. excitation field current.

- Basic speed control of motors

Many industrial installations can benefit from direct and smooth speed control of a drive which is moving the process material (water, compressed air, oil, conveyor belts, lifts etc.). Smooth, controlled acceleration and deceleration also reduces shock loading in the system.

For a d.c. motor on a fixed voltage supply, this is easily achieved by using resistance in the armature or field circuits to control the armature current or field flux (or both). The disadvantage is the overall loss of efficiency due to the power losses in the external control resistance(s).

For an a.c. induction motor or synchronous motor on a fixed voltage and frequency supply, resistance control would only affect the size of operating current but the speed is constant due to the fixed supply frequency. This can only be overcome by changing the frequency of the stator supply currents.

To prevent overheating (by over-fluxing) of the motor while frequency changing, the supply voltage must be changed in direct proportion.

- Advanced speed control

Computer controlled variable speed drives (VSDs) are now applied to d.c. and a.c. motor types of all sizes. The most popular application is for induction motors for the main industrial power range but synchronous motors are used in large installations e.g. marine electric propulsion.

The a.c. motor drives produce a variable frequency output by fast voltage switching from a transistor or thyristor converter which may be ac-dc-ac (PWM and synchroconverter) or ac-ac (cycloconverter). These drives use a mathematical model of the motor and the computer controls the converter output to precisely match the set inputs for speed, torque, acceleration, deceleration, power limits etc.

Such drives may even be tuned to create optimum conditions for run-up/ down, braking and energy savings against the connected shaft load.

- Problems arising

The fast switching (or chopping) of the voltages to VSDs will produce a distorted waveform which includes high frequency harmonic components whose frequencies are exact multiples of the fundamental (base frequency) value.

For example a 7th harmonic of a 60 Hz fundamental will be at 420 Hz. Such harmonics create additional heating in equipment and possible interference (often called radio frequency interference or RFI).

Practical solutions to a harmonic problem include good initial system design, filtering and suppression.

Converter Types

The processes of controlled rectification and inversion are used in converters that are designed to match the drive motor.

The principal types of motor control converters are:

- a.c.---- d.c. (controlled rectifier for d.c. motors)
- a.c.---d.c.---a.c. (PWM for induction motors)
- a.c.---d.c.---a.c. (synchroconverter synchronous motors)
- a-.c.---a.c. (cycloconverter for synchronous motors)

These are examined below.

- a.c.---d.c. converter

This is a three phase a.c. controlled rectification circuit for a d.c. motor drive. Two converters of different power ratings are generally used for the separate control of the armature current (I_A) and the field current which produces the magnetic flux (ϕ).

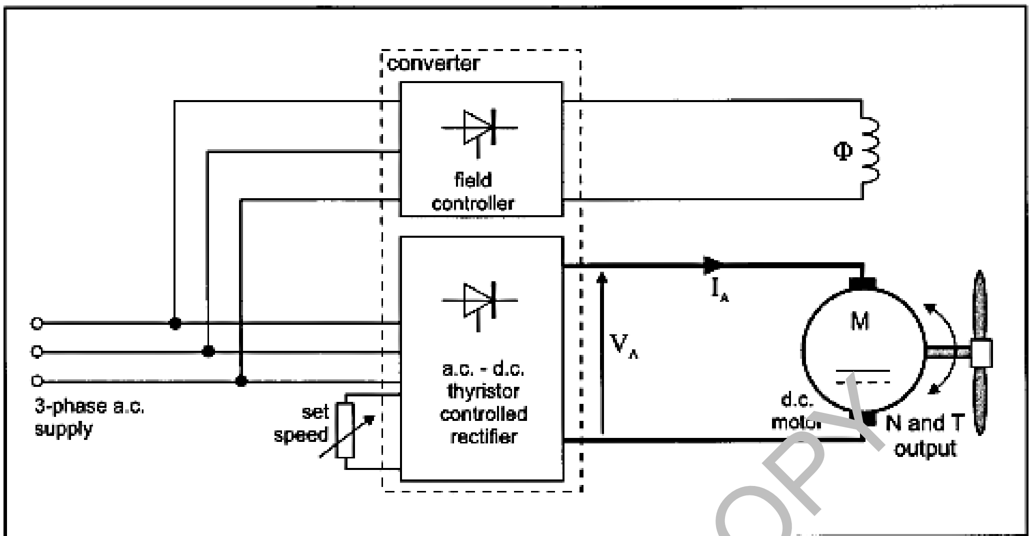
Some systems may current may have a field current which means that the field supply only requires an uncontrolled diode bridge as shown in Figure.

Motor torque is determined from $T \alpha \phi . I_A$ and the speed is controlled from $N \alpha V_A/\phi$. Shaft rotation can be achieved by reversing either the field current or the armature current direction. Ship applications for such a drive would include cable-laying, offshore drilling, diving and supply, ocean survey and submarines.

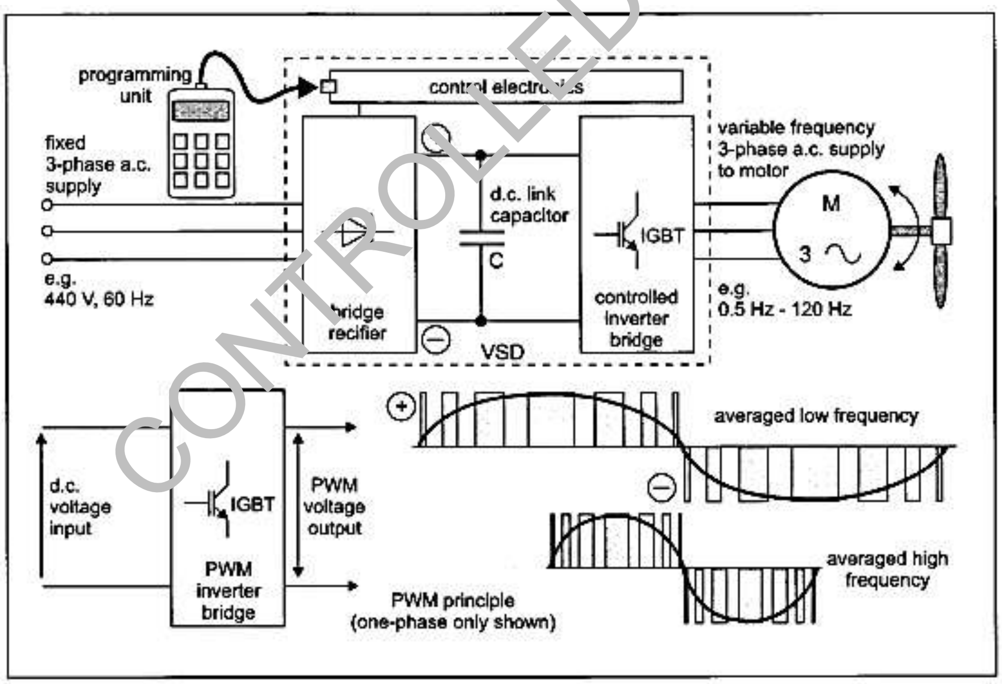
- a.c.---d.c.---a.c. PWM converter

This type of converter is used for induction motor drives and uses transistors as the switching devices. Unlike thyristors, a transistor can be turned on and off by a control signal and at a high switching rate.

The input rectifier stage is not controlled so is simpler and cheaper but the converter will not be able to allow power from the motor load to be regenerated back into the mains supply during a braking operation. From a 440 V a.c. supply, the rectified d.c. (link) voltage will be smoothed by the capacitor to approximately 600 V.



Controlled rectification converter and d.c. motor



PWM converter and a.c. induction motor

The d.c. voltage is chopped into variable width, but constant level, voltage pulses in the computer controlled inverter section using IGBTs (insulated gate bipolar transistors). This process is called pulse width modulation or PWM.

By varying the pulse widths and polarity of the d.c. voltage it is possible to generate an averaged sinusoidal a .c. output over a wide range of frequencies typically 0.5-120Hz. Due to the smoothing effect of the motor inductance, the motor currents appear to be nearly sinusoidal in shape. By sequentially directing the currents into the three stator windings, a reversible rotating magnetic field is produced with its speed set by the output frequency of the PWM converter.

Accurate control of shaft torque, acceleration time and resistive braking are a few of the many operational parameters that can be programmed into the VSD, usually via a hand-held unit. The VSD can be closely tuned to the connected motor drive to achieve optimum control and protection limits for the overall drive. Speed regulation against load changes is very good and can be made very precise by the addition of feedback from a shaft speed encoder.

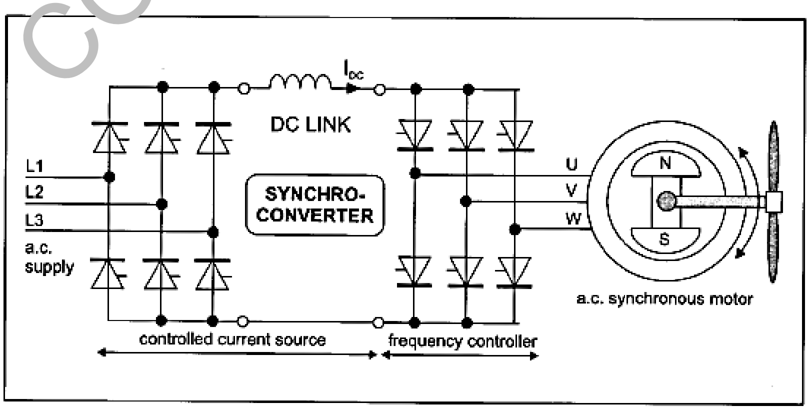
VSDs, being digitally controlled, can be easily networked to other computer devices e.g. programmable logic controllers (PLCs) for overall control of a complex process.

- a.c.---d.c.---a.c. synchroconverter

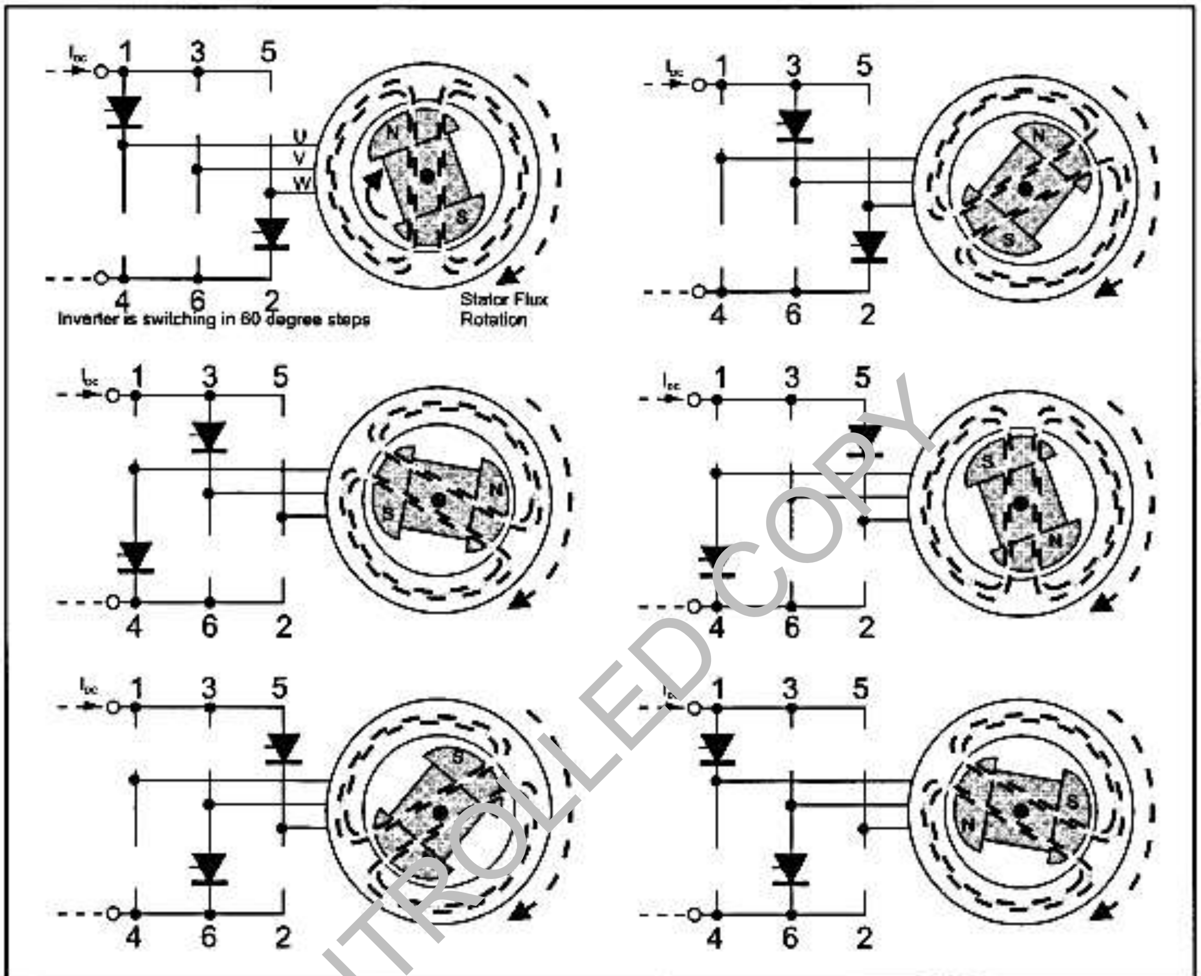
This type of converter is used for large a.c. synchronous motor drives (called a synchrodrive) and is applied very successfully to marine electric propulsion. A synchroconverter, as shown in Figure, has controlled rectifier and inverter stages which both rely on natural turn-off (line commutation) for the thyristors by the three phase a.c. voltages at either end of the converter.

Between the rectification and inversion stages is a current-smoothing reactor coil forming the d.c. link.

An operational similarity exists between a synchrodrive and a d.c. motor drive.



Synchroconverter circuit



Inverter current switching sequence

This view considers the rectifier stage as a controlled d.c. supply and the inverter/synchronous motor combination as a d.c. motor. The switching inverter acting as a static commutator.

The combination of controlled rectifier and d.c. link is considered to be a current source for the inverter whose task is then to sequentially direct blocks of the current into the motor windings as shown in Figure.

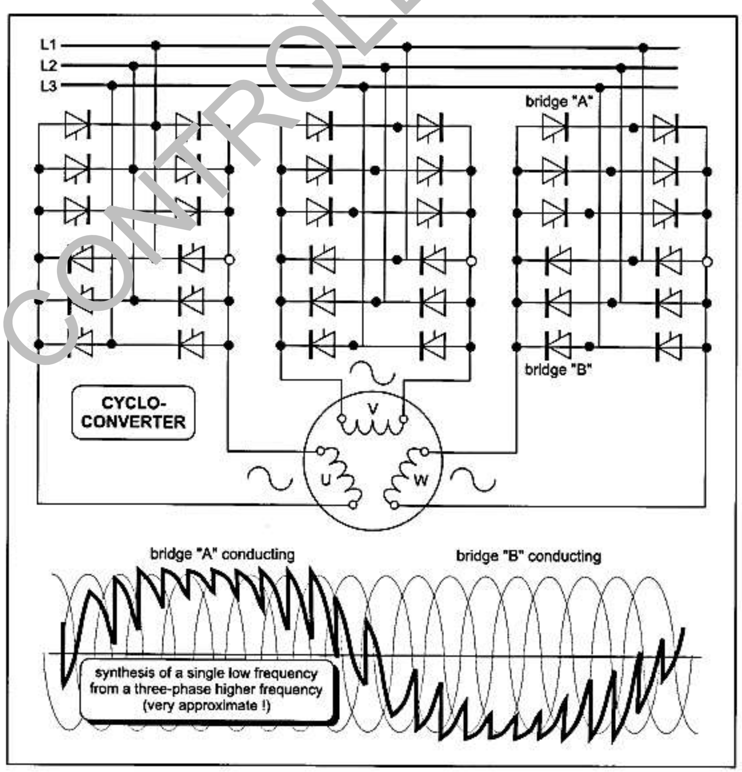
The size of the d.c. current is set by the controlled switching of the rectifier thyristors. Motor supply frequency (and hence its speed) is set by the rate of inverter switching. The six inverter thyristors provide six current pulses per cycle (known as a six-pulse converter).

A simplified understanding of synchroconverter control is that the current source (controlled rectification stage) provides the required motor torque and the inverter stage controls the required speed. To provide the motor e.m.f. which is necessary for natural commutation of the inverter thyristors, the synchronous motor must have rotation and magnetic flux in its rotor poles. During normal running, the synchronous motor is operated with a power factor of about 0.9 leading (by field excitation control) to assist the line commutation of the inverter thyristors. The d.c. rotor field excitation is obtained from a separate controlled thyristor rectification circuit.

As the supply (network) and machine bridges are identical and are both connected to a three-phase a.c. voltage source, their roles can be switched into reverse. This is useful to allow the regeneration of motor power back into the mains power supply which provides an electric braking torque during a crash stop of the ship.

- a.c. ---a.c. cycloconverter

While a synchroconverter is able to provide an output frequency range typically up to twice that of the mains input (e.g. up to 1.20 Hz), a cycloconverter is restricted to a much lower range.



Cycloconverter circuit and output voltage waveform

This is limited to less than one third of the supply frequency (e.g. up to 20 Hz) which is due to the way in which this type of converter produces the a.c. output voltage wavefoim. Ship propulsion shaft speeds are typically in the range of 0-145 rev/min which can easily be achieved by the low frequency output range of a cycloconverter to a multi-pole synchronous motor. Power regeneration from the motor back into the main power supply is available.

A conventional three phase converter from a.c. to d.c. can be controlled so that the average output voltage can be increased and decreased from zero to maximum within a half-cycle period of the sinusoidal a.c. input. By connecting two similar converters back-to-back in each line art a.c. output frequency is obtained. The switching pattern for the thyristors varies over the frequency range which requires a complex computer program for converter control.

The diagram gives a basic circuit arrangement for a cycloconverter together with an approximate voltage Waveform for the low frequency output.

The corresponding current waveform shape (not shown) will be more sinusoidal due to the smoothing effect of motor and line inductance.

The output voltage has a significant ripple content which gets larger (worse) as the output frequency is raised and it is this feature that limits the maximum useful frequency.

There is no connection between the three motor windings because the line converters have to be isolated from each other to operate correctly to obtain line commutation (natural) switching of the thyristors.

The converters may be directly supplied from the HV line but it is more usual to interpose step-down transformers.

This reduces the motor voltage and its required insulation level while also providing additional line impedance to limit the size of prospective fault current and harmonic voltage distortion at the main supply bus-bar.

Propulsion System Operation

This section describes the overall operation of a propulsion system and is based on a diesel-electric arrangement with synchroconverter frequency control.

For a large ship, the power system will employ high voltage (HV) generation as in the diagram.

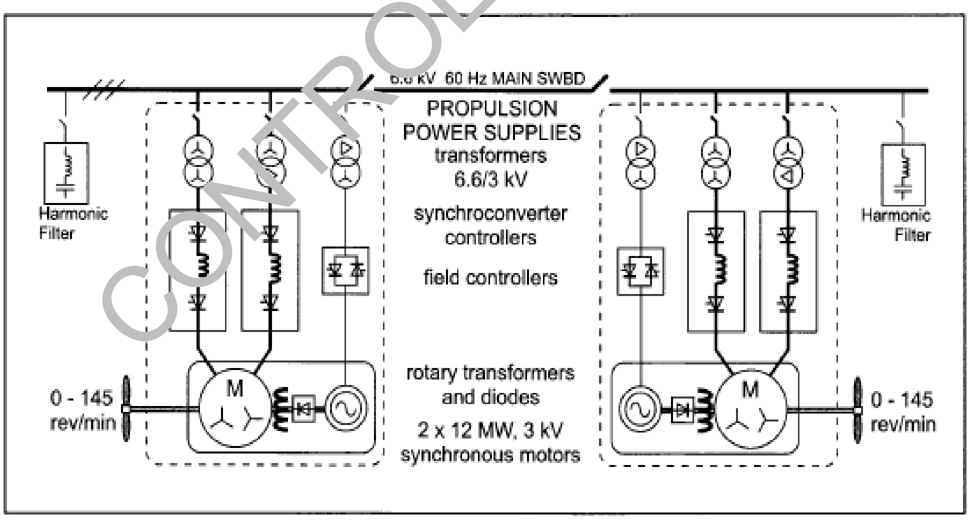
In this example each L2 MW, 3 kV propulsion motor has two separate 6 MW stator windings and each half winding is supplied from a 6.613.0 kV propulsion transformer and a static six-pulse synchroconverter. The 24 pole motors have a shaft speed range of 0-145 rev/min controlled from the converter output frequency range of 0-29 Hz.

By using two converters feeding two separate stator windings fitted 30o apart, a 12-pulse shaft torque is achieved to minimise shaft vibration. A more complicated arrangement of supply transformers and converters can produce a 24-pulse shaft torque.

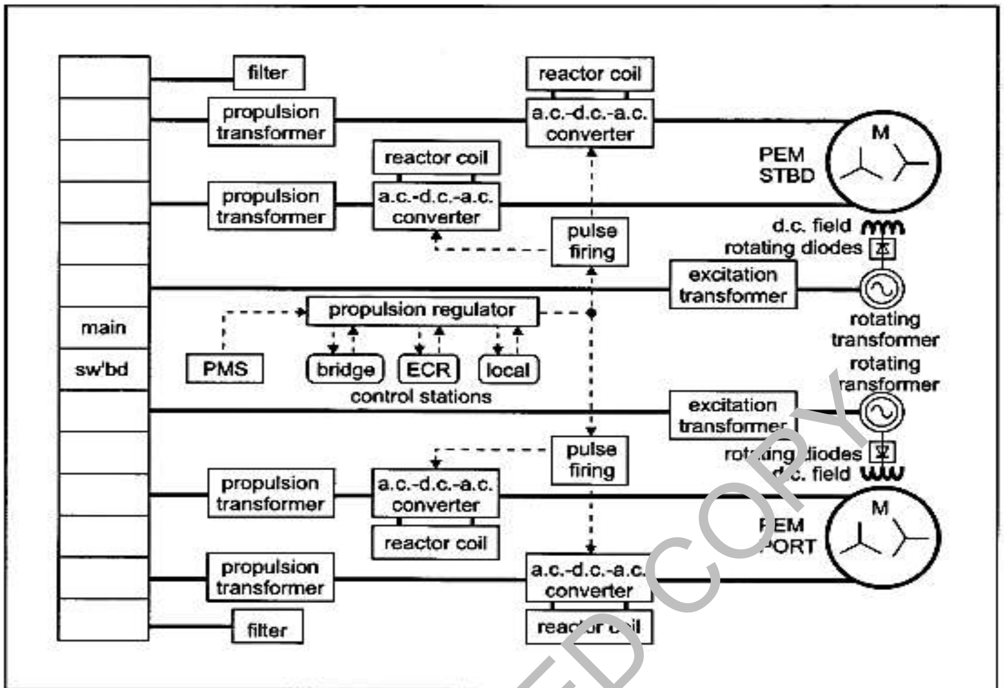
Motor brushless excitation is also obtained from the HV bus-bars via a 6.6/0.44 kV static transformer, a thyristor controller, an a.c.---a.c. rotary transformer (inside the motor) and a set of shaft mounted diodes for the final conversion to d.c. A third (standby) static excitation supply and controller is available but not shown in the diagram.

The related physical arrangement of the main components in the propulsion system are shown in the next figure.

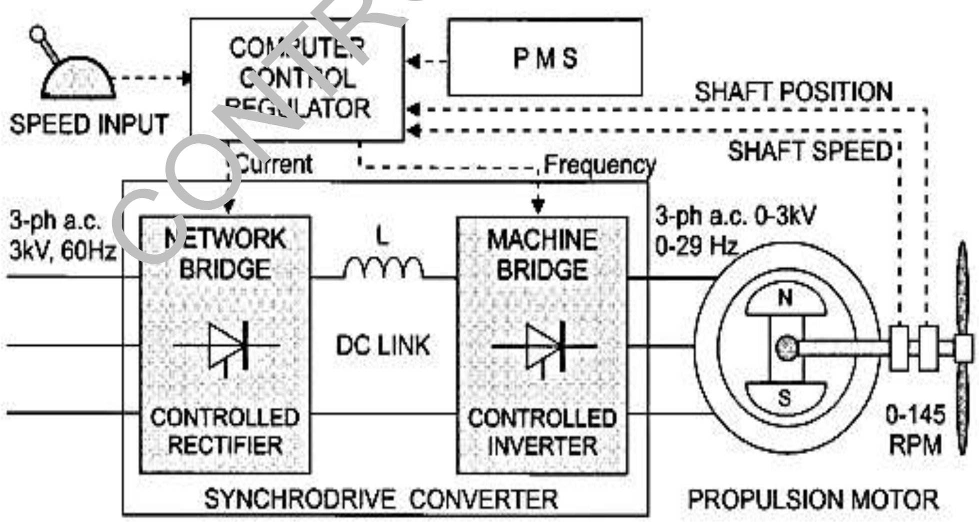
Control throttle stations for both shafts are installed on the bridge (in wheelhouse and on the wings), engine control room and local (in HV switchboard room) positions. At sea the shaft speed commands are set from the bridge and repeated in the ECR. In port the control position is transferred to the ECR. The local control position is mainly used for testing and maintenance duties but also acts as an emergency control station.



Propulsion power system



Interconnection of main propulsion components



Propulsion motor control scheme

Selection of the command position is determined by a switch on the propulsion console in the ECR.

An emergency push-button telegraph giving set speed commands (dead-slow, half-ahead etc.) is available at each control station. The ship propulsion regulator and side-thruster regulators can be combined into a master joy-stick controller to give overall directional control for accurate manoeuvring in port.

In a synchrodrive system as shown in the figure, the computer receives a command (set speed) input and many feedback signals (voltage, current, power, frequency etc.) but the obvious regulating item is the actual shaft speed feedback forming a closed control loop. The principal parameters to be controlled are the size of motor stator current (to set motor torque) and the motor frequency to set the shaft speed. In addition, the d.c. motor field current has to be continually controlled from the propulsion regulator via the excitation converter.

In normal running and full-away with both propulsion motor speeds within 5% of each other, the bridge can select a shafts synchro-phasing mode which applies momentary acceleration/deceleration to bring the propeller blades into an alignment which minimises shaft vibration into the hull.

Speed and position are derived from detectors on the non-drive end of the motor shaft.

At speeds of less than 10%, the motor does not generate sufficient back e.rn.f. to cause automatic thyristor switch-off (line commutation) Remember that a thyristor can only switch off when its current becomes zero. This problem is overcome by pulse-mode operation where the current is momentarily forced to zero by the thyristors in the controlled rectifier stage. This allows the inverter thyristors to turn-off so that the controller can regain control. The decision is now which thyristor and which sequence of. switching is required to maintain the required shaft direction of rotati6n. It is necessary to know exactly the position of the rotor poles and this is provided by the shaft position encoder for low-speed, pulse-mode operation. When kicked above 10% speed, the motor e.m.f. will be large enough to allow the converter to revert to its normal line-commutation mode for synchronous operation For normal running, above about l0% speed, the operation is switched to synchronous mode where the thyristors in both bridges are switched off naturally (line commutated) by their live a.c. voltages from supply and motor.

To reverse the shaft rotation the forward/ahead phase sequence of motor supply currents is reversed by the inverter thyristors. This reverses the direction of stator flux rotation and hence shaft direction to astern. The rate of deceleration to zero speed must be carefully controlled before a shaft reversal to avoid large power surges in the system.

For a motor braking operation, the inverter bridge can be considered as a rectifier bridge when viewed from the live a.c. supply produced by the motor emf. If the network (rectifier) bridge thyristors are switched with a delay angle greater than 90º the d.c. link voltage reverses causing power flow from the motor back to the supply (motor braking). In this mode the roles of the network and machine bridges are swapped over.

Overall system power control is provided by a computer controlled power management system (PMS) which effectively co-ordinates power demand with its supply.

Broadly, the PMS functions are:

- Control of:
  - Automatic power limitation for propulsion motors
  - Auto-start, synchronising and load sharing of standby generators
  - Control of re-generation from the propulsion motors during braking and reversing manoeuvres
  - Power limitation for main generators
  - Load shedding by preferential tripping
  - Dynamic limitation of propulsion motor acceleration

- Monitoring of:
  - Load sharing
  - Diesel performance
  - Proposal to start/stop a generator
  - Running time for generators and
  - propulsion motors
  - Status and data display

.2 Operational safety of high voltage installations.

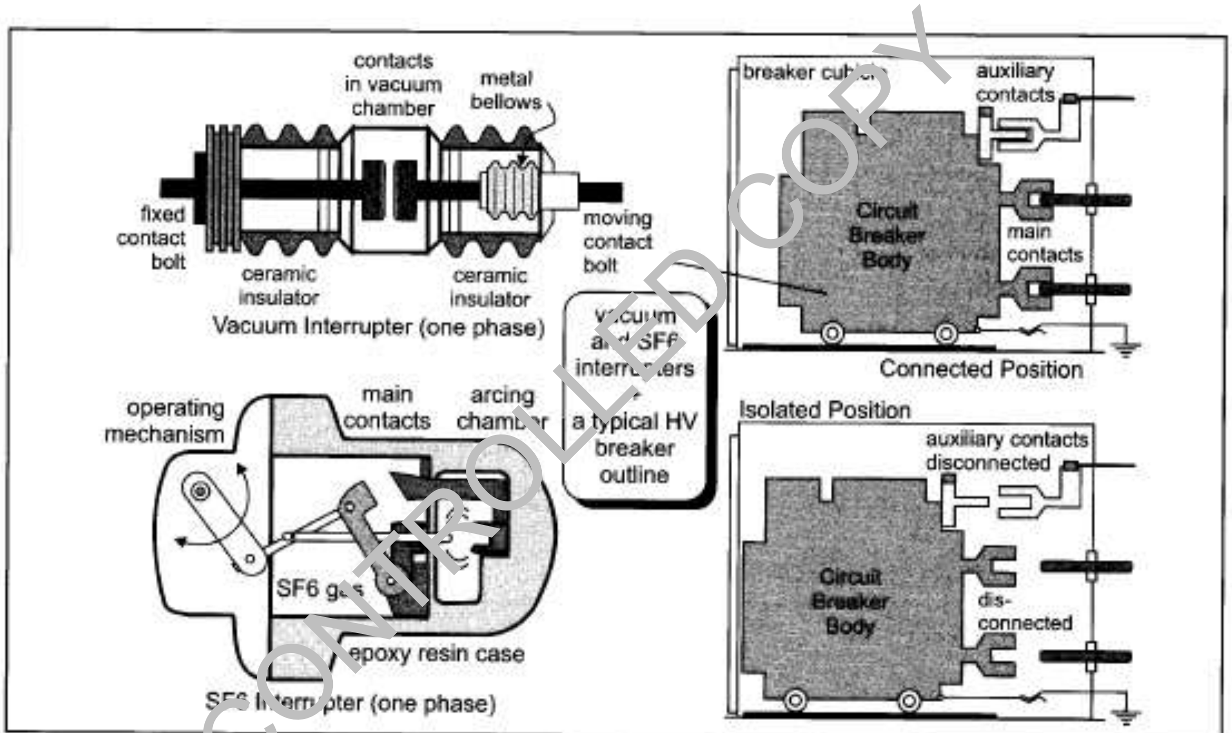
For ships with a large electrical Power demand it is necessary to utilise the benefits of a high voltage (FIV) installation.

For marine practice, HV means > 1000 V. The design benefits relate to the simple ohms law relationship that current size (for a given power) is reduced as the voltage is increased.

Working at high voltage significantly reduces the relative overall size and weight of electrical power equipment. HV levels of 3.3 kV, 6.6 kV and 11 kV are regularly employed ashore for regional power distribution and industrial motor drives.

The main disadvantage perceived by the user/maintainer, when working in an HV installation, is the very necessary adherence to stringent safety procedures.

In the ships power network shown in Figure, all of the equipment indicated above the dotted line is considered as HV. For the purposes of safety, this includes the LV field system for a propulsion motor as it is an integrated part of the overall HV equipment. From lhe HV generators, the network supplies HV motors (for propulsion, side thrusters and air conditioning compressors) and the main transformer feeders to the 440 V switchboard. Further distribution links are made to interconnect with the emergency switchboard.



Vacuum and SF6 interrupters and circuit breaker positions

- HV Circuit breakers and contactors

Probably the main difference between a HV and an LV system occurs at the HV main switchboard. For HV, the circuit breaker types may be air-break, oil-break, gas-break using SF6 (sulphur hexafluoride) or vacuum-break. Of these types, the most popular and reliable are the vacuum interrupters, which may also be used as contactors in HV motor starters. See Figure above.

Each phase of a vacuum circuit breaker or contactor consists of a fixed and moving contact within a sealed, evacuated envelope of borosilicate glass. The moving contact is operated via flexible metal bellows by a charging motor/spring or solenoid operating mechanism. The high electric strength of a vacuum allows a very short contact separation, and a rapid restrike-free interruption of the arc is achieved.

When an alternating current is interrupted by the separating contacts, an arc is formed by u metal vapour from the material on the contact surfaces and this continues to flow until a current zero is approached in the a.c. wave form. At this instant the arc is replaced by a region of high dielectric strength which is capable of withstanding a high recovery voltage. Most of the metal vapour condenses back on to the contacts and is available for subsequent arcing.

A small amount is deposited on the shield placed around the contacts which protects the insulation of the enclosure.

As the arcing period is very short (typically about 15 ms), the arc energy is very much lower than that in air-break circuit-breakers so vacuum contacts suffer considerably less wear.

Because of its very short contact travel a vacuum interrupter has the following advantages:

- compact quiet unit
- minimum maintenance
- non-flammable and non-toxic

The life of the unit is governed by contact erosion but could be up to 20 years.

In the gas-type circuit breaker, the contacts are separated in an SF_6 (sulphur hexafluoride) gas which is typically at a sealed pressure chamber at 500 kPa or 5 bar (when tested at 20ºC).

- HV Insulation Requirements

The HV winding arrangements for generators, transformers and motors are similar to those at LV except for the need for better insulating materials such as Micalastic or similar.

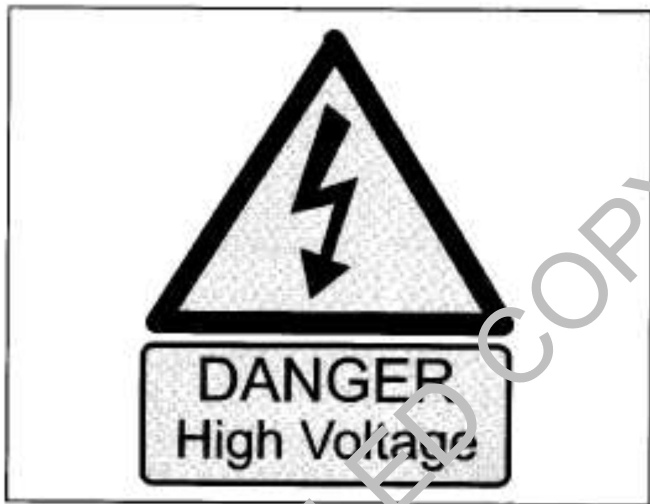
The HV windings for transformers are generally insulated with an epoxy resin/powdered quartz compound. This is a iron-hazard6us material which is maintenance free, humidity resistant and tropicalised.

Conductor insulation for an HV cable requires a more complicated design than is necessary for an LV type. However, less copper area is required for HV conductors which allows a significant saving in space and weight for an easier cable installation. Where the insulation is air (e.g. between bare-metal live parts and earth within switchboards and in terminal boxes) greater clearance and creepage distances are necessary in HV equipment.

High Voltage Safety

Making personal contact with any electric voltage is potentially dangerous.

At high voltage (> 1000 V) levels the electric shock potential is lethal. Body resistance decreases with increased voltage level which enhances the current flow. Remember that an electric shock current as low as 15 mA can be fatal.



HV warning notice

The risk to people working in HV areas is greatly minimised by the diligent application of sensible general and company safety regulations and procedures.

Personnel who are required to routinely test and maintain HV equipment should be trained in the necessary practical safety procedures and certified as qualified for this duty.

Approved safety clothing, footwear, eye protection and hard hat should be used where danger may arise from arcs, hot surfaces and high voltage etc.

The access to HV switchboards and equipment must be strictly controlled by using a permit-to-work scheme and isolation procedures together with live-line tests and earthing-down before any work is started. The electrical permit requirements and procedures are similar to permits used to control access in any hot-work situation, e.g. welding, cutting, burning etc. in a potentially hazardous area.

All work to be carried out on HV equipment is subject to an Electrical Permit to Work (EPTW).

- EPTW

The format of a permit will vary for different companies and organisations.

The broad guidelines for the necessary declarations and procedures are outlined below:

Before work is commenced on HV equipment an EPTW must be issued.

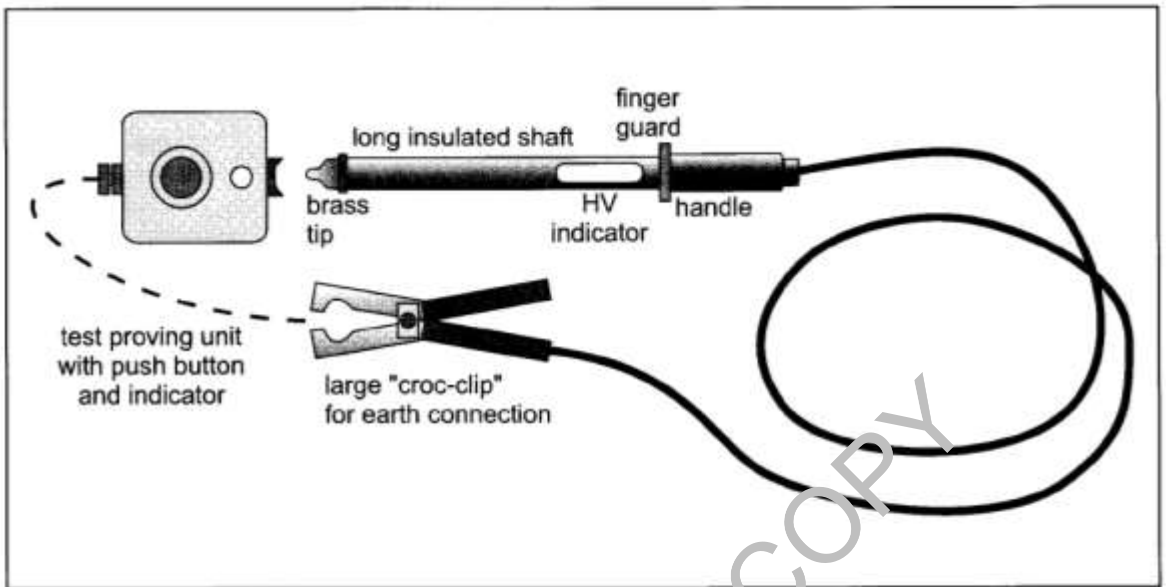
This permit is usually the last stage of a planned maintenance task which has been discussed, prepared and approved by the authorising officer to be carried out by the responsible person. The carbon-copied permit, signed by the responsible person, usually has at least five sections with the first stating the work to be carried out. The next section is a risk assessment declaring where electrical isolation and earthing has been applied and where danger/caution notices have been displayed then the permit is signed as authorised by the Chief Electrotechnical Officer (CETO) or Chief Engineer. In the third section, the person responsible for the work (as named in section one) signs to declare that he/she is satisfied with the safety precautions and that the HV circuit has been isolated and earthed.

Section four relates to the suspension or completion of the designated work.

Finally, the last section cancels the permit with a signature from the authorizing officer. A Permit-to-Work is usually valid only for 24 hours.

Some marine and offshore companies will also require an associated Electrical lsolation Certificate to declare and record exactly where the circuit isolation and earthing has been applied before the EPTW can be authorised. A Sanction to-Test safety certificate may also be required when an electrical test (e.g. an electrical insulation test) is to be applied.

This is necessary as the circuit earth generally has to be removed during such testing. Before earthing-down the particular circuit or equipment declared in the EPTW it must be tested and proved dead after disconnection and isolation.



HV live-line testing components

This can only be carried out by using an approved live-line tester as shown in Figure above. The tester itself must be proven before and after such a test. This is checked by connecting the tester to a known HV source (supplied either as a separate battery operated unit or included as an internal self-test facility).

Two people should always be together when working on HV equipment.

- Earthing-down

Before work can be allowed to commence on HV equipment it must be earthed to the hull for operator safety. As an example, consider the earthing arrangements at an HY switchboard.

Here, the earthing-down method is of two types:

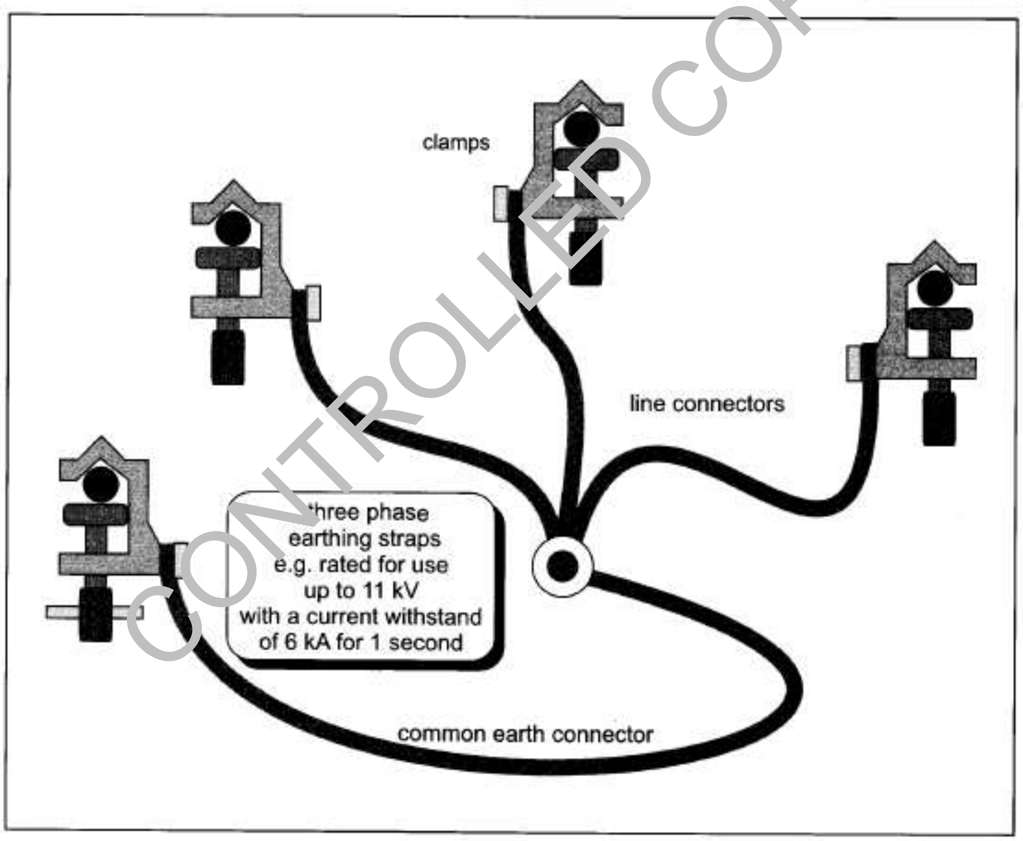
- Circuit Earthing:

After disconnection from the live supply, an incoming or outgoing feeder cable is connected by a manually operated switch to connect all three conductors to earth. This action then releases a permissive-key to allow the circuit breaker to be withdrawn to the TEST position. The circuit breaker cannot be re-inserted until the earth has been removed and the key restored to its normal position.

- Bus-bar Earthing:

When it is necessary to work on a section of the HV switchboard bus-bars, they must be isolated from all possible electrical sources. This will include generator incomers, section or bus-tie breakers and transformers (which could back-feed) on that bus-bar section. Earthing down is carried out at a bus-section breaker compartment after satisfying the permissive key exchanges. In some installations the application of a bus-bar earth is by a special earthing circuit breaker which is temporarily inserted into the switchboard solelv for the bus-bar earthing duty.

For extra confidence and operator safety, additional earthing can be connected local to the work task with approved portable earthing straps and an insulated extension tool, e.g. at the terminals of an HV motor as shown in Figure below.



Portable earthing connectors

2.1.5 FEATURES OF PNEUMATIC AND HYDRAULIC CONTROL EQUIPMENT

The high voltage (e.g.6.6 kV) installation covers the generation, main supply cables, switchgear, transformers, electric propulsion (if fitted) and a few large motors e.g. for side-

thrusters and air conditioning compressors. For all electrical equipment the key indicator to its safety and general condition is its insulation resistance (IR) and this is
particularly so for HV apparatus. The IR must be tested periodically between phases and between phases and earth.
HV equipment that is well designed and maintained, operated within its power and temperature ratings should have a useful insulation life of 20 years.

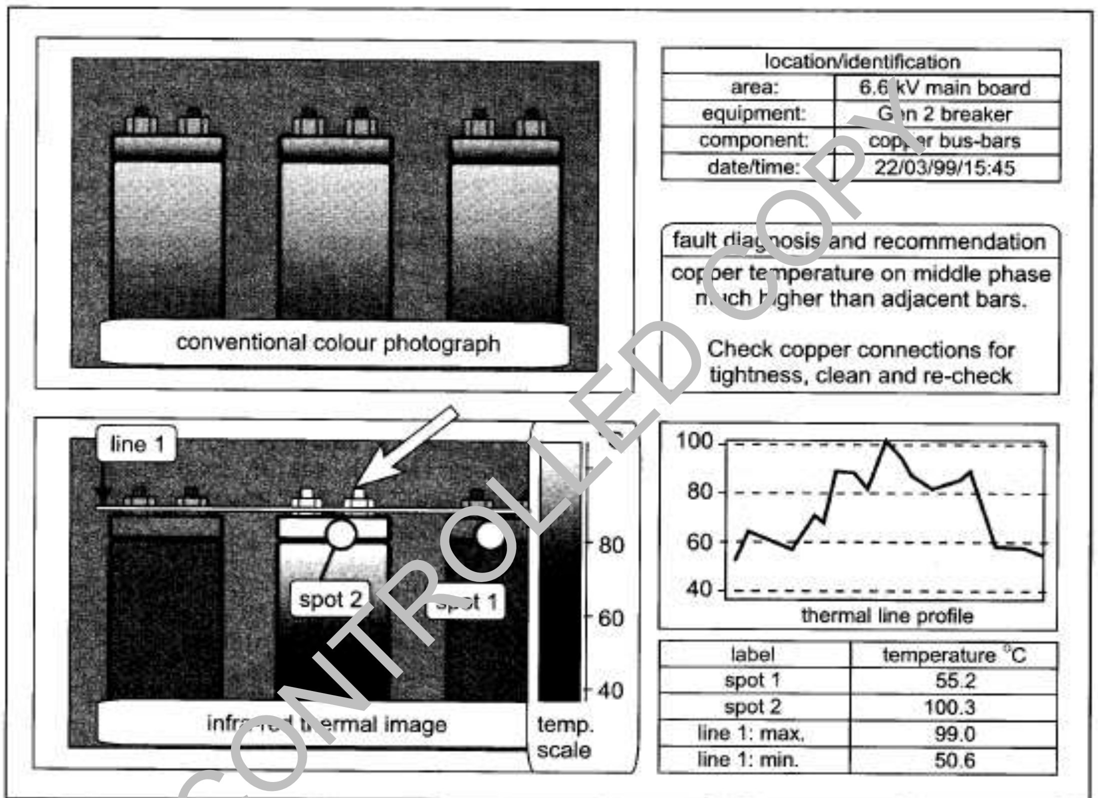
An IR test is applied with a high d.c. voltage which applies a reasonable stress to the dielectric material (insulation).
For 6.5 kV rated equipment, a periodical 5000 V d.c. insulation resistance (megger) test is recommended. The IR test should be applied for one minute and temperature corrected to a standard of 40ºC. The minimum IR value is usually recommended as (kV + 1) MΩ where kV is the equipment voltage rating. e.g. 7.6 MΩ would be an acceptable IR value for a 6.6 kV machine. For machines with healthy insulation, an IR test result may indicate a value up to L00 times greater than the recommended minimum.
A more involved IR test (the polarization index or P.I.) is used when the insulation value may be suspect or recorded during an annual survey. The P.I. value is the ratio of the IR result after 10 minutes of testing to the value recorded after one minute. For class F insulation materials the recommended P.I. value is 2.0. To apply a P.I. test over a ten minute period requires a special IR tester that has a motor-driven generator or an electronic converter powered from a local 220 V a.c. supply.

The condition of HV insulation is governed by many factors such as temperature, humidity, surface condition and operating voltage level. Be guided by the manufacturers recommendations when testing and maintaining HV insulation.
Before applying an IR test to HV equipment its power supply must be switched off, isolated, confirmed dead by an approved live-line tester and then earthed for complete safety in accordance with the current EPTW regulations.

The correct procedure is to connect the IR tester to the circuit under test with the safety earth connection ON.
The safety earth may be applied through a switch connection at the supply circuit breaker or by a temporary earth connection local to the test point. This is to ensure that the operator never touches a unearthed conductor. With the IR tester now connected, the safety earth is disconnected (using an insulated extension tool for the temporary earth).
Now the IR test is applied and recorded. The safety earth is now reconnected before the IR tester is disconnected.
This safety routine must be applied for each separate IR test.
Large currents flowing through machine windings, cables, bus-bars and main circuit breaker contacts will cause a temperature rise due to I2R resistive heating. Where overheating is suspected, e.g. at a bolted bus-bar joint in the main switchboard, the local continuity resistance may be measured and checked against the manufacturers recommendations or compared with similar equipment that is known to be satisfactory. A normal ohmmeter is not suitable as it will only drive a few mA through the test circuit. A special low resistance tester

or micro-ohmmeter (traditionally called a ducter) must be used which drives a calibrated current (usually I: 10 A) through the circuit while measuring the volt-drop (V) across the circuit. The meter calculates R from V/I and displays the test result. For a healthy bus-bar joint a continuity of a few mΩ would be expected.

Normally the safe testing of HV equipment requires that it is disconnected from its power supply. Unfortunately, it is very difficult, impossible and unsafe to closely observe the on-load operation of internal components within HV enclosures. This is partly resolved by temperature measurement with an recording infra-red camera from a safe distance.



Infrared image testing

The camera is used to scan an area and the recorded infra-red image is then processed by a computer program to display hot-spots and a thermal profile across the equipment. To examine internal components, e.g. bus-bar joints, a camera recording can be made immediately after the equipment has been switched off and isolated in accordance with an EPTW safety procedure. Alternatively, some essential equipment, e.g. a main switchboard, can be monitored on-line using specially fitted and approved enclosure windows suitable for infra-red testing. These windows are small apertures with a permanently fixed steel mesh through which the camera can view the internal temperature from a safe position. An outer steel plate fixed over the window mesh maintains the overall enclosure performance during normal operation.

A conventional photograph of the equipment is taken simultaneously to match the infra-red image and both are used as part of a test report. Such testing is usually performed by a

specialist contractor who will prepare the test report and propose recommendation/ repair advice to the ship operator.
In the Figure above (unfortunately not in colour like the original) gives typical results from an infra-red camera test on a bus-bar connection.
In this on-line test, the camera recorded hot-spot temperatures up to 100ºC and the report recommended that this copper connection is checked for tightness as it is running very hot compared to that on the neighbouring copper-work.

To test the insulating integrity of an HV vacuum-type circuit breaker requires a special high voltage impulse test. The tester produces a short duration voltage pulse, of typically 10 kV for a 6.6 kV circuit, which is connected across the open breaker contacts. Any weakness in the insulating strength of the vacuum in the interrupter chamber will be detected as a current flow and the tester will display the condition as a pass or fail.
Gas (SF6) HV circuit breakers rely on the quality and pressure of the gas acting as the insulation between the contacts. A falling gas pressure can be arranged to initiate an alarm from pressure switches fitted to each switching chamber. Normal gas pressures are typically 500 kPa or 5 bar.
Overall circuit protection of HV equipment is supervised by co-ordinated protective relays. These must be periodically tested to confirm their level settings (for current, voltage, frequency etc.) and their tripping times. This requires the injection of calibrated values of current and voltage into the protective relays which is usually performed by u specialist contractor during a main ship survey while in dry-dock.

2.2 MANAGE TROUBLESHOOTING AND RESTORATION OF ELECTRICAL AND ELECTRONIC CONTROL EQUIPMENT TO OPERATING CONDITION

Practical knowledge

2.2.1 TROUBLESHOOTING OF ELECTRICAL AND ELECTRONIC CONTROL EQUIPMENT

1. Electrical safety

Large power equipment and processes utilise high forces. Electrical, mechanical, thermal and chemical changes produce the desired operation. Very high values of voltage, current, power, temperature, force, pressure etc. create the possibility of danger in an engineering system.

To minimise the safety risk to personnel and equipment a system must be designed and manufactured to the latest high standards and be correctly installed.

During its working life the equipment must be continuously monitored and correctly maintained by professionally qualified personnel who understand its operation and safety requirements.

Before attempting any electrical work, there are some basic safety precautions you must bear in mind. The possible dangers arising from the misuse of electrical equipment are well known.

Electric shock and fire can cause loss of life and damage to equipment.

Regulations exist to control the construction, installation, operation and maintenance of electrical equipment so that danger is eliminated as f.ar as possible. Minimum acceptable standards of safety are issued by various bodies including national governments, international governmental conventions (e.g. SOLAS), national and international standards associations (e.g. BS and IEC), learned societies (e.9. IEE), classification societies (e.g. Lloyds), etc. Where danger arises it is usually due to accident, neglect or some other contravention of the regulations.

Ships' staff must operate equipment in a safe manner and maintain it in a safe condition at all times. Failure to do so will cause danger with serious consequences arising. Keep in mind an essential list of DO's and DO NOT's when working with electrical equipment:

- DO get to know the ship's electrical system and equipment. Study the ship's diagrams to pinpoint the location of switches and protection devices supplying distribution boards and essential items of equipment. Write down this information in a note book. Become familiar with the normal indications on switchboard instruments so that abnormal operation can be quickly detected.
- DO operate equipment according to the manufacturer's recommendations.
- DO maintain equipment according to the manufacturer's recommendations or the shipowner's maintenance procedures.
- DO ensure that all guards, covers and doors are securely fitted and that all bolts and fixings are in place and tight.
- DO inform the Officer of the Watch before shutting down equipment for maintenance.
- DO switch off and lock-off supplies, remove fuses, and display warning notices before removing covers of equipment for maintenance.
- DO confirm that circuits are DEAD (by using an approved voltage tester) before touching conductors and terminals.
- DO NOT touch live conductors under any pretext
- DO NOT touch rotating parts.
- DO NOT leave live conductors or rotating parts exposed.
- DO NOT overload equipment.
- DO NOT neglect or abuse equipment.

You should think SAFETY at all times and so develop a safety conscious attitude.

This may well save your life and the lives of others. Most accidents occur due to a momentary loss of concentration or attempts to short-circuit standard safety procedures.

DO NOT let this happen to YOU.

2. Circuit Testing

At the various electrical circuit testing operations you may need to carry out, and at the instruments you will need.
The main tests are for:

Insulation Resistance (IR)	Using a (megger) tester (at 500 V d.c. for a 440 V circuit) Do not use a multimeter for this task
Continuity Resistance (Low Ω)	Typically using a multimeter
Component Resistance (Ω or kΩ)	
Voltage (a.c. or d.c.)	
Current	Using a clampmeter (or multimeter for small currents)

Insulation Testing

A measurement of the insulation resistance (IR) gives one of the best guides to the state of health of electrical equipment. The resistance should be measured between insulated conductors and earth, and between conductors.
An insulation tester is a high reading resistance meter using a high test voltage - usually 500 V d.c. The test voltage is produced either by an internal hand-driven generator or by u battery and electronic voltage charger. A test voltage of 500 V d.c.

is suitable for testing ships' equipment rated at 400 V a.c. Test voltages of 1000 V and 5000 V are used for high voltage (Fry systems on board ship.

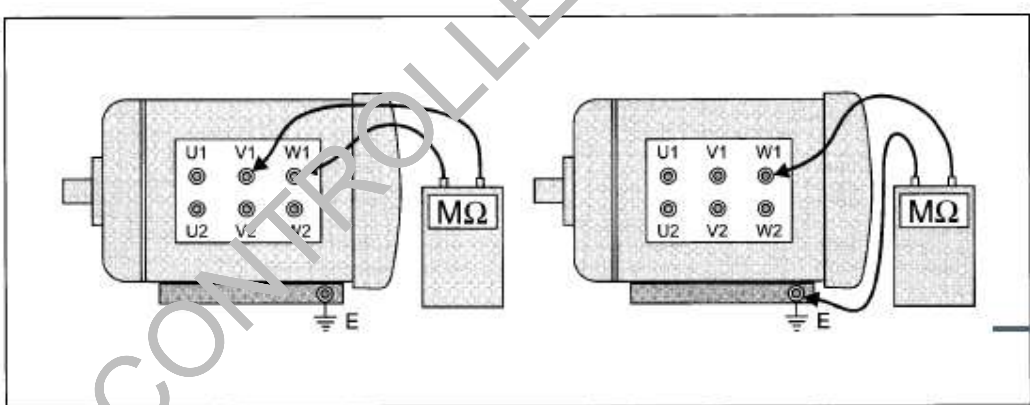
There are several manufacturers of insulation testers available but the Megger trade name is known worldwide. To prove the basic operation of the tester, short the two probes together, switch to "Ω" and press the test button or rockerswitch. The pointer should indicate approximately "0Ω".

Before applying the test, the equipment to be tested must be disconnected from the live power supply and locked-off according to standard safety procedures.

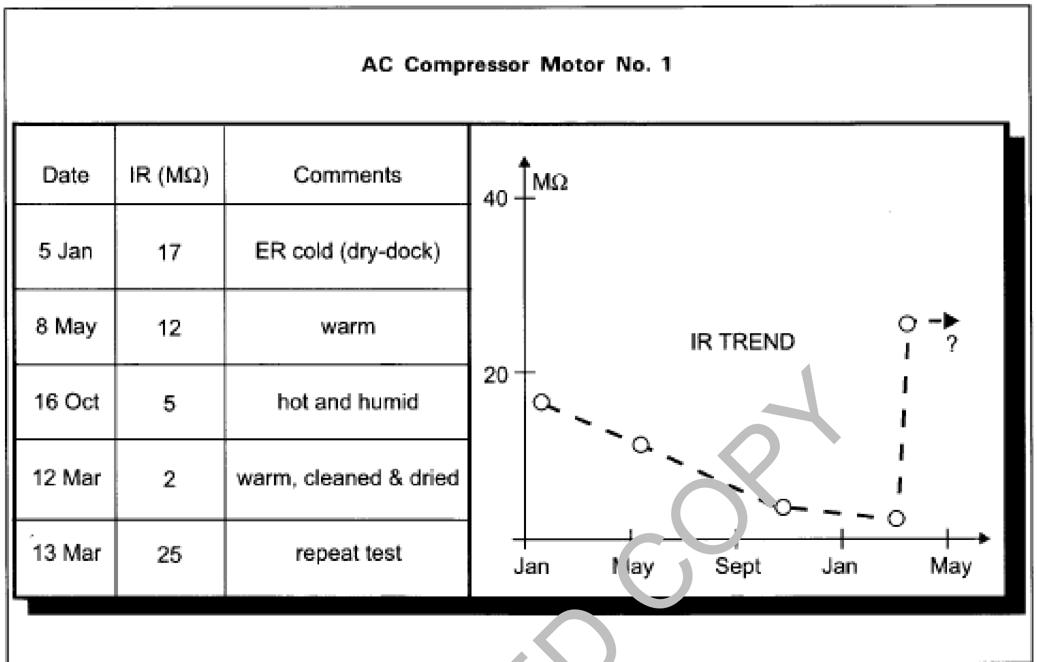
A megger type IR tester can be used to check whether the circuit to be tested is live. Switch the instrument to "MΩ" and connect the probes to pairs of equipment terminals. DO NOT press the button. The meter will now indicate that the circuit is live or not. If the circuit is dead it is then safe to press the test button. Confirm that a reliable earth connection is obtained by connecting the probes to two separate earth points on the equipment frame while testing for low resistance continuity.

For an IR test on a three-phase machine, measure and log the phase-to-phase insulation resistance values.

Three readings should be measured as U-V, V-W, W-U as shown in the figure below.



IR test connections


AC Compressor Motor No. 1

Date	IR (MΩ)	Comments
5 Jan	17	ER cold (dry-dock)
8 May	12	warm
16 Oct	5	hot and humid
12 Mar	2	warm, cleaned & dried
13 Mar	25	repeat test

IR log and trend

Measure and log the phase-to earth insulation resistance values. Three readings should be measured as U-E, V-E, W-E:
Note: Insulation resistance decreases with increase of temperature.

Continuity Testing
An insulation tester normally also incorporates a low voltage continuity test facility. This is a low resistance instrument-for measuring the continuity (or otherwise) of conductors. It can be used to measure the low resistance of cables, motor windings, transformer windings, earthing straps, etc. The procedure for use is similar to that for the insulation tester.

- PROVE the correct operation of the instrument.
- ISOLATE and lock off the equipment to be tested.
- PROVE the equipment to be dead.
- Switch the instrument to "Ω" or "continuity".
- Connect the probes to the circuit.

In the case of three-phase motors and transformers, etc. the comparison between readings is usually more important than the absolute value of the readings.

All readings should be identical. If one reading is significantly smaller than the others this could indicate the possibility of short-circuited turns in that winding. Conversely, a high continuity resistance value indicates a high resistance fault or an open-circuit (e.9. a loose connection).

Some models of insulation/continuity testers also provide facilities to measure resistance in the kΩ range and "a.c. voltage" (acV).

To measure very low continuity resistance values such as those between bus-bar joints and circuit breaker contacts it is necessary to use a micro-ohmmeter This
type of tester drives a set d.c. current, e.g. l-0 A, through the circuit while measuring the resulting volt-drop across it.

A set of four test leads are used - two to apply the current and two to measure the volt-drop directly at the current injection points.

The meter then calculates R= V/I (Ohms Law), and displays the result as a digital readout in milli-ohms (mΩ) or micro-ohms (μΩ).

Multimeters

Routine electrical test work involves measuring current, voltage and resistance i.e. Amps, Volts and Ohms. This is most conveniently done using a multimeter with all the necessary functions and ranges. The instrument may be the traditional switched-range analogue type (pointer and scale) or the more common digital type with auto-ranging and numerical display.

Digital meters have a clear numeric readout which may be supported by a bar-graph display. Where distorted voltage waveforms are likely (e.g. with variable frequency motor drives) it is necessary to use a "true-rms" meter for accuracy. Digital meters are also available which display the test voltage waveform shape with a storage oscilloscope facility on the LCD screen.

In all instrument models an internal battery is fitted for use when measuring resistance.

Before measuring the resistance of a component it is essential that the circuit is switched off, locked off, and any capacitors discharged. The instrument is likely to be damaged otherwise

Digital multimeter

The multimeter should be proved for correct operation before use. The manufacturer's instructions should be carefully followed for this but a general procedure is as follows:

Use the correct probe leads and insert into the correct sockets on the meter.

If the multimeter is an analogue type:

Ensure the pointer indicates zero - adjust if necessary. Set selector switches to "Ω" and connect probe tips together.

Pointer should deflect to indicate 0 Ω.

If not at the zero point adjust trimming controls. Check each resistance range in this way.

Set selector switch to "ac V" (highest range). Connect probes to a suitable known live supply (with CARE) such as the electrical workshop test panel. Pointer should indicate correct voltage.

Very special care is necessary when using a multimeter to check for a live voltage. If the multimeter has been accidentally set to the current or resistance range the instrument acts as a low resistance across the live supply. The resulting short-circuit current may easily cause the meter to explode with local fire damage and very serious consequences for the operator.

Fused probe leads are therefore highly recommended for use with a multimeter.

Instrument battery failure is checked when the instrument is set to read "Ω" with the probe tips connected together.

If the pointer fails to reach "0Ω" after adjustment of the resistance range trimmer, the battery must be replaced.
The instrument should be switched-off when not in use to preserve battery life.
If the multimeter is a digital type:

- Switch on and connect the two probe tips together. Set selector switches "dcY" to (highest range). Display should indicate zero (000).
- Repeat for all " dc V" selector switch positions and note the shift of the decimal point. Separate the probe tips. Set selector switches to "Ω" (highest range).

Display should indicate "0L" (over range) or "100" (depends upon model). Connect probe tips together – display indicate zero (000).

Repeat for all "Ω" selector switch positions and note movement of the decimal point.

Set selector switches to " acV" (highest range). Connect probes to a suitable known live supply. Display should indicate correct voltage.

Test the d.c. voltage range also and note the polarity indication on the meter.

Instrument battery failure is usually indicated by the numeric display. The display may include "BT" or the decimal-point may blink, or some other display effect may be used.

The instrument should be switched off when not in use to preserve battery life.

These simple proving tests should be performed every time before using the instrument for real. It is obviously very dangerous to touch conductors believing; them to be dead having checked them with a faulty instrument.

- To measure resistance:
- ✓ PROVE the correct instrument
- ✓ ISOMTE and lock to be tested
- ✓ PROVE the equipment to be dead
- ✓ SWITCH the instrument to the appropriate resistance range, connect the probes to the equipment and note the resistance value.
- ✓ Disconnect the probes and switch the instrument to OFF.

- To measure voltage:
- ✓ PROVE the correct instrument operation

- ✓ SWITCH the instrument to the highest voltage range (either acV or dcV as appropriate)
- ✓ CONNECT the probes to the terminals being tested. Take great care not to touch the probe tips and remember that the equipment being tested is LIVE.
- ✓ NOTE the voltage reading.

  If a lower voltage range would give a more accurate reading, adjust the selector switches accordingly to shift the decimal point. However, most digital meters have an auto-ranging facility.

  No harm will be caused to the instrument by operating the selector range switches while still connected to a live supply. But GREAT CARE must be taken not to switch into either the current or resistance mode. This would almost certainly operate the instrument overload device and may cause severe damage to the instrument and danger to yourself. Take your time to operate the selector switches during the operation and THINK about what you are doing. Fused probe leads are highly recommended.

- ✓ Disconnect the probes and switch the instrument to OFF.
- To measure current:

  Most test instruments can only measure up to a few amps (usually 10 A maximum).

  The current measuring facility is intended only for small-current components, and in particular, for electronic circuits. The instrument will almost certainly be damaged if it is used to measure the current to motors and other Dower circuits.

  The basic current range can be extended by using external shunts (d.c.) and current transformers (a.c.). These accessories are generally purchased separately from the instrument manufacturers.

  The procedure to be used to measure current in a small-current circuit:

- ✓ PROVE the correct instrument operation.
- ✓ SWITCH the instrument to the highest current range (either acA or dcA as appropriate).
- ✓ TURN OFF the power to the circuit to be tested and discharge all capacitors.
- ✓ OPEN the circuit in which current is to be measured - removing a fuse-link often gives a convenient point for current measurement.

Securely connect the probes in SERIES with the load in which current is to be measured.

Turn ON the power to the circuit being tested. Note the current size on the meter display.

Turn OFF the power to the circuit being tested and discharge all capacitors.

Disconnect the test probes and switch the instrument to OFF. Reconnect the circuit that was being tested.

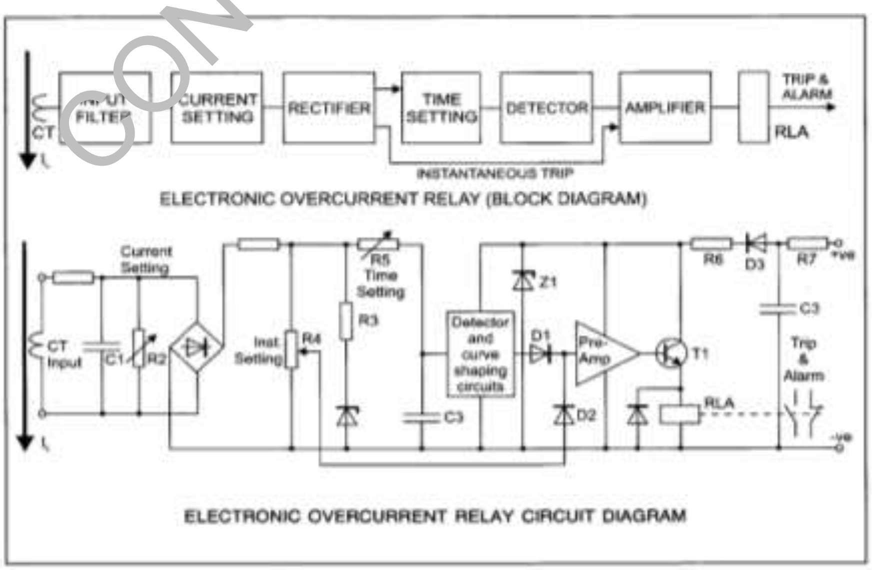
Often, the most convenient way to measure current is to use a clamp-meter which is simply clamped around an insulated conductor.

3. Electrical Diagrams

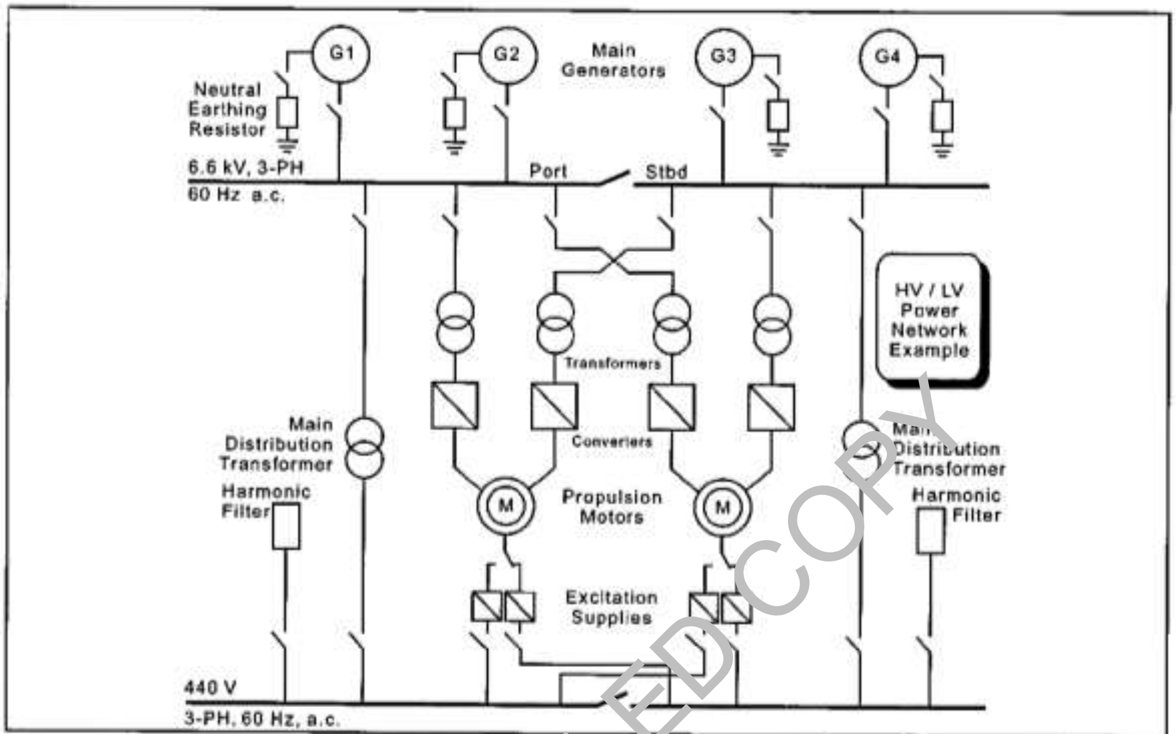
There are various types of diagram which attempt to show how an electrical circuit operates. Symbols are used to represent the various items of equipment.

The shipbuilder provides a complete set of ships' electrical diagrams. It is important that you study these diagrams to be able to read and understand them competently, and to use them as an aid in locating electrical faults.

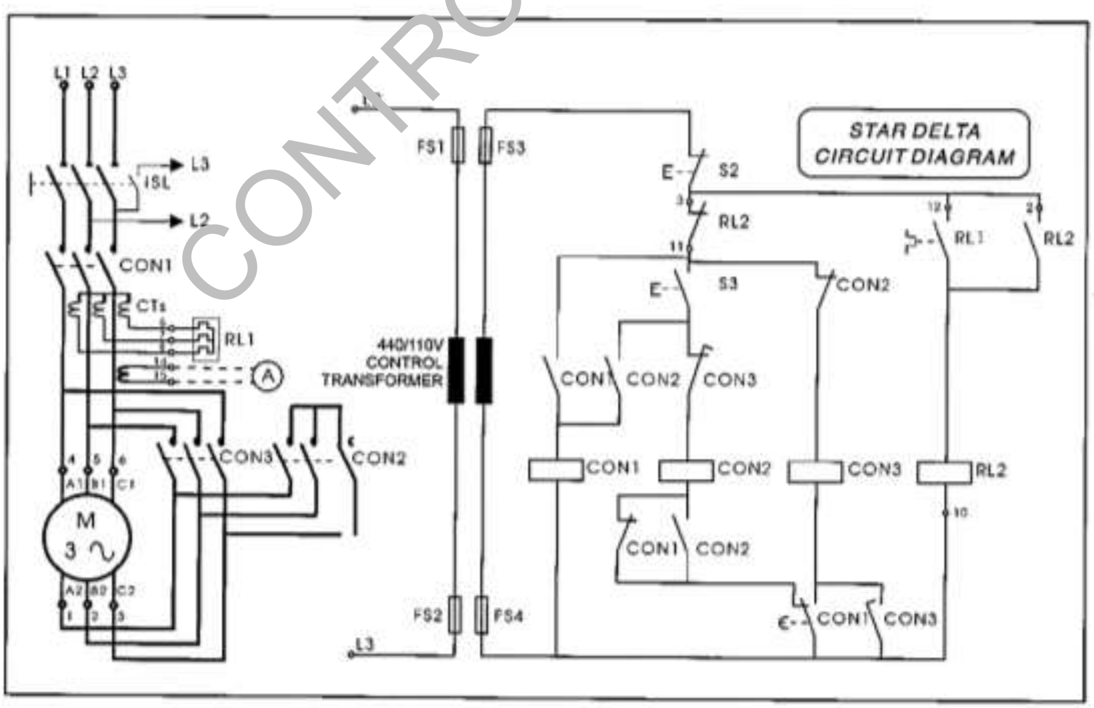
A block diagram shows in simplified form the main inter-relationships of the elements in a system, and how the system works or may be operated. Such diagrams are often used to depict control systems and other complex relationships. The block diagram in Figure below describes the main functions of an overcurrent relay (OCR) used for protection. Its circuit diagram shows one way of realising the overall OCR function.



Block and circuit diagrams



Power system diagram



Power and control circuit diagram

without regard to the physical layout of the various items, their parts or connections.

The electrical connections in Figure or a motor starter are clearly shown in the simplest possible way. A most important point is that no attempt is made to show the moving contacts of a relay or contactor alongside the coil that operates them (where they are actually physically located). Instead, the coil and its related contacts are identified by a common number or letter. Although there are international agreements as to the symbol to be used to represent electrical components you must be prepared to meet various different symbols representing the same component.

The use of a circuit diagram is to enable the reader to understand the operation of the circuit, to follow each sequence in the operation from the moment of initiating the operation (e.g. by pressing a start button) to the final act (e.g. starting of the motor). If the equipment fails to operate correctly, the reader can follow the sequence of operations until he comes to the operation that has failed. The components involved in that faulty operation can then be examined to locate the suspect item. There is no need to examine other components that are known to function correctly and have no influence on the fault, so the work is simplified. A circuit diagram is an essential tool for fault finding.

A wiring diagram shows the detailed connections between components or items of equipment, and in some cases the routeing of these connections.

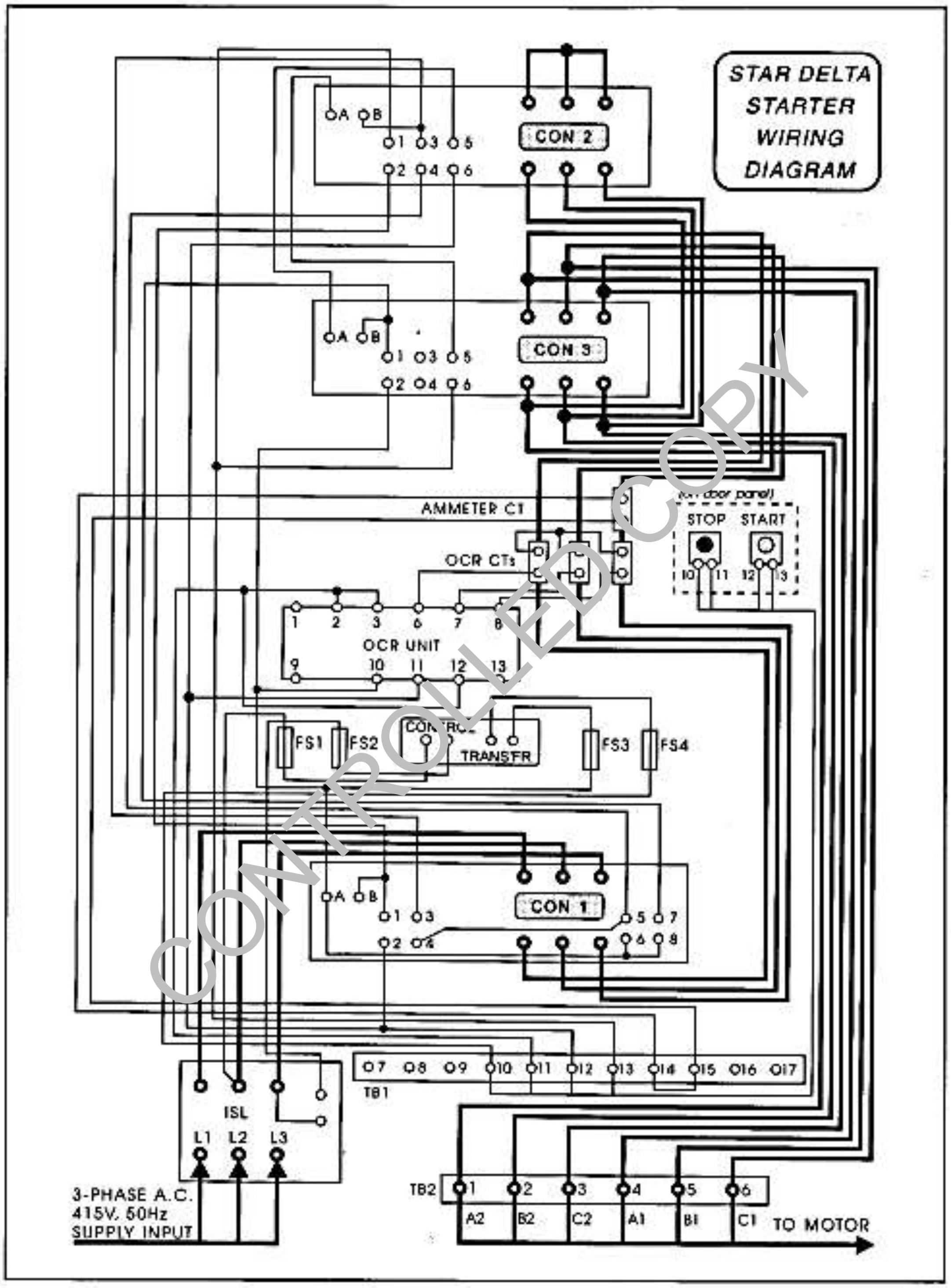
An equipment wiring diagram shows the components in their approximate positions occupied within the actual enclosure. The component may be shown complete (e.g. a contactor coil together with all the contacts it drives) or may be simply represented by a block with the necessary terminals clearly marked. A different thickness of line can be used to differentiate between power and control circuit connections.

A wiring diagram may be of a fairly simple circuit, but its layout makes it quite difficult to use and to understand the sequential operation of the circuit.

The purpose of a wiring diagram is mainly to instruct the wiring installer how to construct and connect the equipment. It is of little use in trouble shooting apart from identifying the exact position of suspect components, terminals and wires.

2.2.2 FUNTION TEST OF ELECTRICAL, ELECTRONIC CONTROL, EQUIPMENT AND SAFETY DEVICES.

.1 Funtion test of electrical, electronic control equipment and safety devices



Power and control wiring diagram

There are other conventions but these cover the main points of good systematic diagrams. Block, system, circuit and wiring diagrams are the main types in general use for electrical work. Other types of diagram are sometimes used to give information for which the basic types are unsuitable (e.g. a pictorial view of a component).

All equipment is subject to wear and tear, eventually reaching the end of its useful life when it must be replaced.

As equipment nears the end of its safe working life its condition can deteriorate to such an extent as to be a danger to personnel and other plant.

The purpose of maintenance, therefore, is to extend the useful life by repair and/or replacement of defective parts and to maintain it in a safe and serviceable condition.

The marine environment is particularly arduous for electrical equipment du-e to the damp, salt-laden atmosphere, extremes of temperature and constant vibration. Shipboard equipment is in particular need of correct maintenance.

The continuous operation of equipment on board ship demands high efficiency and optimum economy in order to help keep operational costs to a minimum to maintain financial competitiveness.

Nearly all equipment needs maintenance.

An efficient maintenance engineer must get to know the power system and its equipment. The ship's drawings and circuit diagrams must be checked and updated to relate them to the actual equipment. Electrical services and equipment must be kept under continuous observation so that normal healthy operating conditions become known, and abnormal operation becomes quickly apparent. Faults can then be pin-pointed and corrected before a breakdown occurs.

Maintenance can be classified as:

- Breakdown maintenance
- Planned maintenance
- Condition monitoring

Breakdown maintenance (corrective maintenance) is when equipment is left untouched until a breakdown occurs.

At this time the equipment is repaired or replaced and any other specified maintenance procedure carried out.

Planned maintenance (preventive maintenance) is when equipment is regularly inspected and maintained according to a fixed timetable and set of procedures specifying the actual work to be done to prevent equipment failure.

Condition monitoring (another form of preventive maintenance) is when equipment is regularly monitored and tested. When monitoring indicates that a breakdown is imminent, the equipment is repaired or replaced and any other specified maintenance procedures are carried out. Regular insulation testing and vibration testing are two forms of condition monitoring.

There are several disadvantages in breakdown maintenance:

- A serious breakdown of equipment may cause sufficient down-time to put the ship out of commission until it is repaired.
- If several breakdowns occur simultaneously the available manpower on board ship may not be able to cope adequately, resulting in delays.
- Some items of equipment may need the specialist services of the manufacturer to carry out repairs which may cause further delays.

Planned maintenance is carried out at fixed regular intervals whether the equipment needs it or not and the aim is to prevent breakdown.

This type of maintenance has the following advantages:

- Fewer breakdowns and reduced down time produces higher levels of operating efficiency.
- Maintenance is carried out at times favourable to the operation of the plant.
- More effective labour utilization because maintenance is carried out at times favourable to the ship's staff.
- Replacement equipment can be ordered in advance.
- Equipment is maintained in a safe condition with reduced possible dangers.
- Where a specialist manufacturer's services are required these can be obtained at convenient times to suit the ship operation.
- Replacement of short-life components at scheduled intervals.

Condition monitoring is also carried out, at fixed regular intervals. The aim is to forestall breakdown by predicting probable failure from the TREND shown by the monitoring results.

The advantage of this type of maintenance is that equipment is not subjected to unnecessary maintenance.

Equipment is regularly condition monitored according to a monitoring schedule. Measurements are taken of insulation resistance, temperature and vibration (of motors). Contacts and other parts subject to deterioration are inspected.

All findings are recorded in an historical record file. No maintenance is carried out until the trend of test results indicate that it has become necessary.

The equipment is then either replaced, repaired or subjected to a major overhaul as specified on a job card.

A maintenance records system is required. The recorded measurements of insulation resistance may show a falling trend indicating a progressive degradation of insulation. The equipment should be inspected and repaired before the insulation resistance falls to a dangerously low value.

Hot-spot temperatures emitted from live electrical equipment can be monitored from a safe distance using an infra-red detector or camera.

The recorded measurements of the vibration of a motor may follow a rising trend indicating progressive bearing deterioration. Bearings should be replaced before failure occurs. Immediate repair or maintenance is probably not necessary but should be put in hand at the earliest convenient moment.

Generally, fault finding is not an easy task.

It is essential to have a good understanding of the operation of the particular n equipment and general insight into some of the diagnostic skills used to solve the problem.

Here is a list of the general techniques used:

- ✓ Planning

A good fault-finder has a mentally planned strategy. The evidence is carefully considered before deciding what action to take. In contrast, the "muddler" acts on impulse.

A good diagnostician will use most of the following mental abilities:

- Memory
- Logical thinking
- Perception
- Spatial mechanical ability
- Social skills
- Persistence

- ✓ Background (underpinning) knowledge. Together with the mental abilities above, knowledge and experience are essential. This is wide ranging andincludes knowledge of components, methods and systems together with their operational characteristics. The combination of knowledge and direct practical experience with the equipment is a powerful aid to fault finding.
- ✓ Diagnostic performance

  In addition to the necessarv skills of the diagnostician, systematic use of " job aids" will improve fault finding method. Examples are:

  - Fault charts

  A list of typical symptoms and faults for a particular equipment plus suggested remedies.

  These lists should be updated according to experience to show the most probable faults.

  - FACERAP

  The seven letters of the mnemonic "FACERAP" are the key steps to logical fault finding:

F	(fault)	the name and classification of a fault;
A	(appearance)	the description of the fault or its related symptom;
C	(cause)	the operational reason for the fault;
E	(effect)	the consequential effect of the fault;
R	(responsibility)	the correct person to take remedial action;
A	(action)	the standard procedure adopted to rectify the fauLt;
P	(prevention)	the procedure to avoid repetition of the fault.

- Search strategy

Once the diagnostician can visualize the circuit or machine as a series of functions and/or use a job aid, a search strategy can be applied to locate the fault in the minimum time.

A "six step approach" is summarized as:

1. Collect evidence (stop and think).
2. Analyse evidence (check assumptions).
3. Locate fault (inspect and test).
4. Determine and remove cause.
5. Rectify fault.

Check system.

Conclusion

Fault finding is not easy! However, a logical approach supported by knowledge and experience will certainly help.

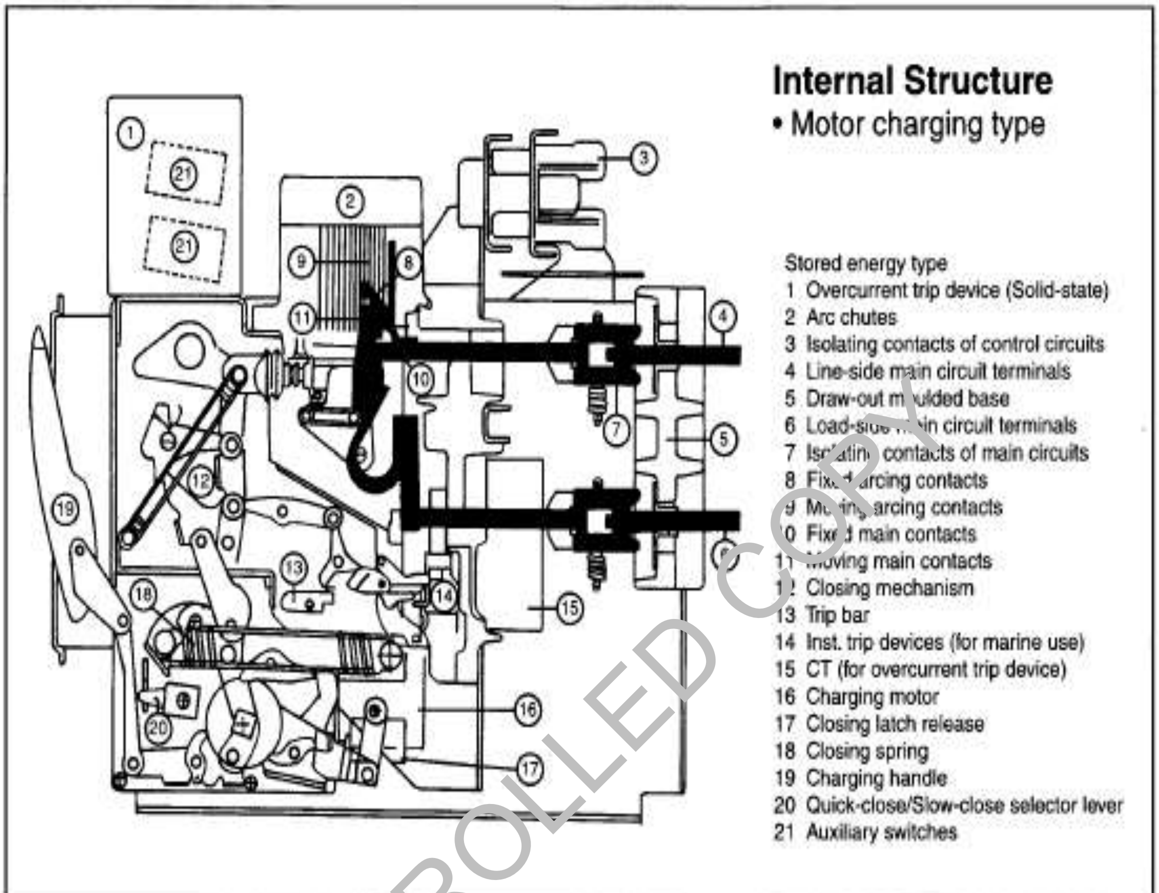
Main air circuit breaker

LV generator circuit-breakers and other large distribution circuit-breakers

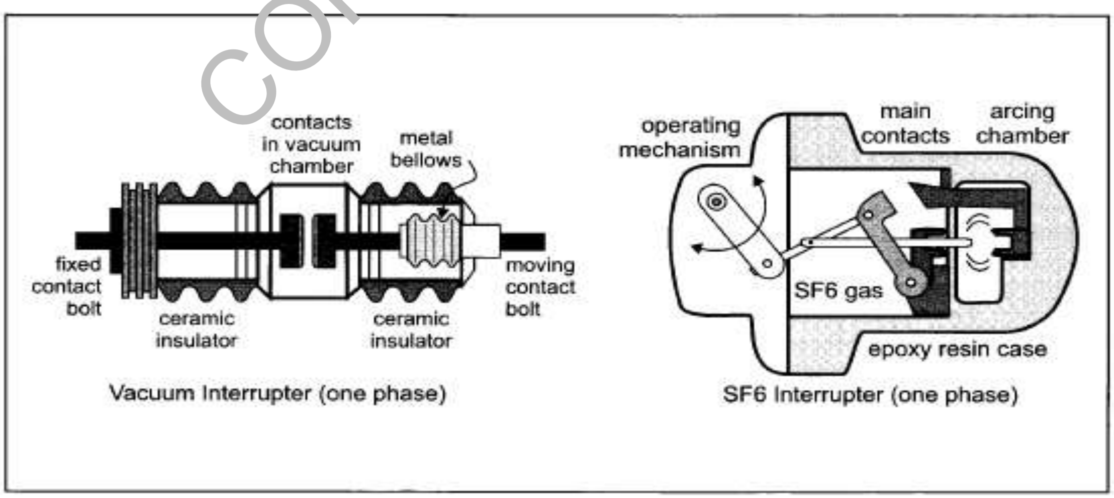
(600-6000 A) on board ship are traditionally of the air break type called ACB (air circuit breaker). This means that the circuit-breaker contacts separate in air. An ACB outline is shown in the figure below.

High voltage (HV) installations e.g. at 6.6 kV and L1 kV generally use the vacuum interrupter type or gas-filled (sulphur hexafluoride - SF6) breakers.

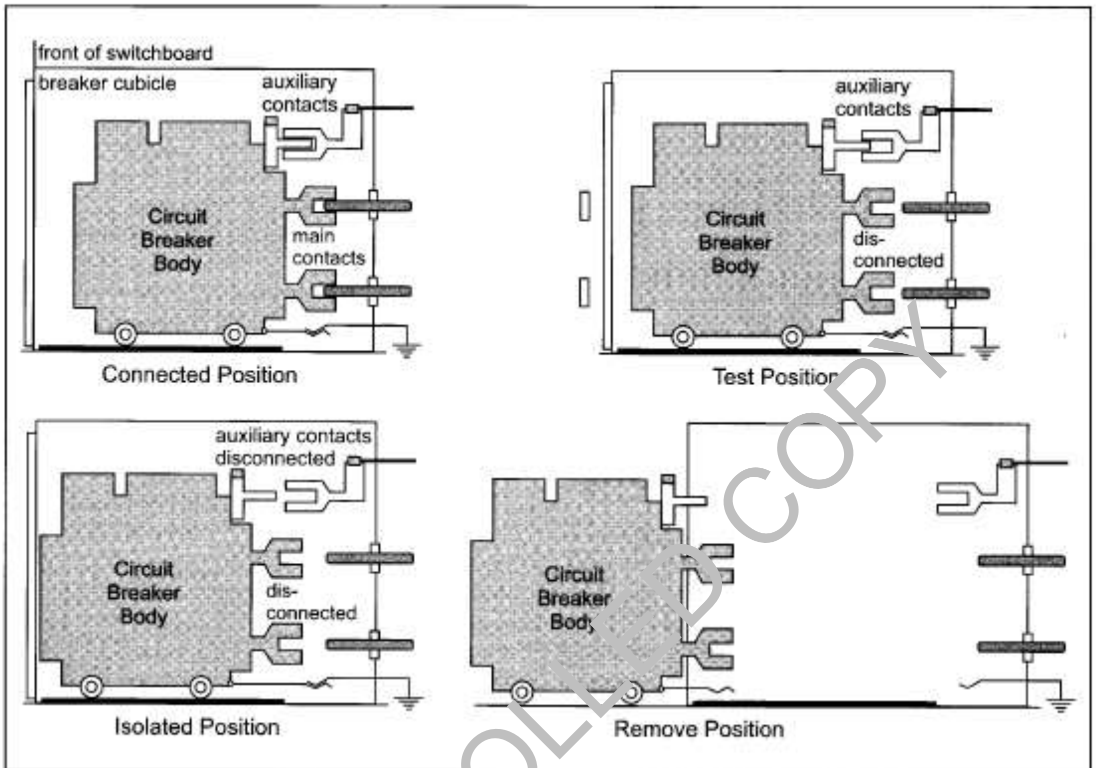
In a vacuum interrupter the contacts only need to be separated by a few miliimetres as the insulation level of avacuum is extremely high. The quality of the vacuum in the sealed interrupter chamber is checked by applying a short duration HV pulse (e.g. 10 kV for a 6.6 kV breaker) across the open contacts.



Circuit breaker components



Vacuum and SF6 interrupter units



2.2.3 TROUBLESHOOTING OF MONITORING SYSTEMS

.1 Test and calibration of sensors and transducers of monitoring system.

In the gas breaker the contacts separate in a special interrupter chamber containing SF6 gas typically at 500 kPa (5 bar) at 20ºC.

The operating mechanism for vacuum and SF6 breakers is similar to that employed for an ACB. In the figure above shows how each main circuit breaker is mounted on guide rails inside a main switchboard cubicle from which it must be withdrawn and isolated from the bus-bars for maintenance and testing.

The breaker and its guide rails are usually mounted in a special cassette bolted into the switchboard cubicle and electrically connected to the bus-bars. If repair work demands that the breaker is to be completely removed from its cassette then usually a special hoist or fork-lift is required for large, heavy-duty units.

The action of withdrawing the circuit breaker causes a safety shutter to cover the live bus-bar contacts at the rear of its cubicle.

The mechanical linkage in a circuit breaker is quite complex and should not be interfered with except for maintenance and lubrication as specified by the manufacturer.

The main fixed and moving contacts are of copper (sometimes of special

arc-resistant alloy or silver tipped) and usually silver-alloy coated. Main contacts should not be scraped or filed. If the main contacts suffer severe burning they will probably require realignment as specified by the manufacturer.

Arcing contacts normally suffer burning and may be dressed by a smooth file as recommended by the manufacturer. Carborundum and- emery should not be used - the hard particles can embed themselves in the soft contacts and cause future trouble.

The arc chutes or arc splitter boxes confine and control the inevitable arc to rapidly accelerate its extinction. These must be removed and inspected for broken parts and erosion of the splitter plates.

Various types of circuit breaker closing mechanism may be fitted:

- Independent Manual Spring

The spring charge is directly applied by manual depression of the closing handle.The last few centimetres of handle movement releases the spring to close the breaker. Closing speed is independent of the operator.

- Motor Driven Stored Charge Spring (most common type for marine applications) Closing springs are charged by a motor-gearbox unit. Spring recharging is automatic following closure of the breaker which is initiated by a pushbutton. This may be a direct mechanical release of the charged spring, or more usually, it will be released electrically via a solenoid latch.

- Manual Wound Stored Charge Spring is similar to above method but with manually charged closing springs.

- Solenoid

The breaker is closed by a d.c. solenoid energised from the generator or bus-bars via a transformer/rectifier unit, contactor, push button and, sometimes, a timing relay.

WARNING: Circuit breakers store energy in their springs for:

- Store-charge mechanisms in the closing springs.

- Contact and kick-off springs.

Extreme care must be exercised when handling circuit breakers with the closing springs charged, or when the circuit breaker is in the ON position.

Isolated circuit-breakers racked out for maintenance should be left with the closing springs discharged and in the OFF position.

Circuit-breakers are held in the closed or ON position by u mechanical latch.

The breaker is tripped by releasing this latch allowing the kick-off springs and contact pressure to force the contacts open.

Tripping can be initiated:

- Manually - a push button with mechanical linkage trips the latch.
- Undervoltage trip coil or relay (trips when de-energised).
- Overcurrent/short-circuit trip device or relay (trips when energised).
- Solenoid trip coil - when energized by a remote push-button or relay (such as an electronic overcurrent relay).

Mechanical interlocks are fitted to main circuit breakers to prevent racking-out if still in the ON position.

Care must be taken not to exert undue force it the breaker will not move, otherwise damage may be caused to the interlocks and other mechanical parts.

Electrical interlock switches are connected into circuit-breaker control circuits to prevent incorrect sequence operation,,e .g. when a shore-supply breaker is closed onto a switchboard. The ship's generator breakers are usually interlocked OFF to prevent parallel running of a ship's generator and the shore supply.

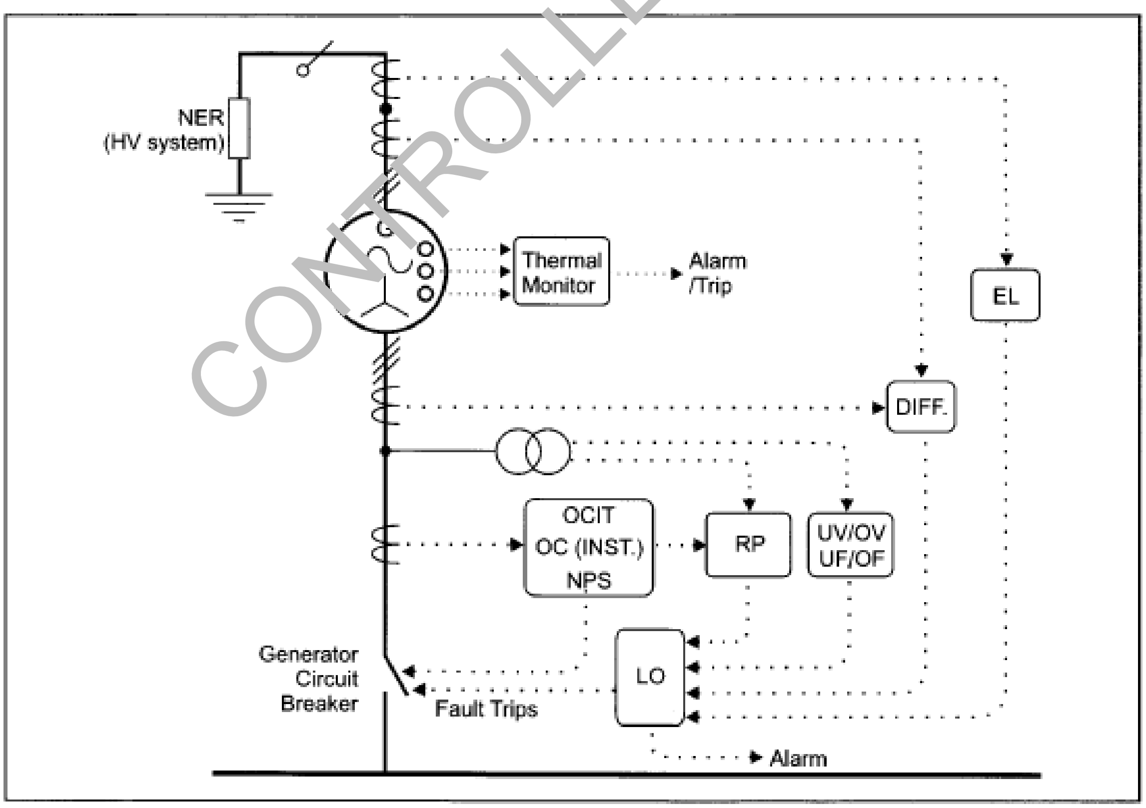
6. Generator Protection

Apart from direct temperature measurement of the stator windings and the internal air, the protection of a generator is largely based on the sensing of current and voltage from CTs and VTs. The number and type of protective relay functions increases with the generator kVA rating and voltage level. Protective relays are electromagnetic (traditional) or electronic (increasingly more common) which are mounted on the generator front panel of the main switchhoard.

Some protective functions may be grouped together within a single relay case. Settings for level and time-delay must be periodically checked by injecting currents and/or voltages directly into the relay (usually via a special multi-pole socket adjacent to the relay and internally wired to it).

- OCRT

The Over Current Inverse Time relay function monitors general balanced overloading and has current/time settings determined by the overall protective discrimination scheme.



Generator protection scheme

Typical setting ranges for current (I) and time (t) are:

I>:0.7-2. In, (In: normal or rated generator current) and t: 1-10s

- OC(INST.)

"Instantaneous" trip to protect against extremely high overcurrent caused by a short-circuit fault. Typical setting ranges are:

I >> : 2-10.In, and t: 0.1-1s

- NPS

A Negative Phase Sequence relay determines the amount of unbalance in the stator currents which is an indirect measure of the generator stator and rotor temperature. A relatively small degree of unbalance causes a significantly increased temperature rise so the NPS current setting is low at around 0.2.In.

- DIFF

This is a differential measurement of current at each end of a stator phase winding. This comparison of current is to detect an internal fault in the stator windings which may be caused by partially short-circuited coil turns and/or earth faults.

Current settings for this very serious fault are very low e.g. about 0.1.In.

- E L

An Earth Leakage relay (sometimes called Zero Phase Sequence) detects an earth fault current returning back through the earthed neutral connection.

In a ship's HV generator system the earth fault current is limited by a high impedance NER (neutral earthing resistor) or earthing transformer so the pick-up current setting is very low, e.g. 1-5A with a time delay of 0.1-0.5 s.

- UV/OV

Under Voltage and Over Voltage functions are monitored by these relays with settings of around 0.8.Un and 1.2.Un respectively (Un: rated voltage) with time delays of about 2s. An overvoltage function may not be required in many protection schemes.

- UF/OF

Under and Over Frequency settings are typically 58 Hz and 62 Hz for a 60 Hz system.

- L O

This is the master Lock Out or trip/hand-reset relay responsible for tripping the generator circuit breaker. Its action is instantaneous when triggered by ^ protective relay. It can also be used to trip the generator prime-mover and initiate generator field suppression together with the signalling of an alarm.

- R P

Generators intended to operate in parallel must have reverse power protection (RP).

A reverse power relay monitors the direction of power flowing between the generator and the load. If a prime-mover failure occurred the generator would act as a motor. The reverse power relay detects this fault and acts to trip the generator circuit-breaker.

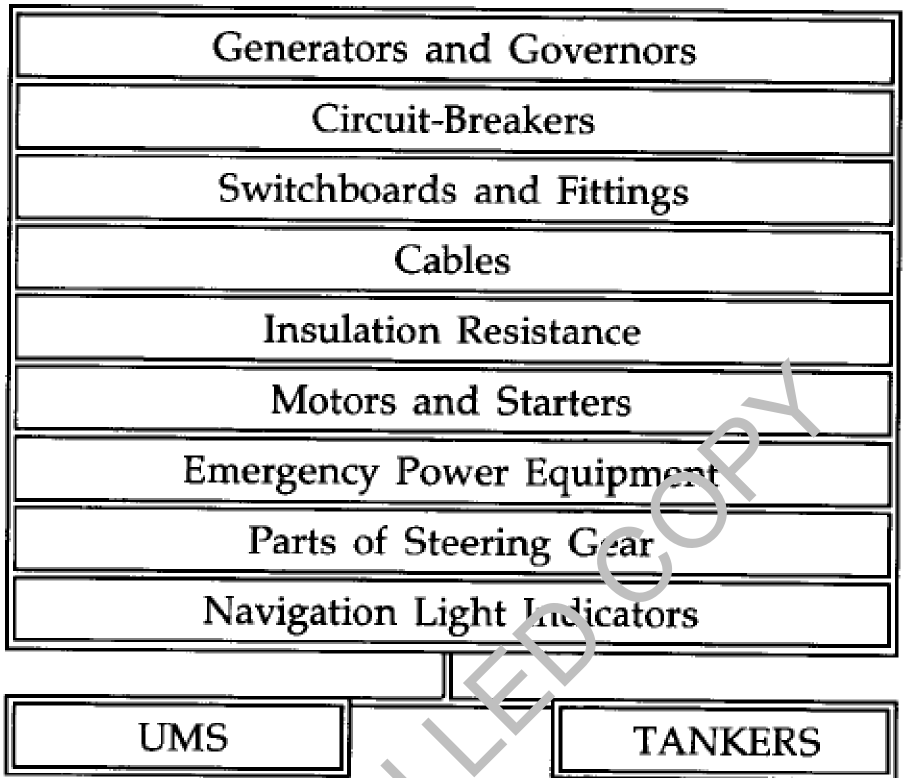
The pick-up power level setting and time-delay setting are adjustable and are pre-set to suit the prime-mover. If the prime mover is a turbine, very little power is absorbed when motoring and a reverse-power pick-up setting of 2-3o/o is usual. If the prime mover is a diesel then a setting range of 5-15% is usually adopted. A time delay range of about 0.5-3 s is usual.

The RP relay operation is easily checked during a generator changeover.

The outgoing generator is gradually throttled down so that it motors causing the reverse power relay to trip its generator circuit-breaker.

7. Main Electrical Survey Items

The following survey items apply in general to all ships:



For UMS operation, a survey of the associated alarms, controls and fire detection is required.

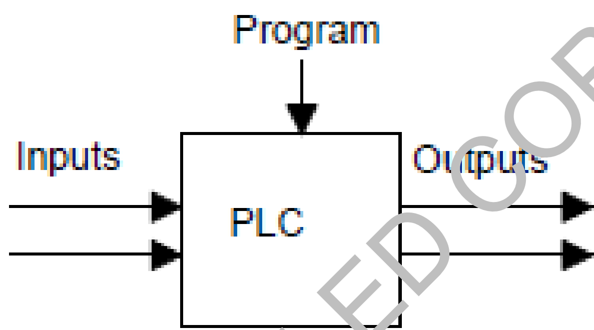
For tankers/gas carriers and other ships transporting flammable cargo, an additional survey of all electrical equipment in hazardous areas is carried out iiuring each docking survey and annual survey.

This means that hazardous area electrical equipment is surveyed every year.

2.2.4 SOFTWARE VERSION CONTROL

1. Programmable logic controller (PLC)

A programmable logic controller (PLC) is a special form of microprocessor- based controller that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes and are designed to be operated by engineers with perhaps a limited knowledge of computers and computing languages. They are not designed so that only computer programmers can set up or change the programs. Thus, the designers of the PLC have pre-programmed it so that the control program can be entered using a simple, rather intuitive, form of language. The term logic is used because programming is primarily concerned with implementing logic and switching operations, e.g. if A or B occurs switch on C, if A and B occurs switch on D. Input devices, e.g. sensors such as switches, and output devices in the system being controlled, e.g. motors, valves, etc., are connected to the PLC. The operator then enters a sequence of instructions, i.e. a program, into the memory of the PLC. The controller then monitors the inputs and outputs according to this program and carries out the control rules for which it has been programmed.



A programmable logic controller

PLCs have the great advantage that the same basic controller can be used with a wide range of control systems. To modify a control system and the rules that are to be used, all that is necessary is for an operator to key in a different set of instructions. There is no need to rewire. The result is a flexible, cost effective, system which can be used with control systems which vary quite widely in their nature and complexity.

PLCs are similar to computers but whereas computers are optimised for calculation and display tasks, PLCs are optimised for control tasks and the industrial environment. Thus PLCs are:

1. Rugged and designed to withstand vibrations, temperature, humidity and noise.
2. Have interfacing for inputs and outputs already inside the controller.
3. Are easily programmed and have an easily understood programming language which is primarily concerned with logic and switching operations.

The first PLC was developed in 1969. They are now widely used and extend from small self-contained units for use with perhaps 20 digital inputs/outputs to modular systems which can be used for large numbers of inputs/outputs, handle digital or analogue inputs/outputs, and also carry out proportional-integral-derivative control modes.

PLC systems

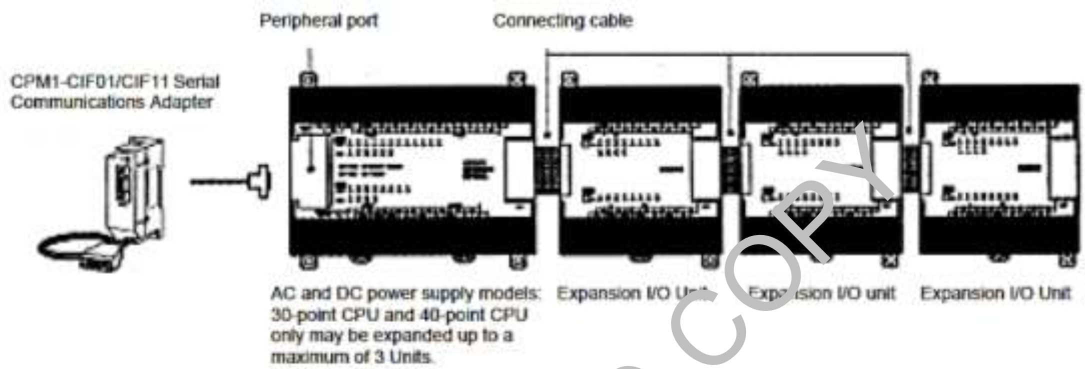
There are two common types of mechanical design for PLC systems; a single box, and the modular/rack types. The single box type (or, as sometimes termed, brick) is commonly used for small programmable controllers and is supplied as an integral compact package complete with power supply, processor, memory, and input/output units. Typically such a PLC might have 6, 8, 12 or 24 inputs and 4, 8 or 16 outputs and a memory which can store some 300 to 1000 instructions. In the figure below shows the Mitsubishi MELSEC FX3U compact, i.e. brick, PLC and in the Table gives details of models in that Mitsubishi range.

Mitsubishi Compact PLC – MELSEC FX3U (By permission of Mitsubishi Electric Europe)

Type	FX3U-16 MR	FX3U-32 MR	FX3U-48 MR	FX3U-64 MR	FX3U-80 MR
Power supply			100-240 V AC		
Inputs	8	16	24	32	40
Outputs	8	16	24	32	40
Digital outputs			Relay		
Program cycle period per logical instruction			0.065 μs		
User memory			64k steps (standard), FLROM cassettes (optional)		
Dimensions in mm (W × H × D)	130 × 90 × 86	150 × 140 × 86	182 × 90 × 86	220 × 90 × 86	285 × 90 × 86

Mitsubishi Compact PLC – MELSEC FX3U Product range (By permission of Mitsubishi Electric Europe)

Some brick systems have the capacity to be extended to cope with more inputs and outputs by linking input/output boxes to them. The figure below shows such an arrangement with the OMRON CPM1A PLC. The base input/output brick, depending on the model concerned, has 10, 20, 30 or 40 inputs/outputs (I/O). The 10 I/O brick has 6 d.c. input points and four outputs, the 20 I/O brick has 12 d.c. input points and 8 outputs, the 30 I/O brick has 18 d.c. input points and 12 outputs and the 40 I/O brick has 24 d.c. input points and 16 outputs. However, the 30 and 40 I/O models can be extended to a maximum of 100 inputs/outputs by linking expansion units to the original brick. For example a 20 I/O expansion module might be added, it having 12 inputs and 8 outputs, the outputs being relays, sinking transistors or sourcing transistors. Up to three expansion modules can be added. The outputs can be relay or transistor outputs.



Basic configuration of the OMRON CPMIA PLC (By permission of Omron Electronics LLC)

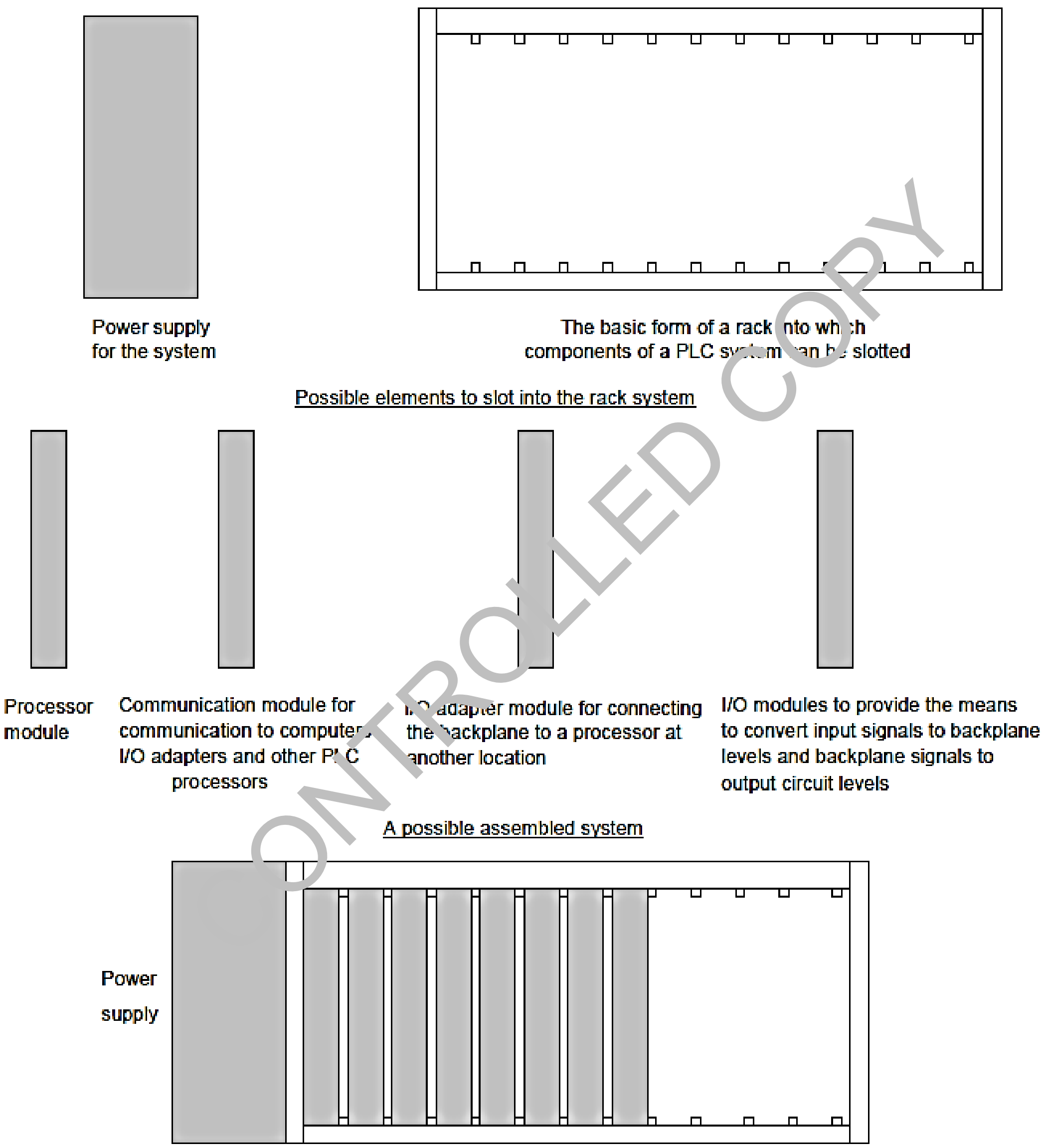
Systems with larger numbers of inputs and outputs are likely to be modular and designed to fit in racks. The modular type consists of separate modules for power supply, processor, etc., which are often mounted on rails within a metal cabinet. The rack type can be used for all sizes of programmable controllers and has the various functional units packaged in individual modules which can be plugged into sockets in a base rack. The mix of modules required for a particular purpose is decided by the user and the appropriate ones then plugged into the rack.

Thus it is comparatively easy to expand the number of input/output (I/O) connections by just adding more input/output modules or to expand the memory by adding more memory units.

An example of such a modular system is provided by the Allen-Bradley PLC-5 PLC of Rockwell automation. PLC-5 processors are available in a range of I/O capacity and memory size, and can be configured for a variety of communication networks. They are single-slot modules that are placed in the left-most slot of a 1771 I/O chassis. Some 1771 I/O chassis are built for back-panel mounting and some are built for rack mounting and are available in sizes of 4, 8, 12, or 16 I/O module slots. The 1771 I/O modules are available in densities of 8, 16, or 32 I/O per module. A PLC-5 processor can communicate with I/O across a DeviceNet or Universal Remote I/O link.

A large selection of 1771 input/output modules, both digital and analogue, are available for use in the local chassis, and an even larger selection available for use at locations remote from the processor. Digital I/O modules have digital I/O circuits that interface to on/off sensors such as pushbutton and limit switches; and on/off actuators such as motor starters, pilot lights, and annunciators. Analogue I/O modules perform the required A/D and D/A conversions using up to 16-bit resolution.

Analogue I/O can be user-configured for the desired fault-response state in the event that I/O communication is disrupted. This feature provides a safe reaction/response in case of a fault, limits the extent of faults, and provides a predictable fault response. 1771 I/O modules include optical coupling and filter circuitry for signal noise reduction.



A possible arrangement of a rack system, e.g. the Rockwell Automation, Allen-Bradley PLC-5

Digital I/O modules cover electrical ranges from 5…276V a.c. or d.c. and relay contact output modules are available for ranges from 0…276 V ac or 0…175 V dc. A range of analogue signal levels can be accomodated, including standard analogue inputs and outputs and direct thermocouple and RTD temperature inputs.

2. Microcontrollers

A microcontroller is a computer-on-a-chip, or, if you prefer, a single-chip computer. Micro suggests that the device is small, and controller tells you that the device might be used to control objects, processes, or events. Another term to describe a microcontroller is embedded controller, because the microcontroller and its support circuits are often built into, or embedded in, the devices they control.

You can find microcontrollers in all kinds of things these days. Any device that measures, stores, controls, calculates, or displays information is a candidate for putting a microcontroller inside. The largest single use for microcontrollers is in automobiles—just about every car manufactured today includes at least one microcontroller for engine control, and often more to control additional systems in the car. In desktop computers, you can find microcontrollers inside keyboards, modems, printers, and other peripherals. In test equipment, microcontrollers make it easy to add features such as the ability to store measurements, to create and store user routines, and to display messages and waveforms. Consumer products that use microcontrollers include cameras, video recorders, compact-disk players, and ovens. And these are just a few examples.

A microcontroller is similar to the microprocessor inside a personal computer. Examples of microprocessors include Intel's 8086, Motorola's 68000, and Zilog's Z80. Both microprocessors and microcontrollers contain a central processing unit, or CPU. The CPU executes instructions that perform the basic logic, math, and data-moving functions of a computer.

To make a complete computer, a microprocessor requires memory for storing data and programs, and input/output (I/O) interfaces for connecting external devices like keyboards and displays.

In contrast, a microcontroller is a single-chip computer because it contains memory and I/O interfaces in addition to the CPU. Because the amount of memory and interfaces that can fit on a single chip is limited, microcontrollers tend to be used in smaller systems that require little more than the microcontroller and a few support components. Examples of popular microcontrollers are Intel's 8052 (including the 8052-BASIC, which is the focus of this book), Motorola's 68HC11, and Zilog's Z8.

Choosing a chip

All microcontrollers contain a CPU, and chances are that you can use any of several devices for a specific project.

Within each device family, you'll usually find a selection of family members, each with different combinations of options. For example, the 8052-BASIC is a member of the 8051 family of microcontrollers, which includes chips with program memory in ROM or EPROM, and with varying amounts of RAM and other features. You select the version that best suits your system's requirements.

Microcontrollers are also characterized by how many bits of data they process at once, with a higher number of bits generally indicating a faster or more powerful chip. Eight-bit chips are popular for simpler designs, but 4-bit, 16-bit, and 32-bit architectures are also available.

The 8052-BASIC is an 8-bit chip.

Power consumption is another consideration, especially for battery-powered systems. Chips manufactured with CMOS processes usually have lower power consumption than those manufactured with NMOS processes. Many CMOS devices have special standby or "sleep" modes that limit current consumption to as low as a few microamperes when the circuits are inactive. Using these modes, a data logger can reduce its power consumption between samples, and power up only when it's time to take data.

The 8052-BASIC chip is available in both NMOS and CMOS versions. The original

8052-BASIC was an NMOS chip, offered directly from Intel. (Intel's term for its NMOS process is HMOS.) Although Intel never offered a CMOS version directly, Micromint became a source by ordering a batch of CMOS 8052's with the BASIC-52 programming language in ROM. The CMOS version, the 80C52-BASIC, has maximum power consumption of 30 milliamperes, compared to 175 milliamperes for the NMOS 8052-BASIC.

All microcontrollers have a defined instruction set, which consists of the binary words that cause the CPU to carry out specific operations. For example, the instruction 0010 0110 tells an 8052 to add the values in two locations. The binary instructions are also known as operation codes, or opcodes for short. The opcodes perform basic functions like adding, subtracting, logic operations, moving and copying data, and controlling program branching.

Control circuits often require reading or changing single bits of input or output, rather than reading and writing a byte at a time. For example, a microcontroller might use the eight bits of an output port to switch power to eight sockets. If each socket must operate independently of the others, a way is needed to change each bit without affecting the others. Many microcontrollers include bit-manipulation (also called Boolean) opcodes that easily allow programs to set, clear, compare, copy, or perform other logic operations on single bits of data, rather than a byte at a time.

3. Digital techniques

Logic Gates

The logic gate is the most basic building block of any digital system, including computers. Each one of the basic logic gates is a piece of hardware or an electronic circuit that can be used to implement some basic logic expression. While laws of Boolean algebra could be used to do manipulation with binary variables and simplify logic expressions, these are actually implemented in a digital system with the help of electronic circuits called logic gates. The three basic logic gates are the OR gate, the AND gate and the NOT gate.