7. POWER GENERATION, ELECTRICAL DISTRIBUTION SYSTEMS AND AUTOMATION SYSTEMS

7.1. Electrical load balance or electric load analysis

7.1.1. Introduction

The complete electrical plant on board ship is made up of power generation equipment, a distribution system and the many power utilizing devices. Electricity is used for the motor drive of many auxiliaries and also for deck machinery, lighting, ventilation and air conditioning equipment. Since a vessel at sea is isolated from external sources of electric energy, a constant supply of electricity is essential for safe ship and machinery operation, and therefore standby or additional capacity is necessary together with emergency supply equipment.

Emergency equipment may take the form of an automatically starting emergency alternator or storage batteries may be used.

The complete range of electrical equipment will include generators, switch gear for control and distribution, motors and their associated starting equipment and emergency supply arrangements. Power must also be supplied for interior communications systems, controls, radio communications, radar, and other electronic aids to navigation and shipboard operation.

For military ships, a significant amount of electric power is required by mission-related payloads, such as the combat systems (weapons, command, communications, control, electronic warfare and countermeasures, etc.), and combat support and supply systems.

For passengers vessels, the electric power requirements extend to hotel and recreation loads such as theaters, restaurants, and swimming pools.

All ships are provided with shore power supply feature, to receive power from shore when the ship is not operational. One or more suitably located shore power connection boxes are connected to one or more main switchboards through separate feeders and shore power circuit breakers on the switchboard.

The basic configuration of the electric power plant (number of generators, switchboards, load centers, group control centers, etc.) and the selection of the system parameters are a function of safety, economics, continuity of service, survivability, and other requirements dictated by the size and mission of the ship. Regulations for self-propelled merchant vessels require at least two electric generating sets. The electric load analysis is the means used by an experienced systems engineer to establish the overall power system configuration and features early on during the preliminary definition of a new ship design.

7.1.2. Consumers

The identification, tabulation, and summary of all electrical loads on a ship are compiled by an electric load analysis. This analysis is started during concept/preliminary design at a high level. It is subsequently developed and maintained to an ever-increasing level of detail through detail design of the ship. The load analysis is structured to determine the aggregate power requirements of all the electric power-consuming equipments and devices under the various ship operating conditions, such as at-anchor, in-port, maneuvering, at-sea, and fire onboard, for the purpose of establishing the maximum and minimum power requirements. The maximum power summary is required to establish the generating plant capacity and power plant configuration. The minimum power requirement is of special importance when diesel engine prime movers are utilized. Excessive maintenance may be required when diesel engines are operated at light loads for long periods of time. Moreover, fuel consumption at light loads is larger than for operation at regimes of 60-80% of the diesel engine rating power.

The load analysis is also useful for the development of the basic power distribution system configuration. Table 7.1 is a worksheet of a typical electric load analysis. The average demand loads for each power-consuming piece of equipment are calculated by applying anticipated service factors for each operating condition to the maximum [kW] rating, i.e., the maximum [kW] absorbed by the piece of equipment.

Service factors consist of a load component and a cycle component. The load component is the ratio of the actual load when energized under a particular operating condition (e.g., motor running at a lower speed, or pump operating below its rated delivery) to the maximum input rating of the load. The cycle component reflects the percentage of time a piece of equipment operates during the total time frame of an operating condition. For example, the electric load analysis of a cargo vessel with 24 electrical winches installed will not consider all the 24 winch motors running simultaneously. Therefore, the probability of occurrence of the electric load over a period of time should be determined in advance. Considering the same example as above lets assume that off-load operation onboard this cargo vessel involves all the hatchcovers being simultaneously operated and that each winch will be energized during 5 minutes by intervention, which are repeated every 15 minutes. The individual probability of a winch being utilized, *P(s)*, is therefore 1/3. Moreover, the probability of *n* winches are working simultaneously, *P(w)*, is given by a binomial distribution function, as follows:

$$P(w) = \frac{m!}{n!(m-n)!} P(s)^n P(\bar{s})^{m-n} \tag{7.1}$$

, where:

m = number of winches installed;

n = number of winches being simultaneously utilized;

P(s) = individual probability of a winch being utilized;

$P(\bar{s})$ = individual probability of a winch not being utilized;

According to Figure 7.1, this binomial mass distribution function has an expected value of *n* out of *m* pieces being simultaneously utilized simply given by its expected value, i.e.: *E(X)* = *m.P(s)*. Hence, for this particular case it is obtained:

$$E(X) = (24)\left(\frac{1}{3}\right) = 8 \tag{7.2}$$

Thus, assuming the number of winches being simultaneously utilized is 8, the probability of occurrence of this arrangement is given by equation (7.1) as follows:

$$P(w) = \frac{24!}{8!(24-8)!}\left(\frac{1}{3}\right)^8\left(\frac{2}{3}\right)^{16} = 0.17 \tag{7.3}$$

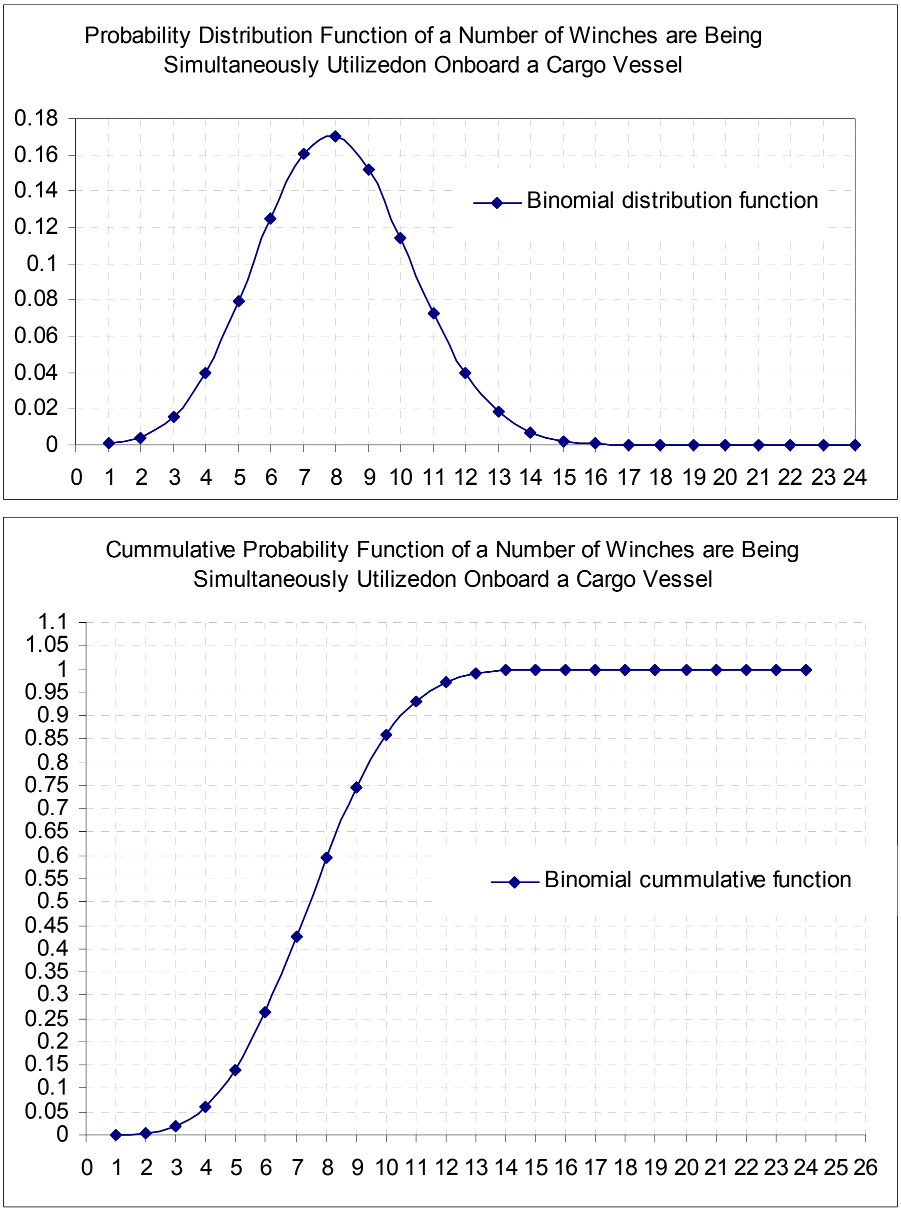

Fig. 7.1 – Probability distribution (top) and probability cumulative (bottom) functions of a certain number of winches on a cargo vessel with 24 winches installed are being simultaneously utilized.

For power generation design purposes the probability of having 8 winches working simultaneously is extremely high. Therefore, it will be highly recommended to consider a design condition where 12 out of 24 would be simultaneously working, which has a probability of occurrence of only 4% (see Figure 7.1). Therefore, based on this probabilistic analysis, the cycle component factor to be introduced in the electric load analysis worksheet of this cargo vessel having 24 winches installed onboard would be *0.5 = 12/24*.

In most cases, these service factors are simply selected from empirical databases. However, in some particular cases (such as major electric power consumers) the factors for major loads must be determined analytically based on specific operating scenarios such as the one presented in the example above.

Once the electric active load has been established, in [kW], then this value is converted into [kVA], assuming a power factor of 0.8.

Finally, the electric power plant should be designed with sufficient margin for future growth and high starting current characteristics of the existing AC motors (transient loads). On the other hand, resistive loads (such as electric heaters) operate at a unity (1.0) power factor.

7.1.3. System voltage and frequency

Voltage and frequency are the primary electrical system design parameters, and their selection is influenced by many factors. Limiting the practical options to the voltage and frequency ratings of components and equipment that are available for commercial and naval shipboard applications, the alternatives are either DC or AC at either 50, 60, or 400 [Hz]; and alternative voltages are 120/240, 480/450, 2400, or 4160 volts.

Alternating-current plants has become the standard for most marine and land-based power plants. As mentioned before, AC provides many significant advantages over DC, e.g., less cost, weight, and space requirements, less maintenance, better availability of equipment in the marketplace, and increased reliability. Many of these advantages are realized through the use of squirrel-cage induction motors as opposed to DC motors, which have commutators and associated brushes that are subjected to wear.

Shipboard electric plants throughout Europe generally use 3-phase AC 440 volts@60 hertz or 380 volts@50 hertz. Electric generators may have delta or star 3-phase connections with 3 or 4 wires. However, 220 volts@50 hertz, or 250 volts@60 hertz is the recognized standard voltage for all lighting systems. Hence, for lighting applications generators having star type with 3-phase, 4-wire are the most appropriate, where a neutral earth-connection may be implemented or not. Nevertheless, it is also common to find some lighting applications at 110 volts@50 hertz so that a set transformers has to be installed, and in this particular case a neutral earth-connection is quite uncommon.

The voltage and frequency of electric systems are maintained within prescribed tolerances by speed governors on the generator set prime movers and voltage regulators within the excitation system of the generators. For commercial ships, the tolerances are defined by regulatory body requirements and are compatible with commercial standards for electric power systems as well as user (power consuming) equipment.

Tab. 6.1 – Electric load analysis.

MACHINERY EQUIPMENT		Power	SAILING			HARBOUR			MANOUEVRING		
No on ship	Consumer	Inputs kW	Unit in operation	limit fact.	Power kW	Unit in op	limit fact.	Power kW	Unit in op	limit fact.	Power kW
	SW cooling pump - Main	1.00	1	0.75	0.75	0	1.0	0.00	1	0.75	0.75
	Fresh water pressure pump	1.00	1	0.75	0.75	1	0.5	0.50	1	0.75	0.75
	Bilge/ Ballast pump	1.00	1	0.75	0.75	1	0.5	0.50	1	0.75	0.75
	Bilge stripping pump	0.50	2	0.40	0.40	2	0.40	0.32	2	0.40	0.40
	General Service/ Fire pump	1.00	1	0.75	0.75	1	0.75	0.56	1	0.75	0.75
	Diesel Oil transfer pump	1.00	1	0.75	0.75	0	0.75	0.00	1	0.75	0.75
	Sewage pump	1.00	1	0.75	0.75	1	0.75	0.56	1	0.75	0.75
	Dispersating pump	1.00	1	0.75	0.75	0	0.75	0.00	1	0.75	0.75
	Steering gear	0.50	1	0.75	0.38	0	0.75	0.00	1	0.75	0.38
		8.00			**6.03**			**2.45**			**6.03**

		Power	SAILING			HARBOUR			MANOUEVRING		
No on ship	Consumer	Inputs kW	Unit in operation	limit fact.	Power kW	Unit in op	limit fact.	Power kW	Unit in op	limit fact.	Power kW
	MACHINERY EQUIPMENT	**8.00**			**6.03**			**2.45**			**6.03**
	VENTILATION & AIR CODIONNING	**13.50**			**11.47**			**10.29**			**11.47**
	GALLEY EQUIPMENT	**4.00**			**6.03**			**2.45**			**6.03**
	ELECTRICAL LIGHTING	**1.50**			**2.23**			**1.58**			**1.28**
	DECK EQUIPMENT	**10.00**			**0.00**			**5.00**			**5.00**
	NAVIGATION EQUIPMENT	**6.50**			**5.73**			**3.80**			**5.73**
					0.00			**5.00**			**5.00**
	TOTAL (ship consumers)	**43.50**			**31.47**			**30.56**			**40.52**

The Ship electrical supply will consit of a Diesel Generator of 50 kW and Shaft Generator of 50 kW

7.2 Power generation (types of generators)

7.2.1 System configuration

The primary electric power plant configuration is defined by the type, number, size, and location of the generator sets and associated switchboards and bus ties. The requirements and constraints, which typically influence the electric power system configuration are:

a) Type of fuel carried on the ship;

b) Type of propulsion plant;

c) Type of major nonelectric energy-consuming support subsystems;

d) Maximum functional load (derived from the electric load analysis);

e) Power margin for future growth;

f) Minimum of two or three ship-service generator sets on merchant ships or naval vessels, respectively;

g) Minimum of one independent emergency generator set for the ship's most vital loads;

h) Space and weight constraints;

i) Economic constraints on first cost and operating costs;

j) Applicable regulatory body requirements.

Alternative plant configurations may be considered for a given set of requirements and constraints. Electric plant trade-off analysis may be conducted in conjunction with propulsion system trade-off. Hence, on most ships the prime movers for the ship-service generator sets are selected to be of the same generic type as the propulsion engines, or at least to operate on the same fuel. Also, on some ships, one of the ship-service generators may be mechanically driven from an auxiliary power-take-off from the propulsion train.

In general, the generator sets and associated switchboards are located within the same space and close to each other to minimize the cable runs between the generator and the generator switchboard.

Self-propelled merchant vessels are fitted with a minimum of two ship-service generator sets located in the engine room, plus a smaller diesel-driven emergency generator set or storage batteries located outside the machinery space, above the freeboard deck, and aft of the collision bulkhead. The emergency power system is designed such that upon a total loss of all ship-service power, the emergency switchboard is automatically isolated from the ship-service power system, and the emergency generator is connected to the emergency switchboard to supply the vital loads necessary for the safety of the ship and to get the ship-service power system and propulsion system back on line. Inherently, a loss of ship-service power results in a 10 to 45 seconds blackout, the time required to start the emergency generator set and bring it on line. On some ships, an automatically connected storage battery acts as a temporary power source to prevent the 10 to 45 seconds blackout.

7.2.2. System protection

The protection of the electric power system from fault currents and overloads, as required to ensure that a reliable, safe, and continuous service of power is provided, is a major design consideration. The maximum available fault-current capacity of an electric power system is a function of the generator characteristics, such as transient reactance. After the basic framework of the electric power distribution system has been laid out, a fault-current analysis must be conducted to determine the maximum available fault currents at the various distribution points (switchboards, load centers, panelboards, etc.) of the system. The result of this analysis are then used to select the type of circuit breakers or fuses to be used at each location. This can be accomplished by providing either fully rated selective protection or cascade (backup) protection. Fully rated selective protection is preferred since a fault current within a branch of the distribution system will result in the loss of that particular branch only, whereas a fault within any branch of a cascade system may result in a loss of power to a number of other branches fed by the same backup circuit breaker. Figure 7.1 illustrates the difference between the two schemes.

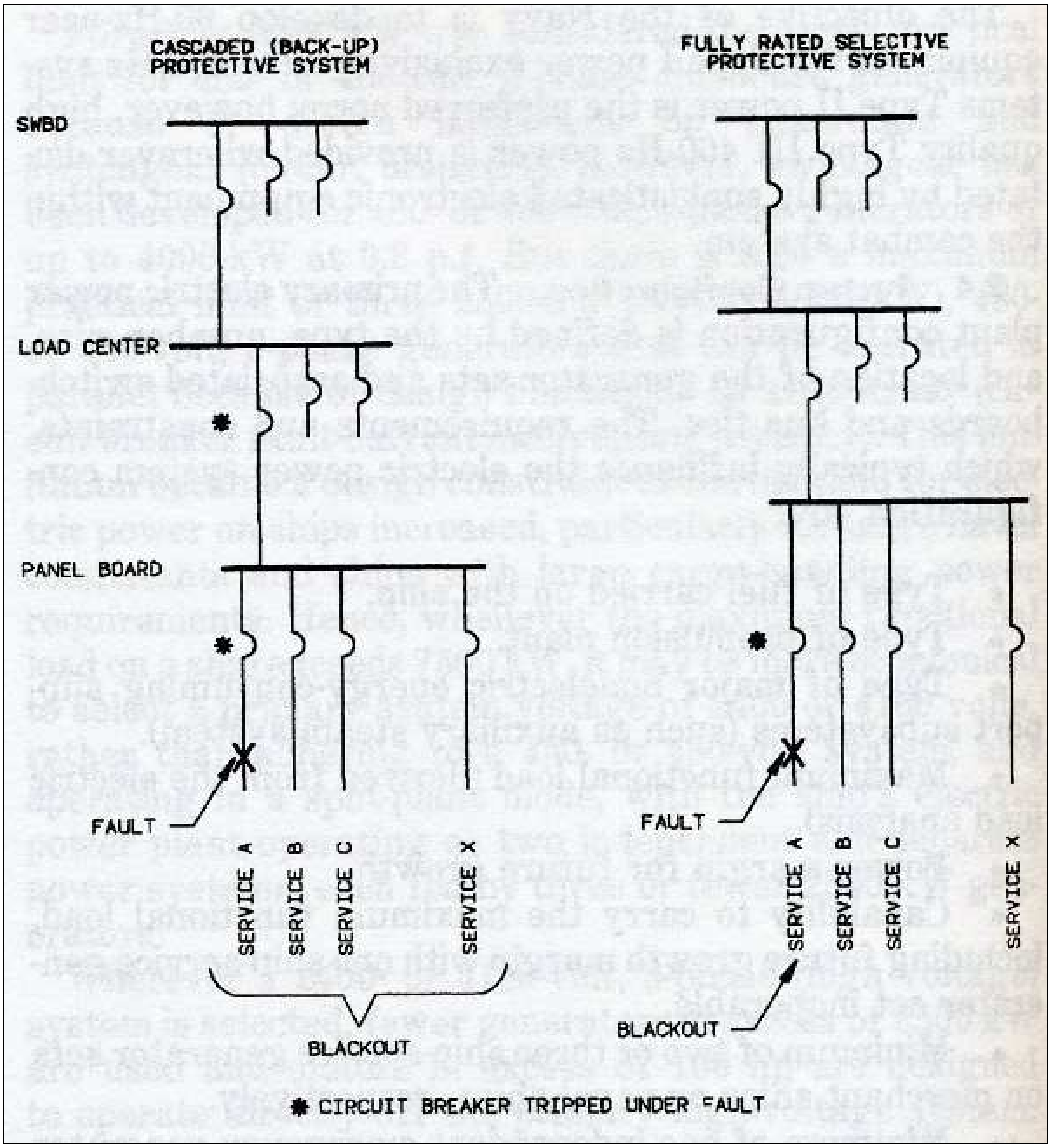

Fig. 7.1 – Alternative approaches to fault-current protection of electric power systems.

7.2.3. Power sources and conversion

a) Generator sets

Generator sets are normally completely packaged with all or most of the major components and auxiliaries, such as the prime mover, reduction gear (if required), generator, exciter, control panel, lubricating oil system, and cooling water system, factory assembled on a common bedplate. Discussion here is confined to consideration regarding prime movers of the diesel engine, since this type of prime movers are the most common on marine applications.

b) Diesel generators

Because of the low speed of the diesel engines, diesel-generators sets are appreciably larger and heavier than turbine-generator sets. Sets rated below about 1000 [kW] operate at speed up to 1800 [rpm]. Above that, most sets are designed for 1200 [rpm] or less. Also because of the low speed, the generator is coupled directly to the engine.

Apart from generator set auxiliaries mentioned above, a starting system is also necessary to run the diesel generator. This starting system may be pneumatic, hydraulic or electric, and consists of a starting motor or air distributor for sequential admission of air to the engine cylinders, strainer, and air control valves. A solenoid-operated valve may be provided for remote engine starting. Starting air systems are generally designed to operate at pressures of 125 to 450 [psi]. Starting air tanks and air compressors are normally furnished by the shipbuilder. Diesel generators rated at 500 [kW] or less generally use either electric or hydraulic starting system. Sufficient capacity for at least ten successive starts, beginning with cold engine, is provided with either method.

The generator may be of the two-bearing type with the rotor flexibility coupled to the engine crankshaft or may have a front bearing only with the rear shaft end coupled rigidly to and supported by the diesel engine crankshaft (see Figure 7.4).

c) Alternators and voltage regulators

A coil of wire rotating in a magnetic field produces a current. The current can be brought out to two sliprings which are insulated from the shaft. Carbon bushes rest on these rings as they rotate and collect the current for use in an external circuit. Current collected in this way will be alternating, that is, changing in direction and rising and falling in value. To increase the current produced, additional sets of poles may be introduced.

The magnetic field is provided by electromagnets so arranged that adjacent poles have opposite polarity. These 'field coils', as they are called, are connected in series to an external source or the machine output.

If separate coils or conductors are used then several outputs can be obtained. Three outputs are usually arranged with a phase separation of 120°, to produce a three-phase supply. The supply phasing is shown in Figure 7.2. The three-phase system is more efficient in that for the same mechanical power a greater total electrical output is obtained. Each of the three outputs may be used in single-phase supplies or in conjunction for a three-phase supply. The separate supplies are connected in either star or delta formation (Figure 7.3). The star formation is most commonly used and requires four sliprings on the alternator. The three conductors are joined at a common slipring and also have their individual slipring. The central or neutral line is common to each phase. The delta arrangement has two phases joined at each of the three sliprings on the alternator. A single-phase supply can be taken from any two sliprings.

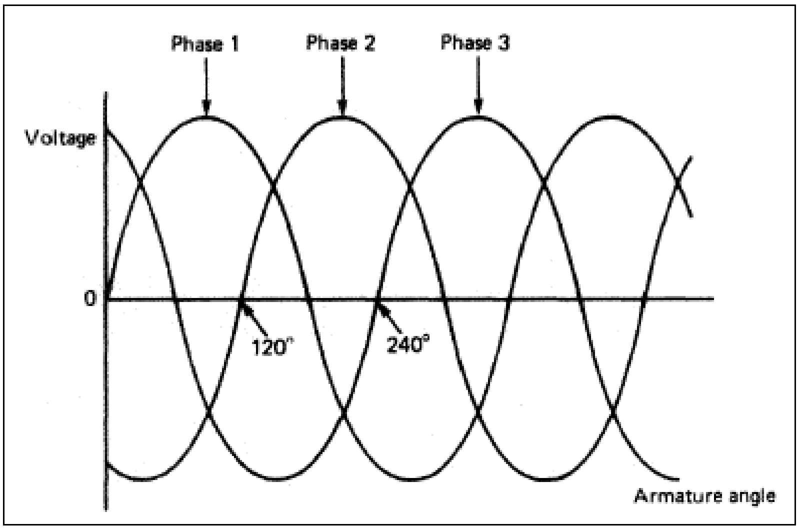

Fig. 7.2 – Three-phase alternator output.

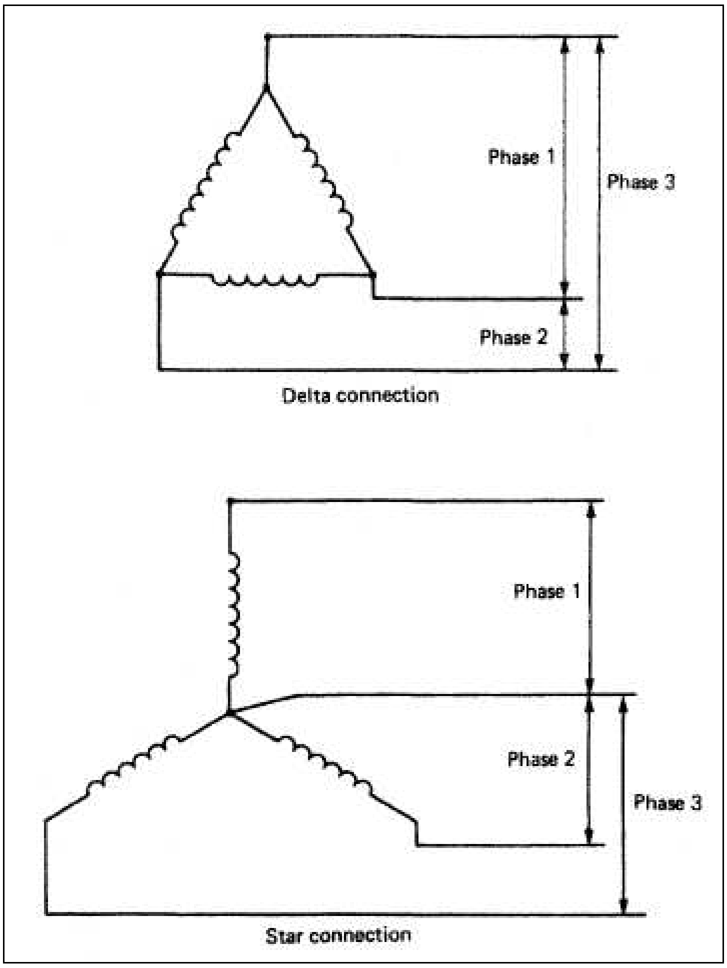

Fig. 7.3 – Star and delta three-phase connections.

So far, alternator construction has considered the armature rotating and the field coils stationary. The same electricity generating effect is produced if the reverse occurs, that is, the field coils rotate and the armature is stationary. This is in fact the arrangement adopted for large, heavy duty alternators.

The field current supply in older machines comes from a low-voltage direct current generator or exciter on the same shaft as the alternator.

Modern machines, however, are either statically excited or of the high-speed brushless type. The exciter is required to operate to counter the effects of power factor for a given load. The power factor is a measure of the phase difference between voltage and current and is expressed as the cosine of the phase angle. With a purely resistance load the voltage and current are in phase, giving a power factor of one. The power consumed is therefore the product of voltage and current.

Inductive or capacitive loads, combined with resistance loads, produce lagging or leading power factors which have a value less than one. The power consumed is the product of current, voltage and power factor.

The alternating current generator supplying a load has a voltage drop resulting from the load. When the load has a lagging power factor this voltage drop is considerable. Therefore the exciter, in maintaining the alternator voltage, must vary with the load current and also the power factor. The speed change of the prime mover must also be taken into account.

Hand control of excitation is difficult so use is made of an automatic voltage regulator (AVR). The AVR consists basically of a circuit fed from the alternator output voltage which detects small changes in voltage and feeds a signal to an amplifier which changes the excitation to correct the voltage. Stabilizing features are also incorporated in the circuits to avoid 'hunting' (constant voltage fluctuations) or overcorrecting.

Various designs of AVR are in use which can be broadly divided into classes such as carbon pile types, magnetic amplifiers, electronic types, etc.

The statically excited alternator has a static excitation system instead of a DC exciter. This type of alternator will more readily accept the sudden loading by direct on-line starting of large squirrel cage motors.

The static excitation system uses transformers and rectifiers to provide series and shunt components for the alternator field, that is, it is compounded. Brushes and sliprings are used to transfer the current to the field coils which are mounted on the rotor. The terminal voltage from the alternator thus gives the no-load voltage arid the load current provides the extra excitation to give a steady voltage under any load condition. The careful matching of components provides a system which functions as a self regulator of voltage. Certain practical electrical problems and the compensation necessary for speed variation require that a voltage regulator is also built into the system.

The brushless high speed alternator was also developed to eliminate DC exciters with their associated commutators and brushgear. The alternator and exciter rotors are on a common shaft, which also carries the rectifiers. The exciter output is fed to the rectifiers and then through conductors in the hollow shaft to the alternator field coils. An automatic voltage regulator is used with this type of alternator.

The construction of an alternator can be seen in Figure 7.4. The rotor houses the poles which provide the field current, and these are usually of the salient or projecting-pole type. Slip rings and a fan are also mounted on the rotor shaft, which is driven by the auxiliary engine. The stator core surrounds the rotor and supports the three separate phase windings. Heat is produced in the various windings and must be removed by cooling. The shaft fan drives air over a water-cooled heat exchanger. Electric heaters are used to prevent condensation on the windings when the alternator is not in use.

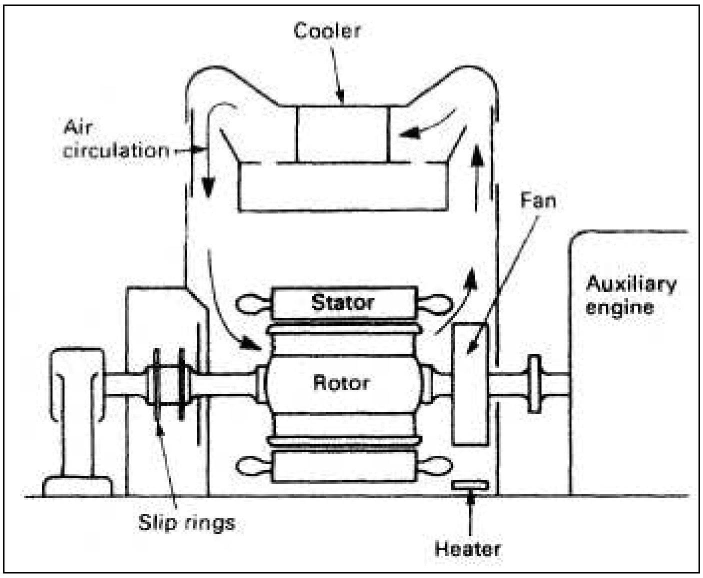

Fig. 7.4 – Alternator construction.

d) Transformers

Transformers are the most cost-effective method of converting AC power from one voltage to another at the same frequency. Transformers for shipboard use are of the dry, air-cooled type; they are rated for continuous duty and protected in a dripproof or splashproof enclosure. Transformers may be either of the single-phase or three-phase type. Three identical single phase transformers properly connected will not render the entire secondary system inoperative, but 3-phase transformers might be preferable because they require less space and weight.

e) Storage batteries

The battery is a convenient means of storing electricity. It is used on many ships as an instantly available emergency supply. It may also be used on a regular basis to provide a low-voltage DC supply to certain equipment. To provide these services the appropriate size and type of battery must be used and should be regularly serviced. Two main types of battery are used on board ship: the lead-acid and the alkaline type, together with various circuits and control gear.

e.1) Lead-acid battery

The lead-acid battery is made up of a series of cells. One cell consists of a lead peroxide positive plate and a lead negative plate both immersed in a dilute sulphuric acid solution. The sulphuric acid is known as the 'electrolyte'. A wire joining these two plates will have a potential or voltage developed across it and a current will flow. This voltage is about 2.2 [V] initially with a steady value of about 2 [V]. A grouping of six separate cells connected in series will give a 12 [V] battery. The word 'accumulator' is sometimes used instead of battery.

Actual construction uses interleaved plates in the cell in order to produce a compact arrangement with a greater capacity. The complete battery is usually surrounded by a heavy-duty plastic, hard rubber or bitumen case.

In the charged condition the battery contains lead, lead peroxide and sulphuric acid. During discharge, i.e. the providing of electrical power, some of the lead peroxide and the lead will change to lead sulphate and water. The sulphuric acid is weakened by this reaction and its specific gravity falls.

When the battery is charged, i.e. electrical power is put into it, the reactions reverse to return the plates to their former material and the water produced breaks down into hydrogen gas which bubbles out.

e.2) Alkaline battery

The basic cell of the alkaline battery consists of a nickel hydroxide positive plate and a cadmium and iron negative plate immersed in a solution of potassium hydroxide. The cell voltage is about 1.4 [V]. A grouping of five cells is usual to give about seven volts.

An interleaved construction is again used and each cell is within a steel casing. This casing is electrically 'live' being in contact with the electrolyte and possibly one set of plates. A battery consists of a group of cells mounted in hardwood crates with space between each. The cells are connected in series to give the battery voltage.

In the charged condition the positive plate is nickel hydroxide and the negative plate cadmium. During discharge oxygen is transferred from one plate to the other without affecting the specific gravity of the potassium hydroxide solution. The negative plate becomes cadmium oxide and the positive plate is less oxidized nickel hydroxide. Charging the battery returns the oxygen to the positive plate.

e.3) Battery selection

The choice between the lead-acid or alkaline type of battery will be based upon their respective advantages and disadvantages.

The lead-acid battery uses fewer cells to reach a particular voltage. It is reasonably priced but has a limited life. It does, however, discharge on open circuit and requires regular attention and charging to keep it in a fully charged condition. If left in a discharged condition for any period of time a lead-acid battery may be ruined.

The alkaline battery retains its charge on open circuit and even if discharged it can be left for long periods without any adverse effect.

Although more expensive it will last much longer and requires less attention. Also a greater number of cells are required for a particular voltage because of the smaller nominal value per cell.

Both types of battery are widely used at sea for the same basic duties.

7.3. Distribution of electrical power (switchboards, cableways and illumination)

7.3.1. Switchboards

The switchboards used in shipboard power systems can be functionally classified as ship-service (main) switchboards, emergency switchboards, load-centers switchboards, and secondary power system (on special purpose) switchboards. Ship-service switchboards generally include a generator section for each ship-service generator feeding the main switchboard, bus-tie, and shore-power sections, primary distribution sections, and secondary distribution units. The generator sections, bus-tie sections, shore-power sections, primary distribution sections are connected to the switchboard main bus and operate at the primary system voltage. The secondary distribution units are fed from the main bus through step-down transformers to permit the distribution of ship-service power at voltages below the primary system voltage.

Commercial ships, with the exception of large passenger vessels, usually have only one main switchboard, which is directly connected to all the ship-service generators. A single main switchboard has only one bus-tie circuit breaker for the main-to-emergency switchboard bus-tie, and one shore-power supply circuit breaker as illustrated in Figure 7.5.

Larger naval vessels and passenger ships have two or more main switchboards, each fed from its associated ship-service generator.

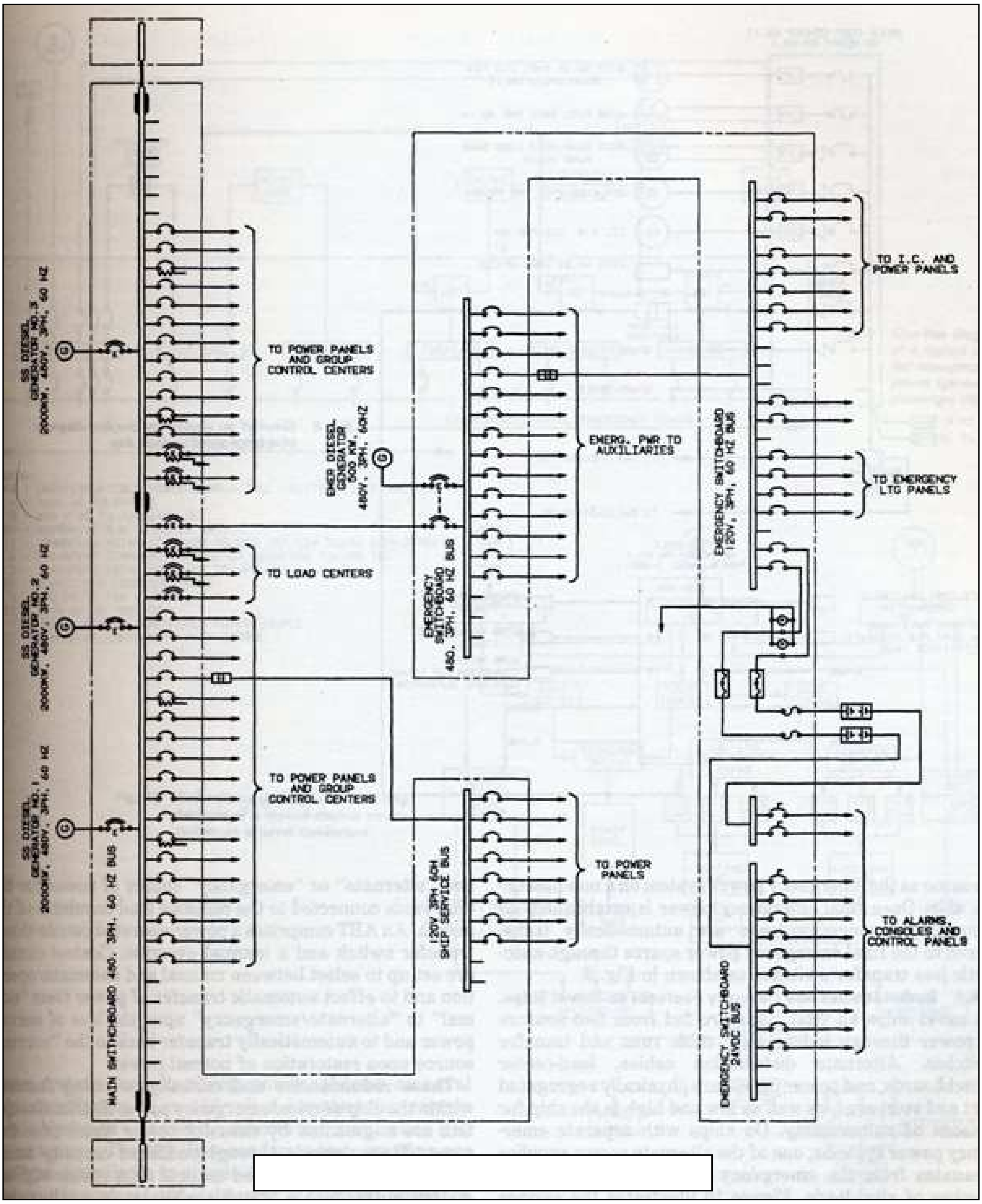

Fig. 7.5 – "Top level" one-line diagram for a typical commercial ship.

Main switchboards are located in the same space as the associated generator sets, although they are often sound isolated from the generator sets, with either the generator being housed in acoustic enclosure, or with the switchboard being arranged in the enclosed centralized machinery control room. The length of the electrically unprotected generator cables must be kept to a minimum through judicious arrangement of the associated generators and switchboards.

Switchboards are of a free-standing deck-mounted construction and may be either dead-front/open-rear or totally enclosed. Live-front switchboards are obsolete. Most switchboards require access from both front and the rear for hook-up, operation and maintenance and cannot be placed against a bulkhead. Switchboards are equipped with nonconducting handrails and gratings in front and with dripshields across the top to protect operating personnel and from dripping liquids and falling objects and debris, respectively. Figure 7.6 illustrates a typical main switchboard configuration.

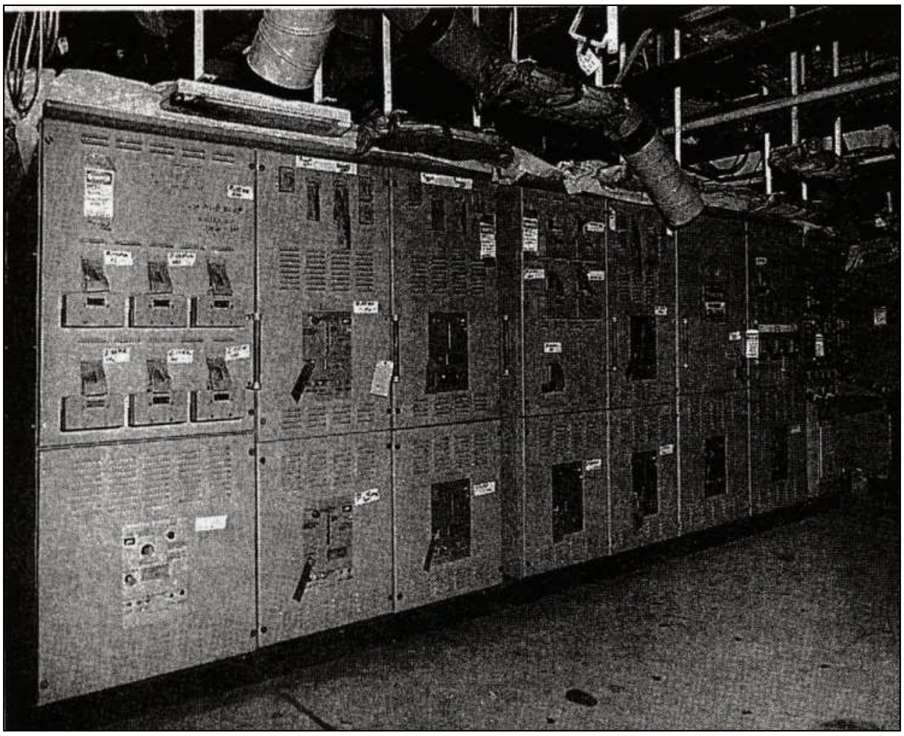

Fig. 7.6 – Typical main switchboard configuration.

7.3.2. Cableways

a) Cables

Shipboard cables may be either armored or unarmored. The armor is provided by a steel, bronze or aluminum basket weave over the outer jacket. Steel armor is rarely used. Bronze armor is preferred in damp or wet areas, such as in the weather. The primary purpose of the armor is to protect the outer jacket of the cable against mechanical damage particularly during installation phase.

Three-conductor cable must be used for all AC 3-phase circuits to neutralize the inductive effect that would cause heating of adjacent equipment or structure.

Signal and control cabling for electronics, command, control and communications are of the multiconductor type to contain most and preferably all of the signals pertaining to the same functional group of interconnections between two pieces of equipment.

The length of each run of cable must be determined from wiring deck plans, or isometrics, using a standard map measure. In addition to the lengths measured from plans, the following allowances should be made:

- 3 meters for each vertical run between decks;

- 1.5 meters for each vertical run from overhead to bulkhead mounted equipment;

- 3 meters for each connection to a switchboard.

b) Cable installation

All cables should be continuous between terminators and, insofar as practicable, be routed to avoid areas where excessive heat, moisture, or oil be encountered. Cables should not be run through oil tanks or pump rooms unless they are enclosed with watertight trunks; also, cables should not be run behind, or embedded in heat insulation, the cable should run in a continuous pipe.

Cables should be grouped and routed in main wireways in an efficient manner and should be supported as shown in Figure 7.7.

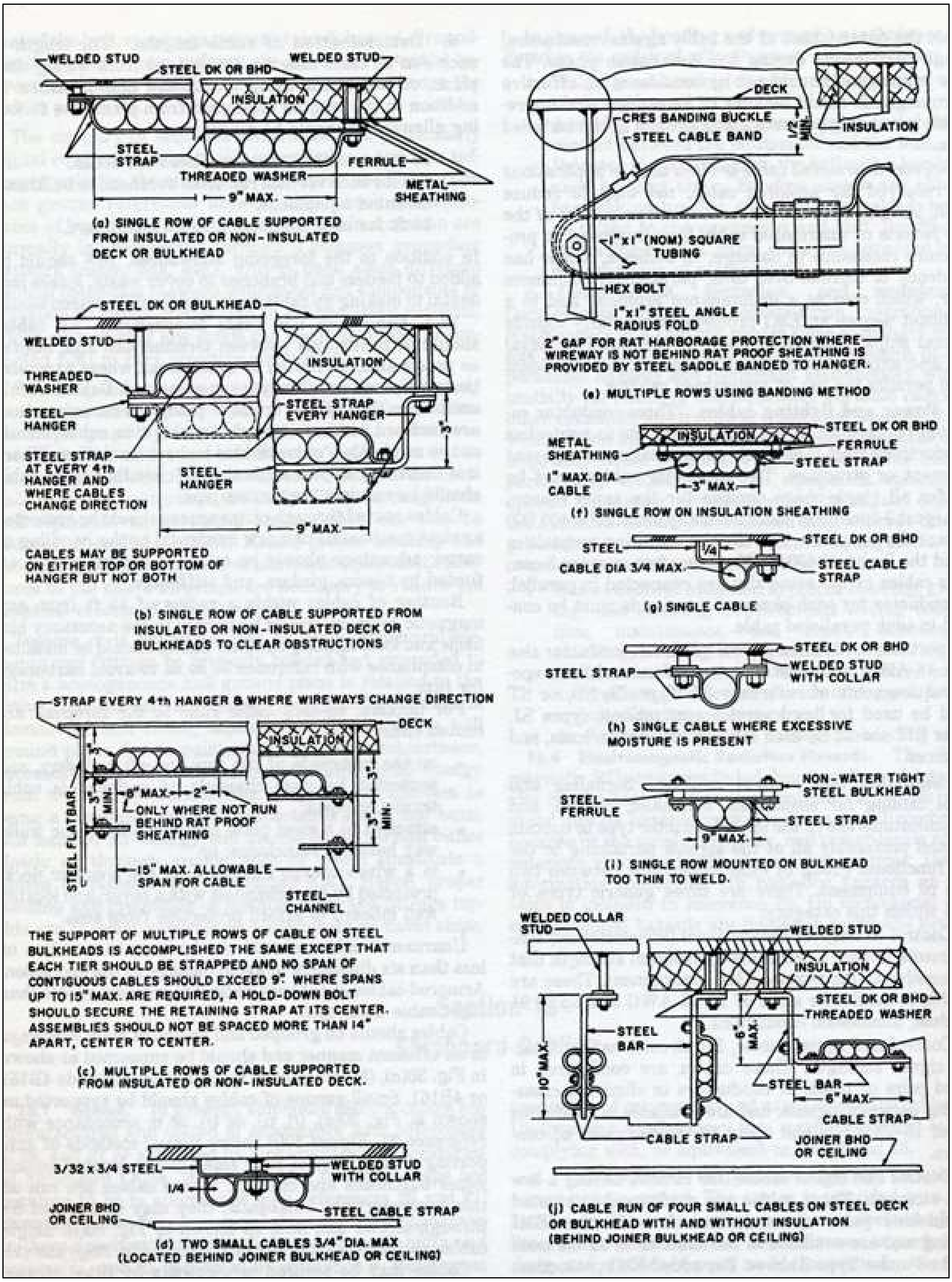

Fig. 7.7 – Typical cable installation methods.

c) Cable penetrations

A variety of the alternative methods of passing cables through decks and bulkheads is illustrated in Figure 7.8.

Cable penetration of non-tight decks and platforms are usually through clear openings of adequate size. Cable penetration of watertight and airtight bulkheads are through stuffing tubes (see Figure 7.9).

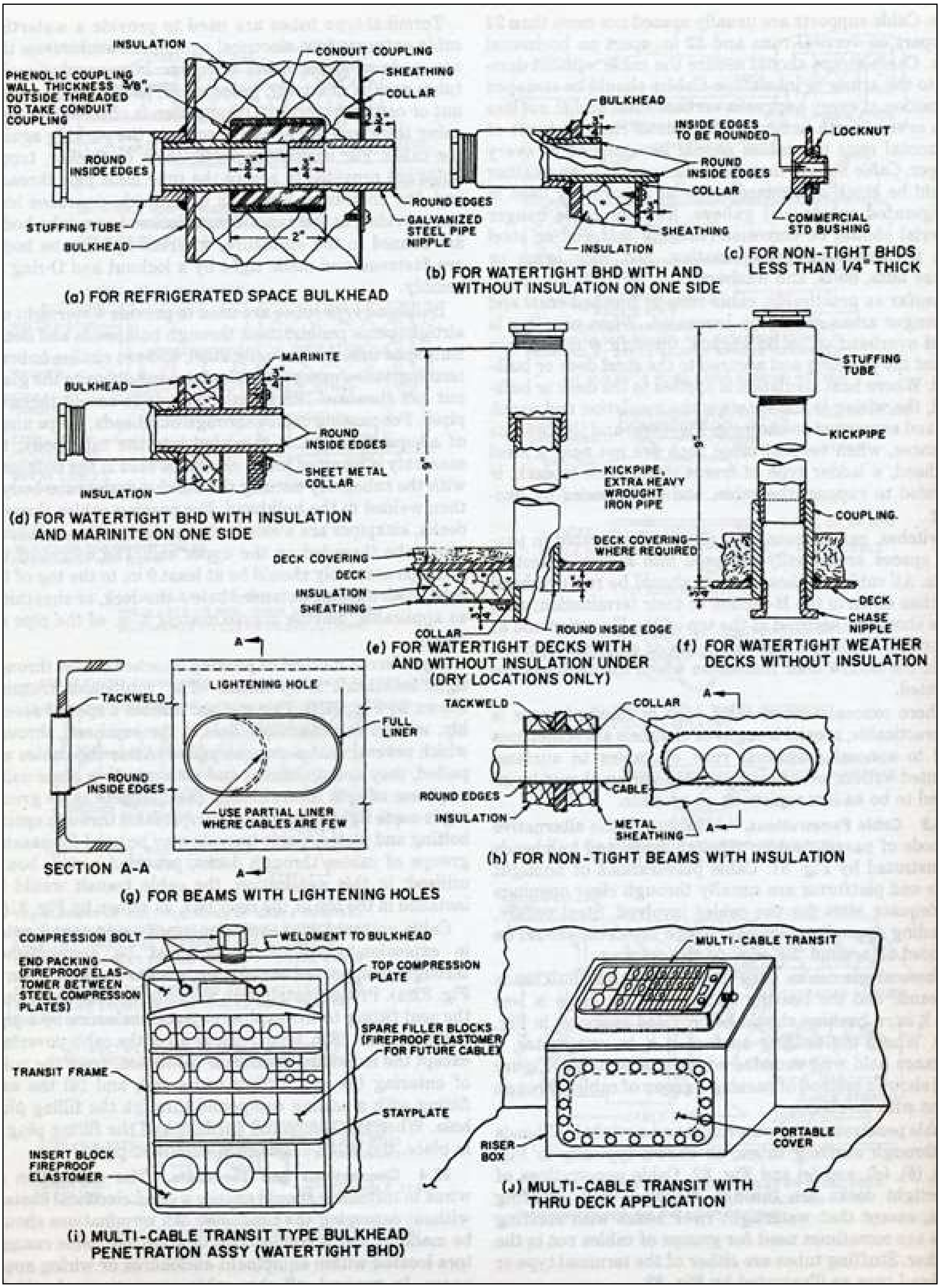

Fig. 7.8 – Typical cable penetration methods.

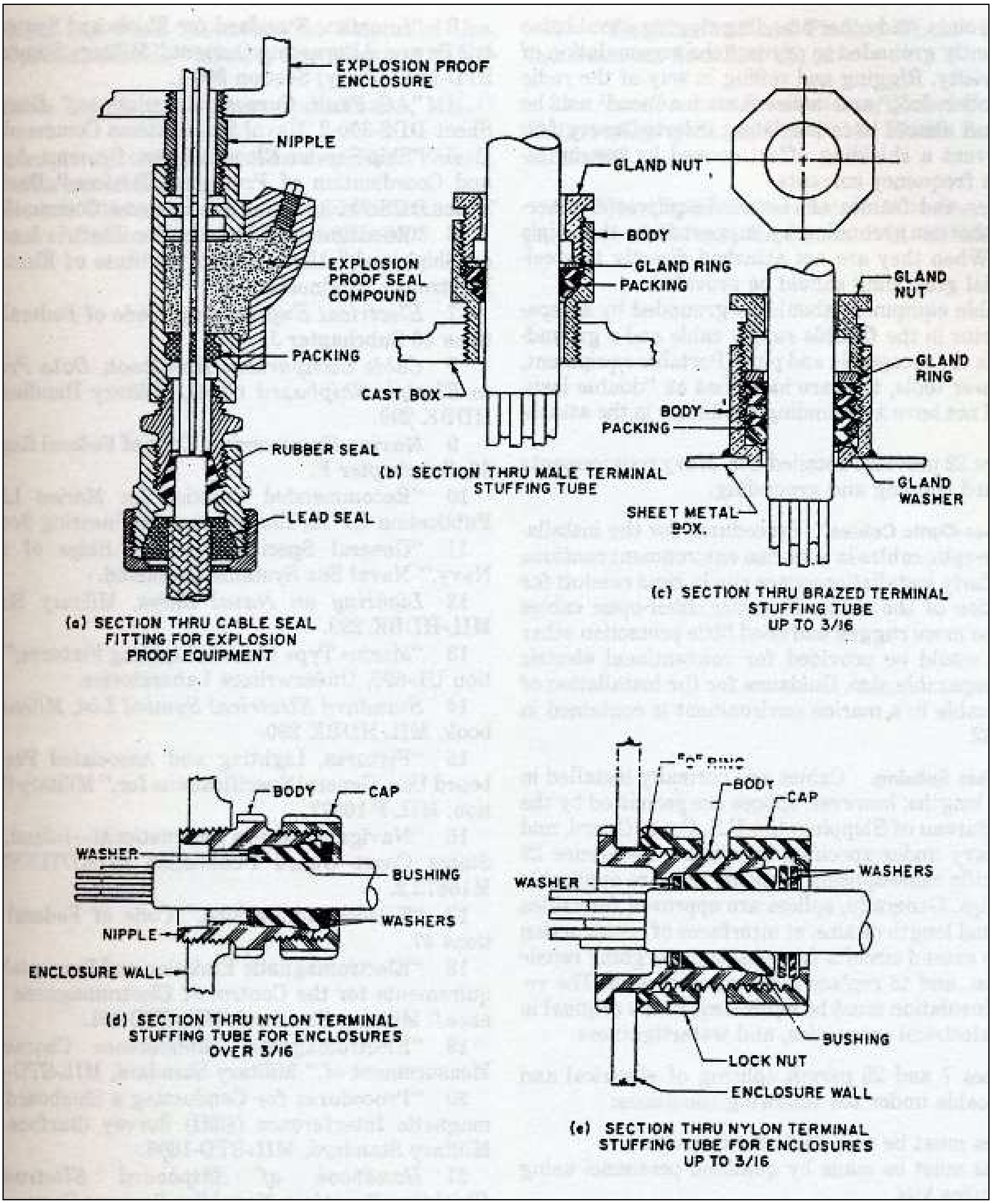

Fig. 7.9 – Typical cable stuffing tubes.

d) Connections and terminals

The connection of wires to terminals should ensure a good electrical contact without damaging the conductor. All terminals should be made of screw connections or approved cable connectors located within equipment enclosures or wiring appliances.

e) Cable splicing

Cables are normally installed in continuous lengths; however, splices are permitted by the regulatory bodies under specified conditions. Generally, splices are approved for cables of exceptional length or size, at interfaces of construction modules, to extent circuits for vessels undergoing repair or alteration, and to replace a damaged section. The replacement insulation must be equivalent to the original in thickness, electrical properties, and watertightness.

7.3.3. Illumination

The lighting system is one of the ship's vital support subsystems. Its purpose is to provide illumination of spaces, operating stations, and other features and functions throughout the ship in support of the activities and duties of personnel.

The selection and layout of the number of fixtures for any given space, area, or work task are determined through lighting calculations. For general illumination calculations in regular compartments with even and normal deck heights, the "lumen" method is used.

As illustrated in Figure 7.10, the light intensity of a fixture (light projector) at a point *P* will be given by:

$$E(lux) = \frac{I.\alpha}{\left(\sqrt{a^2 + h^2}\right)^3} = \frac{I.\alpha.\cos^3 \alpha}{h^2} \qquad (7.4)$$

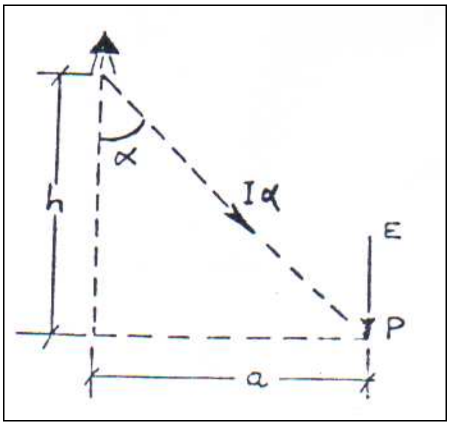

Fig. 7.10 – Light intensity of a vertical projector.

As illustrated in Figure 7.11, if the projector is now installed at a certain inclination angle relatively to the deck, then the light intensity of a projector at a point *P* will be given by:

$$E^{'}(lux) = I.\alpha \frac{\phi}{1000} \frac{\cos^3 \alpha}{h^2} \cos \beta \qquad (7.5)$$

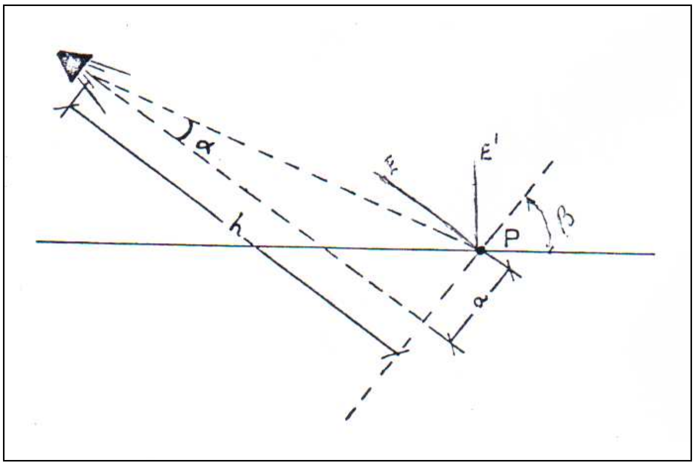

Fig. 7.11 – Light intensity of an inclined projector.

7.4. Description of the most common servomotors configurations

Practically all of the electric motors for ship's auxiliaries are of the AC asynchronous squirrel-cage induction type.

7.4.1. Electrical characteristics of AC squirrel-cage induction motors

The speed, power, and duty rating of a motor are fixed by the required input to the driven machine. The duty ratings (operating cycle) for shipboard applications are classified as continuous duty or intermittent duty.

Squirrel-cage induction motors are designated as design A, B, C and D. Each design offers different torque, speed, and current characteristics to meet various operating requirements, as may be seen from Figures 7.12 and 7.13.

Design A motors have normal starting torque, high starting current, and low slip. This motor is not used for the usual shipboard applications because of its high starting current characteristics.

Design B motors have normal starting torque, low starting current, and low slip. This is the motor most commonly used on shipboard applications; it is generally used for centrifugal pumps, fans, blowers, motor-generator sets, and compressors that are not loaded when started.

Design C motors have a high starting torque, low starting current, and low slip. This motor is normally used for applications such as steering gear, anchor windlass, and compressors that are loaded when started.

Design D motors have a high starting torque, moderate starting current, and high slip. This motor is normally used for capstans, winches, valve operators, conveyors, elevators, and hoists.

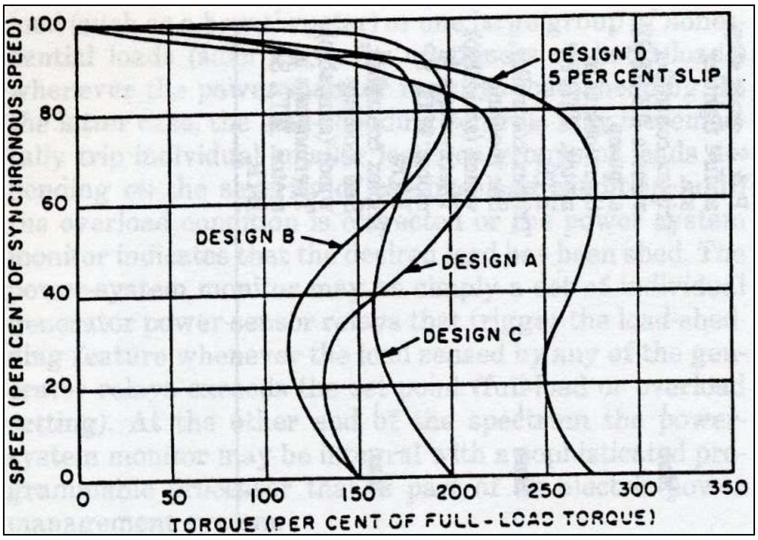

Fig. 7.12 – Torque-speed curves of squirrel-cage induction motors rated 30 to 50 [HP].

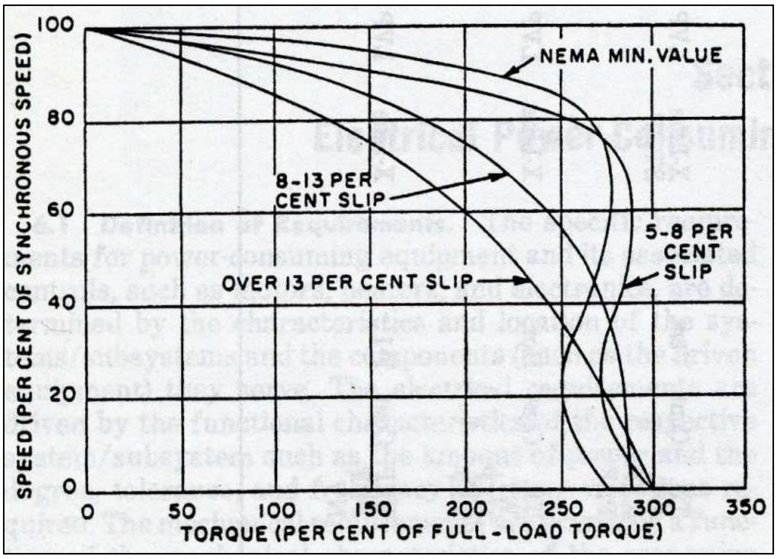

Fig. 7.13 – Torque-speed curves of design D squirrel-cage induction motors for various slip values.

7.4.2. Mechanical characteristics of AC squirrel-cage induction motors

A wide variety of enclosures and methods of ventilation is available for motors in marine service. The specific types selected depend on particular environmental condition to which the motor is subjected. The types of enclosures and methods of ventilating motor most commonly use are as follows:

a) Dipproof protected, self-ventilating – used for most applications in dry, sheltered locations;

b) Totally enclosed, fan-cooled– used to prevent the entry of foreign contaminants;

c) Waterproof, non-ventilated – applications mounted on weather deck;

d) Explosion-proof, fan-cooled – applications in atmosphere containing an explosive mixture;

e) Submersible, self-ventilated – normal operation in air and in emergency when submerged.

7.5. Obtaining electrical power by means of motor aggregates

In addition to auxiliary-engine-driven alternators a ship may have a shaft-driven alternator. In this arrangement a drive is taken from the main engine or the propeller shaft and used to rotate the alternator. The various operating conditions of the engine will inevitably result in variations of the alternator driving speed. A hydraulic pump and gearbox arrangement may be used to provide a constant-speed drive, or the alternator output may be fed to a static frequency converter. In the static frequency converter the AC output is first rectified into a variable DC voltage and then inverted back into a three-phase AC voltage. A feedback system in the oscillator inverter produces a constant-output AC voltage and frequency.

7.6. Description of current automation solutions for propulsion and marine auxiliary systems

Automation can be defined as an apparatus, process, or system that is self-acting or self-regulating generally through the employment of mechanical or electrical devices that take the place of human observation, effort, and decision making. This is done through the application of various control schemes generally referred as “close-loop” or “open loop” controls. A close-loop control system maintains the desired operation by comparing the actual output (the controllable variable) to the desired output (the set point). The difference between actual and desired creates an error signal. The error signal is fed back to the control elements, which act upon it to reduce the error signal within an acceptable tolerance band. Such a system is self-regulating. Open loop control systems do not employ the feedback principle. A simple switch is an example of an “open loop” control. Open loop controls are used in automated systems where system operation can be predicted with a high degree of certainty. For example, engine room ventilation fans are often driven by two-speed motors which, if started across the line on high speed, might impose an unacceptably large voltage dip on the electrical distribution system. An open-loop control scheme could be devised which, upon depression of the fast-speed pushbutton, would cause the motor to start on low speed but, after sufficient time has elapsed for the fan to accelerate, to transfer to high-speed automatically. Open-loop control systems are self-acting but not self-regulating.

When designing automated systems, in addition to the purely engineering considerations involved, marine engineers of the command and control branch must also have an appreciation for the skill level and training of the crew and the requirements of the regulatory bodies.

Automation is an essential and integral aspect of the design of virtually all shipboard equipment and systems. Automated systems that are self regulating can hold process variables within very close tolerances – tolerances that manual control could not maintain indefinitely. An example of such control is the regulation of voltage and frequency of the ship’s electrical generators under varying load conditions.

Automation can enhance safety by constantly and simultaneously monitoring hundred of operational parameters, such as operational conditions of a propulsion plant. Rather than simply displaying raw data, automated systems are generally designed to provide information that is needed to make a decision during an emergency. For example, a collision avoidance radar system warns the watch officer of other ships operating in the vicinity, ships in the area, and displays information giving the closest point and time to approach for each target.

In addition to enhancing ship safety, automated systems serve numerous other functions. Those that monitor the stack emissions and oil content of bilge water discharged overboard in order to guard against potential environment pollution. Other types of automated systems are used to ensure that allowable hull stresses are not exceeded because of the improper loading of cargo. More mundane yet essential tasks such as spare-parts inventory and crew timekeeping are also reliant upon automation for effective execution.

In summary, automated shipboard systems have generally been developed within the following disciplines:

a) Propulsion systems;

b) Navigation;

c) Vessel management;

d) Cargo control.

7.6.1 Propulsion systems

One of the first approaches used to reduce the size of the engine-room crew was the centralization of then indicating devices and manual controls, such as meters, gauges, and switches, which had been located adjacent to the equipment affected. A single console based on computers technology with micro-processors-controllers, CRT or TFT displays, and keyboards is shown in Figure 7.14. Figure 7.15 is a schematic view of a typical system layout. The microprocessor controllers are the principal devices that control various processes. Each controller is able to receive analog and digital inputs from the field, perform processing and alarm checking, perform control algorithms, and output to motor controllers, valves, and other actuators.

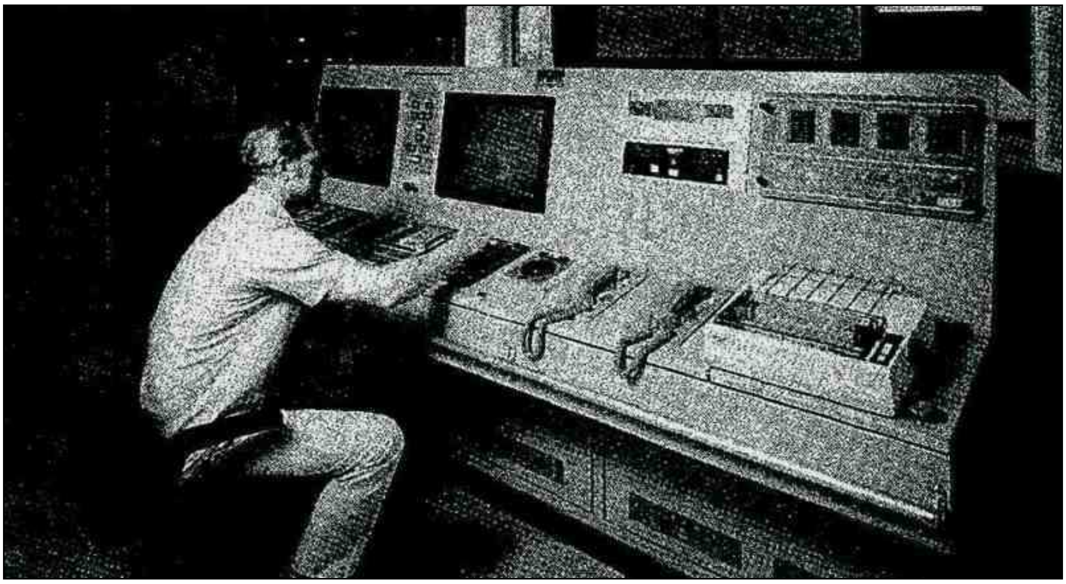

Fig. 7.14 – Microprocessor-controlled propulsion plant console.

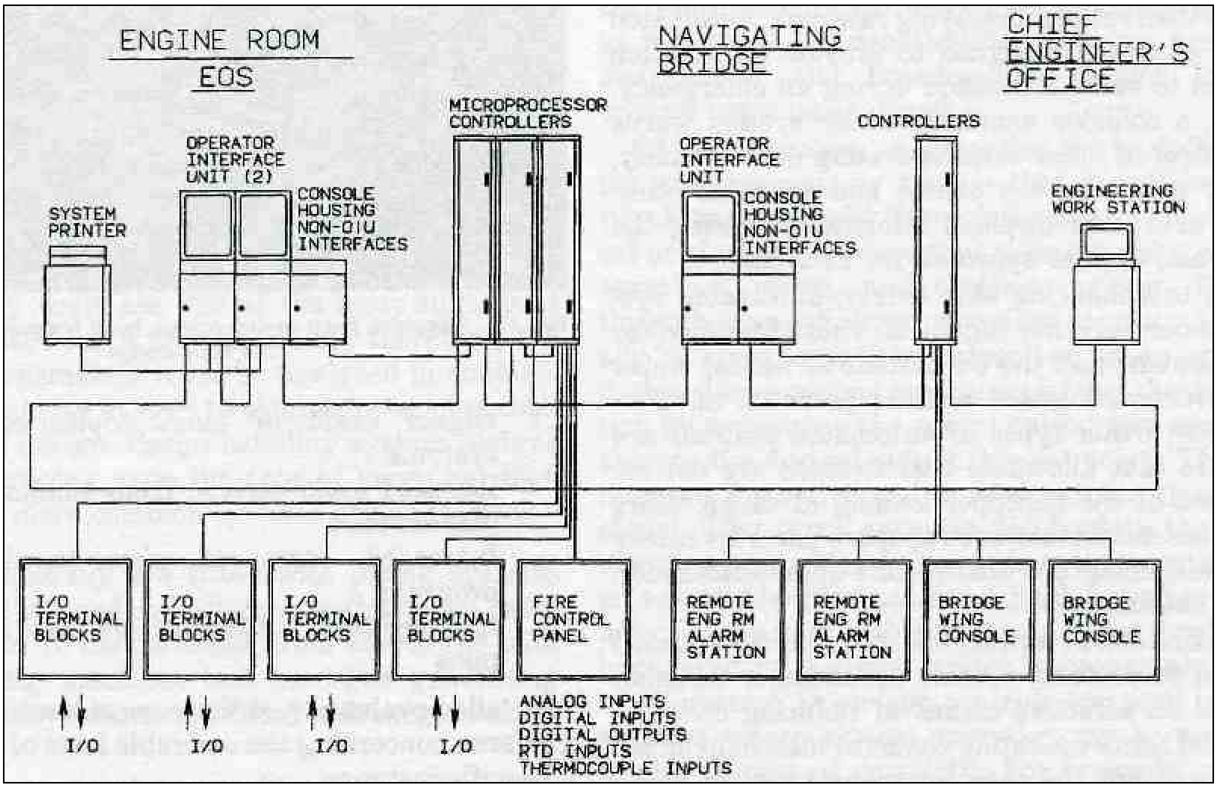

Fig. 7.15 – Typical propulsion plant control system schematic.

7.6.2 Navigation

The term "automation" is seldom used when discussing navigation systems but, in fact, advances in electronic aids to navigation have taken the place of human observation, effort, and decision making in most if not all aspects of ship's navigation.

Radar extends man's vision not only in range but into darkness and fog; echo depth sounders provide the depth of water under the keel, and sonar maps the contour of the bottom. Global Satellite Positioning (GPS) and other navigation systems give the ship position and render the sextant and chronometer obsolete. The gyro-pilot keeps the vessel on the correct heading without the helmsman's intervention. Collision-avoidance radar systems act as "lookouts" able to automatically acquire and constantly monitor a number of targets, plot their speeds and courses, present these vectors on the display screen, and calculate their closest points of approach to own ship and the time before that will occur.

On an integrated bridge all electronic inputs – from radar, gyro-compass, speed-log, depth sounder, GPS, wind-speed/direction, outside temperature, and barometric pressure - are combined in a common control/display. Figure 7.16 is a photograph of a typical integrated bridge.

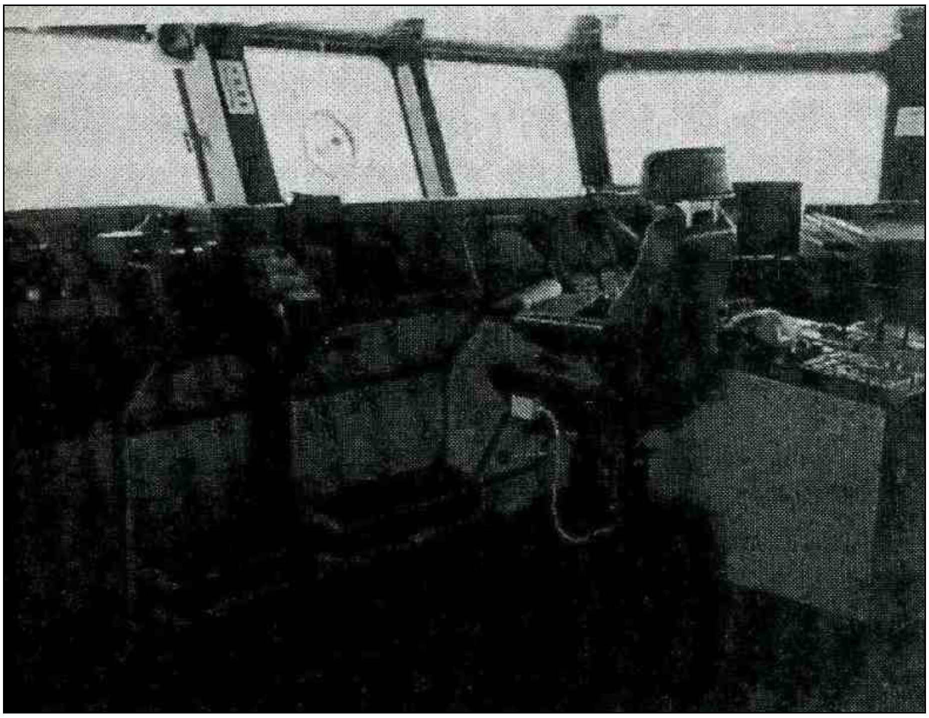

Fig. 7.16 – Typical integrated bridge arrangement.

7.6.3 Vessel management

The same computer used in navigation or engine-room automation packages can also be used, with appropriate software, to enhance vessel management. A typical application of spare-parts inventory system, which can record and control spare-parts availability not only on an own-ship basis, but on a fleet-wide basis as well. Another example is a planned maintenance program, which is also designed to control maintenance activity on fleet-wide basis.

7.6.4 Cargo control

Just as with engine-room automation systems, cargo automation systems are microprocessor based. On tank vessels mimic displays of pumps and valves are enhanced with real-time status information of that equipment, which appears on the screen with tank ullage data.

Tank-level information can be automatically transmitted to a loading computer that calculates the ship trim and stability and hull stresses during cargo loading and unloading operations. On tankers and on other types of cargo vessels, such as containerships and RORO, loading sequence data can be entered manually, to explore any potential adverse effects on a planned loading scheme, before actually taking on cargo.