Developments in Marine Electrical Installations with Particular Reference to A.C. Supply

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In selecting the above title for this paper the author fully realized how impossible it was to cover the whole field of marine electrical engineering in one paper.

An endeavour has been made, however, to give the marine engineer a clearer understanding of the technical, operational and economic problems which have arisen as a result of the continually increasing size and capacity of electrical installations.

The author considers that the 220-volt d.c. system, particularly for the larger installations, is completely out-of-date. The adoption of a 440-volt 3-phase a.c. system, properly planned and carried out, will result in a safer and more reliable system, together with a far more economical use of valuable raw materials. In general, the first cost will be less and maintenance cost considerably less.

INTRODUCTION

In considering the preparation of this paper it was appreciated that the subject of most interest was that related to a.c. installations, but if the reasons for such a system are to be clearly understood it is necessary to start at the beginning and proceed step by step. On deciding to proceed on these lines, it was also realized that the paper could not be effective without a little outspoken comment; such comment, however, is considered to be constructive criticism and privileged by virtue of qualification and a lifetime of experience in the operation and maintenance of electrical installations.

In the past these installations have chiefly been developed by the shipbuilder and equipment manufacturers to which shipowners' representatives have in general acquiesced, and it is in the interest of both shipbuilders and equipment manufacturers to maintain the *status quo*.

There is a growing school of thought that the term "marine" is often misapplied and it was encouraging to note in the Institute's TRANSACTIONS(1) the observation of a progressive shipowner that "In some costing departments the word 'marine' seemed to mean an automatic 30 per cent increase above the prices for similar equipment destined for land use". Such an observation is perfectly true.

If real progress is to be made, if the shipowner is to reap the economic benefits which he is entitled to receive by the adoption of new ideas and the use of different materials, a radical change must take place in the attitude towards marine electrical engineering. It must be recognized by all for what it is, a specialized subject, and the shipowner must have on his staff a person who by virtue of his technical qualifications and practical experience can speak the same language, sometimes, it may be said, better than the builders' and sub-contractors' electrical experts.

That an entirely different approach should be made is recognized in certain quarters by the very fact that today the shipowner has very strong representation, through his electrical representatives, on the major national technical committees.

D.C. DEVELOPMENT

Previous to the advent of the motorship, electrical installations were of a simple nature, and consisted of electric lighting, cabin fans, a small number of ventilating fans and possibly one or two electric toasters, the system operating at 110 volts with earth, or hull, return, the average 15,000 ton passenger/cargo liner having a total generating capacity of some 300 kW.

With the coming of the Diesel-propelled vessel it became desirable to adopt electrically-driven auxiliaries for engine room, steering gear and deck machinery, and the only logical step to take, and which was taken, was to double the operating voltage, and so the 220-volt double-wired system became the standard, thus reducing the weight, volume and cost of equipment relative to power generated, distributed and utilized.

In those early days of the motorship the total generating capacity of a 10,000 ton, twelve passenger cargo liner was some 400 kW. Then, electricity having proved to be successful for auxiliary purposes, the next step was to utilize it for cooking and heating services, and in the mid 1920s the position was reached where a 20 000-ton passenger liner had a generating capacity of 1,600 kW. Another development was the installation of electrically-driven refrigerating compressors and the substitution of electrically-driven fans for air cooling in lieu of brine piping.

As a further indication of the growth of electrical installations it is of interest to record that the company with which the author is associated is replacing a class of vessel built in 1928, the generating capacity of these early ships being 800 kW, whereas the capacity of the replacements will be 3,500 kW.

Generating capacity alone is not a true indication of the size of an installation; the total connected load will be two to three times the generating capacity according to the type and class of ship.

Even now there are no signs that we have reached saturation point; standards of lighting and heating are increasing, additional items are being fitted for hotel and cooking services, whilst another question to be faced by the shipowner is that of air conditioning, not only for passenger accommodation, but also for the crew.

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As the demand for power has increased over the years, and still increases, it has been met by continually increasing the size, and hence the weight and space occupied, of generators, cables, control and switch gear. No attempt whatsoever has been made towards a better and more economical utilization of valuable raw material, or to reduce weight/kW or space occupied. The world demand for copper results in the maintenance of a very high price level. Class "A" insulation still remains the generally accepted practice for marine electrical machines, although far more economical alternatives are available. Motors are still designed on a full-load plus sustained overload rating, though it is only fair to state that this question is under discussion. Control gear has over the years become more elaborate, and hence, not only more costly, but more troublesome.

The net result of all this growth, rather than development, results in larger, heavier, more costly and more troublesome installations.

EARTH FAULTS

The tracing of earth faults becomes increasingly difficult the larger these installations become. An earth fault left untraced is a potential fire hazard should a second fault develop on the opposite pole. According to the textbook, two earths, one on each pole, should create a short-circuit and fuses should blow or circuit breakers open. A ship is a live, moving, working body, and such a combination of earths can result and have resulted in arcing taking place and fires have developed. Such earths on the other hand may result in tracking taking place which can once again develop into fires.

A combination of earth faults can arise whereby such circuits as electric heaters become energized, though switched off; motors with automatic controllers may also be energized although the control switch is in the "off" position. Considerable thought has been given to this problem, but there is no easy and effective manner of locating such faults on large d.c. installations. With a.c. installations this problem can be reduced; in fact it could almost be eliminated if economic considerations were not taken into account.

SHORT-CIRCUIT PROTECTION

This is a question which requires very serious consideration. When a short circuit takes place the magnitude of the short-circuit current depends on the capacity and number of generators on the busbars and the resistance or impedance of the circuit.

For d.c. generators the initial short-circuit current can be taken as being ten times full-load current, but with the a.c. generator the initial value of short-circuit current, when a complete short circuit is applied to the terminals of the alternator, depends upon the internal impedance of the alternator and whether the current flow is symmetrical or asymmetrical.

In modern alternators the internal impedance is usually of the order of 10 per cent. This means that if the machine is operating (at any load or power factor) at normal voltage, the instantaneous value of short-circuit current is ten times full-load value (R.M.S. amperes) if the short circuit is applied at the instant which results in a symmetrical current flow, or twice this (R.M.S. amperes) if the short circuit is applied at an instant which results in an asymmetrical current flow. The d.c. component of the asymmetrical short-circuit current decays rapidly during the first cycle. Because of this rapid decay and because the circuit breaker protecting the alternator does not operate instantaneously, it is generally sufficient to assume that the circuit breaker will be called upon to rupture only about 80 per cent of the initial value of the asymmetrical short-circuit current. The full value, however, should be taken into consideration when estimating the mechanical stresses set up when closing a circuit breaker on to a short circuit.

The total contribution towards the magnitude of the current also depends upon the size and number of motors running at the time the short circuit takes place, the motors feeding back into the fault.

In the author's opinion, further research must be carried out in order to solve the question of short-circuit current values for various installations, and in order to ensure that correct protective equipment is fitted. It is suggested that the following values should be accepted in estimating short-circuit current values until more detailed research has been carried out:—

D.C. generators	10 times rated current
D.C. motors	6 times rated current
A.C. generators (10 per cent impedance, symmetrical current flow)	10 times rated current
A.C. generators (10 per cent impedance, asymmetrical current flow)	20 times rated current
A.C. motors	3 times rated current

TABLE I.—COMPARATIVE VALUES OF SHORT CIRCUIT CURRENT FOR 220-VOLT D.C. AND 440-VOLT A.C. 3-PHASE

System	Generator capacity	Short circuit, amperes	Motor capacity, h.p.	Short circuit, amperes	Total short circuit, amperes
220-volt d.c.	2,400 kW	109,080	1,000	24,000	133,080
440-volt a.c., 3-phase	3,000 KVA	39,360 (symmetrical)	1,000	4,800	44,160
440-volt a.c., 3-phase	3,000 KVA	78,720 (asymmetrical)	1,000	4,800	83,520

In order that this problem may be appreciated, Table I is given showing the total prospective short-circuit currents for a typical installation. It is assumed that five 600-kW. generators are installed and that at no time are more than four connected to the busbars, and that 1,000 h.p. of motors are running at the time of maximum load. The table shows the values for 220-volt d.c. and 440-volt 3-phase a.c. symmetrical and asymmetrical current flow.

The true meaning of these figures is that the protective devices, such as fuses and circuit breakers, must be designed to cope with these values of short-circuit current, and hence for the 220-volt d.c. system such devices have to give protection against a prospective current far greater than the "asymmetrical" short-circuit current of the 440-volt a.c system.

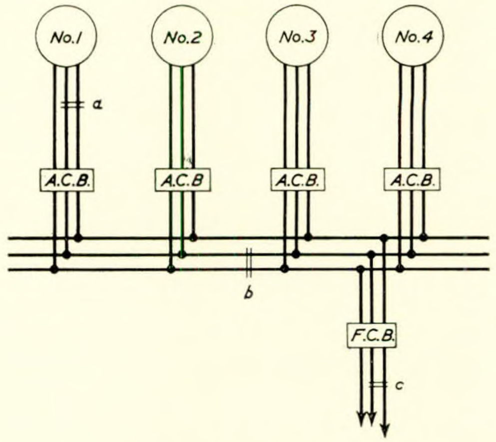


FIG. 1(a)—*Four 750-kVA 440-volt three-phase alternators each of 10 per cent impedance*

ACB—Alternator circuit breaker
FCB—Feeder circuit breaker
a
b } Points of short circuit fault
c

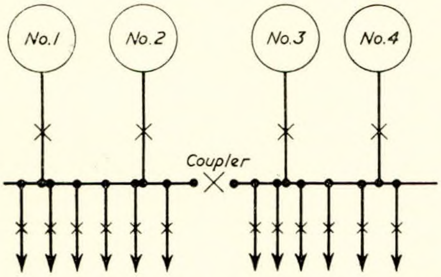


FIG. 1(b)—*Four 600-kW 220-volt direct current generators*

Total short circuit current with coupler closed, 109,080 amperes
Total short circuit current at each section with coupler open, 54,540 amperes

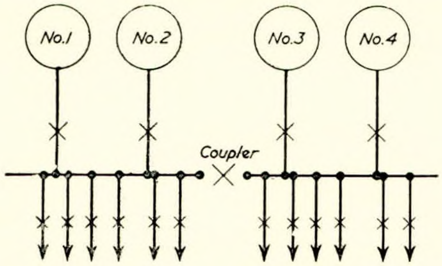


FIG. 1(c)—*Four 750-kVA 440-volt three-phase alternators*

Total short circuit current (asymmetrical) with coupler closed, 78,720 amperes
Total short circuit current at each section with coupler open, 39,360 amperes
Total short circuit current (symmetrical) at each section with coupler open, 19,080 amperes

Fig. 1(a) shows four 750-kVA 3-phase 440-volt alternators connected to the main switchboard busbars, and values of short-circuit current are given when short-circuit faults develop at points (*a*), (*b*) and (*c*), the latter being on an outgoing feeder circuit.

The asymmetrical short-circuit current of each alternator is 19,680 amperes, and with a fault at point (*a*), No. 1 alternator circuit breaker will have to deal with a fault current of 59,040 amperes; that is, the total fault current of the remaining three machines. With a fault at point (*b*) the alternator circuit breaker will only have to deal with the short-circuit current of its respective alternator, namely, 19,680 amperes. A fault at (*c*) results in all four alternators feeding into the fault, and the total short-circuit current the feeder circuit breaker has to cope with is 78,720 amperes.

It has been shown in Table I that the total instantaneous short-circuit current for the 220-volt d.c. installation quoted is 109,080 amperes. As far as fuses are concerned the highest category of duty is one where the fuse will operate efficiently with a prospective current of 33,000 amperes. It is obvious therefore that to fit such fuses on a main switchboard where there is a prospective current of over 100,000 amperes is, to say the least, potentially dangerous—others have used the word "terrifying". As far as circuit breakers are concerned the author knows of no hard and fast rule with regard to stated operating efficiency.

It does appear therefore that the industry is building up installations with astronomical short-circuit current values, closing its eyes, and hoping for the best.

It will be noted from Table I that if an a.c. supply at 440 volts is adopted, there are two values of instantaneous short-circuit current, depending on whether the current wave is symmetrical or asymmetrical. There is a divergence of opinion as to whether the asymmetrical current should be considered at all, but until more is known about operating efficiencies of circuit breakers, then the worst possible circumstances should be taken. It will be noted that both these values are much lower than for the 220-volt d.c. system.

The marine electrical engineer must endeavour to reduce these large prospective short-circuit currents; the first step as shown is to adopt higher operating voltages and a 3-phase a.c. system. Another point which must be considered is the sectionalizing of the main switchboard. Fig. 1(b) shows such an arrangement for 220-volt d.c. and Fig. 1(c) an equivalent arrangement for 440-volt 3-phase a.c. From these two figures it will be seen that the total short-circuit current a feeder circuit breaker has to deal with is now reduced to 54,540 amperes on the d.c. system, which is still too high, 39,360 amperes with an asymmetrical current wave with 440-volt a.c., which is more suitable, and only 19,680 amperes if the symmetrical current wave is adopted.

Another factor to be considered is the mechanical stresses set up in busbars and busbar connexions under short-circuit conditions. If, in Fig. 1(a), a main switchboard is taken where the busbars are spaced six inches apart and supported by insulators every thirty inches, the mechanical force exerted on the insulators under short-circuit conditions will be as follows:—

220-volt d.c. system	2,623lb.
440-volt a.c. system asymmetrical wave form	1,359lb.

Allowing for resonance in the a.c. system, that is, if the short circuit is sustained, and the mechanical frequency of the bars is equal to, or a multiple of, the frequency of the electrical system, the force on the insulators may rise to 2,265lb.

Sectionalizing of the main switchboard, whilst solving one problem, may introduce further complications. The correct solution for the larger installations may yet prove to be generation at even higher voltages than 440 volts.

A natural question to ask is, what does all this mean in practice? It simply means that if the installation is not properly designed it could result in the loss of a vessel. Protective devices are usually designed and allocated a category of duty on the basis of their rupturing capacity, but a far more important point as far as circuit-breakers are concerned is the making capacity. A closed circuit breaker may quite easily open and rupture a short circuit, but an attempt to close a circuit breaker on a short circuit may just as easily result in the welding-in of the breaker and in the complete shut-down of the installation. It might be opportune at this point to quote from a report on the French vessel *Flandre*.

> "The *Flandre*, a transatlantic liner of 20,459 tons, was held up at the entrance to New York harbour in July 1952 by a failure of a technical nature. A commission of inquiry was appointed by the Minister in charge of the French Mercantile Marine. To obtain further details, senators recently adopted the procedure of a special Parliamentary commission of inquiry.
>
> A short circuit occurred, unfortunately, just at the moment of entering New York, and the circuit breakers, having an insufficient cut-out capacity, were fused: the electrical plant was consequently put out of action for some hours.
>
> As all services aboard were electric—engine room auxiliaries, steering gear, kitchens, etc.—the vessel was out of control and circumstances rendered the incident both spectacular and unfortunate; had it occurred far from land, it could have been repaired and the delay probably made up, so that failure would not have become known to the public".

It is quite obvious that further research must be carried out with reference to the magnitude of prospective short-circuit currents, and that all types of circuit breakers should be tested by an appropriate testing authority and granted a certificate of category of duty.

MAINTENANCE AND REPAIR COSTS

There is no question that the direct current generator and motor is a vulnerable piece of equipment, due to the effects of dirt, carbon dust, copper dust and oil vapour on the commutator; furthermore, on a large heavy-current machine, a very considerable quantity of carbon is, in course of time, worn away from the brushes and will be retained in the ventilating system, chiefly in the ventilating ducts of the armature. Dirt, copper and carbon dust and oil vapour on a commutator results in carbonized micas and hence short circuits between commutator segments, and finally, if not cleared in time, burnt out armature coils.

Again, what does this mean to the shipowner? In order to give some idea of the cost in £ s. d., five cases are quoted of costs involved due to carbonized micas.

(a) 100-kW Generator Armature

The coils were on the point of burning out. A new set of commutator micas were purchased in the United Kingdom and flown out to a port abroad. The armature was landed during the outward voyage for repairs. On fitting the armature on the homeward call, the generator failed to excite. The armature was landed at a second port of call and after ten days' delay in sailing the armature was in working (?) condition. The first contractor did not submit an account in view of unsatisfactory workmanship. The second contractor's account was £700. On return to the United Kingdom, the armature in question was examined and the only prudent step to take was to rewind the armature at a cost of £400. The total cost of repair was £1,172, including the cost of mica, plus ten days' docking dues and ten days' loss of earnings.

(b) 175-kW Generator Armature

Two coils were burnt out. The cost of re-insulating two coils and clearing carbonized micas was £1,083, plus 2½ days' docking dues and 2½ days' loss of time.

(c) This was a similar case to *(b)*, being a sister ship—the cost was £1,213.

After two such incidents it was decided to order a spare armature for this class of vessel, the cost being £1,210. Therefore the cost of repairing two armatures was in each case approximately the same as a new armature.

(d) 600-kW Turbo Armature

An earth developed on the armature of a 600-kW turbo-generator due to the commutator back mica "V" ring becoming carbonized. The cost of repair was £3,059 plus three days' docking dues and three days' loss of earnings.

(e) 135-h.p. Motor

Twenty-five commutator micas were renewed at a cost of £436.

A.C. INSTALLATIONS

Suitable as direct-current undoubtedly was for the early shipboard installations where the load was mainly lighting, and small in amount, it is very unlikely that direct-current would be chosen if a clean start could be made in the application of electricity to the various duties met with nowadays on board ship.

There is no doubt that alternators and induction motors are more simple, safe, reliable and economical (both in first cost and maintenance) than direct-current generators and motors. Alternating-current machinery lends itself more readily than direct-current to the adoption of modern insulating materials suited to high temperature, permitting further reduction in weight and bulk. Also, induction motors, especially those with squirrel cage rotors, are much less susceptible to the effects of moisture and dirt in the atmosphere than are direct current machines. Consequently, they can be of the ventilated type for practically every application aboard ship.

Induction motors are inherently constant speed machines and this may be considered a disadvantage, but whereas it may be so from the pump and fan designer's point of view, it is no longer so from the operating angle. The ease with which the speed of a d.c. motor can be adjusted, as distinct from variable speed, gives the designer considerable latitude.

The direct-on started squirrel cage motor can be utilized for all services. In addition to its outstanding advantages of simplicity and great reliability, it is very compact, the combination of motor and control gear requiring less space than with any other type of machine. Also, the extreme simplicity of the control gear, in effect simply a triple pole contactor to connect the motor to the line, permits remote control from a centralized control point. There are also further advantages, as distinct from cost, weight and space, derived from fitting an a.c. installation.

Every maritime nation of importance with the exception of Great Britain is proceeding with such installations, and this being so, and if the above mentioned advantages are correct, then it is pertinent to ask—why are we lagging behind? Such a question can only be answered by being perfectly frank; there are three reasons:

(a) Manufacturers of Electrical Equipment

In view of the low cost of a.c. motors and control gear relative to d.c. one cannot but form the impression that manufacturers view the introduction of a.c. to ship work with much disfavour and endeavour where possible to complicate and therefore inflate the cost of a.c. installations. Furthermore, the manufacturer realizes that there will not be the same demand over the years for spare gear, which is an assured source of income.

(b) The Shipbuilders

Where the shipbuilder carries out his own electrical work, he has been doing so for years long past and is steeped in d.c. working. Alternating current systems do not present any fundamental difficulties, just a different line of thought. There is a growing belief that in many instances the shipbuilders' representatives cannot be bothered. In this connexion the author would like to quote from an article(2) which appeared in a technical journal:

> ". . . . .Alterations to design and specification. When these occur, owing to the absence of detailed costing, the owner usually finds them very expensive, as the shipbuilder plays safe, *and, in any case, may not wish to make the alterations*".

In other words, if a shipowner wishes to progress, to do something more progressive, more technically advanced, and more economical than what the shipbuilder has been accustomed to doing for the past fifty years, then it can be killed on price by the shipbuilder if he so desires.

(c) Shipowners' Representatives

The critics of a.c. installations never seem to tire of raising the bogies of increased generator capacity for a.c. as compared with d.c.—the total blackout of installations due to starting currents of large squirrel cage motors; voltage dips due to starting currents; that the first cost for a.c. will not be less than for d.c. and that saving in maintenance has yet to be proved. Such points do not arise in a correctly designed and fitted installation, and once again, one cannot help but feel that they are raised as a form of scare tactics by interested parties.

Marine electrical engineering has reached the stage where it is a specialized section of shipbuilding and shipowning and it is considered that there are far too many connected with shipowning who are prone to adopt the attitude of "better the devil you know than the devil you don't know".

TYPES OF A.C. DISTRIBUTION SYSTEMS

The following are the recognized systems of distribution:

Three-phase, three-wire.

Three-phase, three-wire with neutral earthed.

Three-phase, four-wire with neutral earthed, but without hull return.

The voltage limitations with such systems are:

440 volts three-phase for power and cooking services.

250 volts single-phase for single-phase motors and heating.

150 volts to earth for lighting and socket outlets.

Figures 2(a), 2(b) and 2(c) show the connexions for these various systems.

Three-phase, Three-wire System (Fig. 2(a))

With this system all motors of 0·25 h.p. and upwards and galley ovens and boiling plates may be connected to the 440-

volt busbars. Heating and single-phase power must be supplied through 440/250-volt transformers, and lighting circuits through 440/230-volt transformers with the mid-point of their secondaries earthed, or, alternatively, 440/150-volt transformers.

The author considers this to be the ideal system; a dead "earth" can occur and this "earth" may be on an essential circuit such as steering gear, or an engine pump, and yet the system can continue to operate satisfactorily. With schemes of distribution as shown in Figs. 2(b) and 2(c), such earthed circuits would be tripped immediately without warning, which could prove embarrassing if not unfortunate. It is essential however to eliminate "earths" as soon as they are observed.

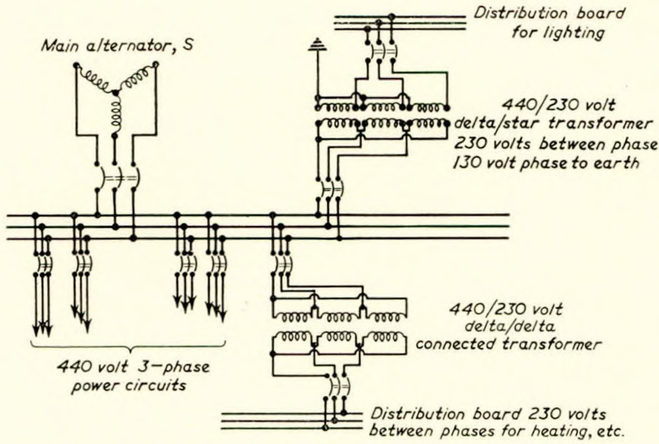


FIG. 2(a)—*Three-phase three-wire system, 440 volts*

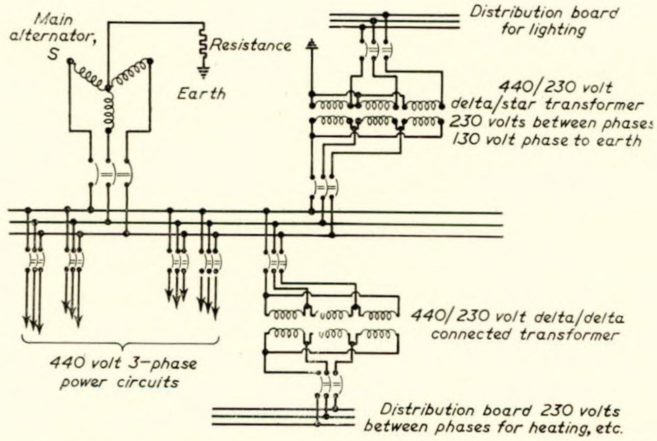


FIG. 2(b)—*Three-phase three-wire system; 440 volts, with neutral earthed*

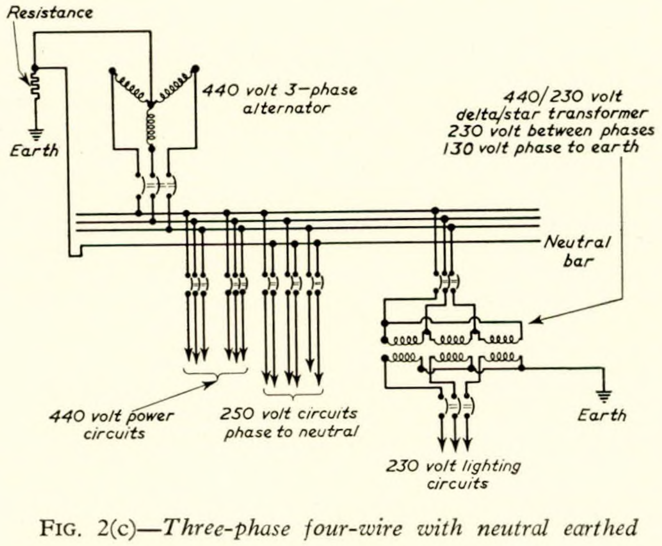


FIG. 2(c)—*Three-phase four-wire with neutral earthed*

For the supply to such circuits as electric heating, etc., the transformers should be in the form of three single-phase units connected delta/delta as shown; should one phase fail, the other two will maintain the supply, though at a reduced output.

For lighting circuits where the requirements limit the voltage to earth to 150 volts, there are two alternatives: 440/150-volt delta/delta or 440/230-volt delta/star transformers, the latter with star point earthed.

The 440/150-volt scheme is not so suitable from an economical point of view or from the point of view of utilizing standard 230-volt equipment.

The 440/230-volt delta/star system with star point earthed is not in the author's opinion suitable from a safety point of view. With this point earthed, the fuse should blow or circuit-breaker open when an "earth" fault occurs on the system fed from the transformer. In practice this is not strictly so; it may result in circulating currents through the hull, circuits which are ostensibly switched off becoming energized, arcing or tracking "earth" faults with their attendant fire risk.

The earthing of this point is in order to limit the voltage to earth from a shock point of view but there is no authority which can state that 230 volts to earth is any more dangerous than 150 volts. If 230 volts to earth is lethal, then the most lethal space today is the British housewife's modern kitchen with its electric refrigerator, cooker, washing machine, electric kettle and laundry iron, all of which are pieces of portable equipment by virtue of being connected to a 230 volts to earth supply through socket-outlets and flexible cables, and over and above the equipment mentioned there will be a kitchen sink with water taps, an Ideal boiler and possibly gas pipes for a gas poker, all of which are earthed.

With an unearthed transformer there will normally be no potential difference to earth; that is, one can make contact with any one line without receiving a shock. On the other hand, with an earthed transformer, there will always be a potential difference of 130 volts. With the unearthed transformer there will be a potential difference of 230 volts should a very low resistance "earth" develop on one line, but it must be borne in mind that all metallic parts not intended to be alive are themselves earthed and therefore in order to receive a shock one would have to touch a live conductor.

It is pointed out by the critics of a.c. installations that the necessity to install transformers results in additional cost, space occupied and weight carried. In a sense this is true, but a complete installation is being considered, not separate items.

Another point to be considered is the factor of safety. From an examination of Fig. 2(a) it will be seen that there is no electrical connexion between the secondaries of heating and lighting transformers and the power busbars, or between the transformer secondaries for heating and lighting. In other words, the complete installation is divided into a number of sections, each section being isolated electrically from any other. An earth fault on one section cannot combine with an earth fault on another to constitute a fire hazard. Further, earth fault indication can be wired back to a centralized indicator to indicate which section is earthed.

Another factor in favour of the transformer is that the short-circuit capacity, and hence the short-circuit current of the 230-volt section of the installation is appreciably reduced by virtue of the transformer reactance. Taking four 750-KVA machines connected to the busbars as previously, Fig. 3 shows the short-circuit capacity and current on the primary and secondary sides of a 200-KVA and a 100-KVA 440/230 volt transformer, each of 5 per cent reactance.

The short-circuit capacity and current is 30 MVA and

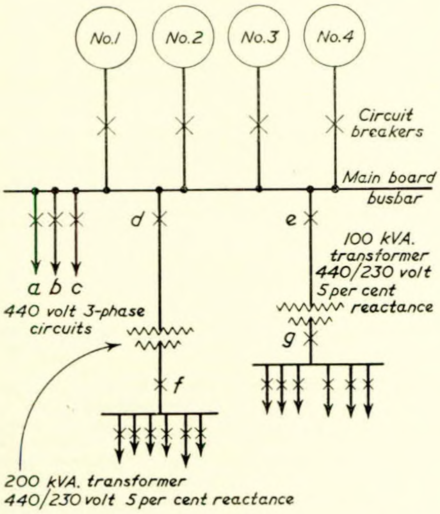


FIG. 3—*Four 750-kVA alternators: 440-volt, three-phase, 10 per cent impedance*

(1) Short circuit capacity at busbars and circuit breakers (*a*), (*b*), (*c*), (*d*) and (*e*), 30 MVA; short circuit current 39,360 amperes symmetrical

(2) Short circuit capacities at circuit breakers (*f*) and (*g*), 3·53 MVA and 1·87 MVA respectively

Short circuit currents at (*f*) and (*g*), 8,794 and 4,698 amperes respectively

39,360 amperes respectively in each case on the primary side but only 3·53 MVA and 8,794 amperes on the secondary side of the 200-KVA transformer, and 1·87 MVA and 4,698 amperes on the secondary side of the 100-KVA transformer.

For an equivalent 220-volt d.c. installation, the short-circuit currents at these points would be considerably greater, and would require protective gear of a much higher category of duty.

Three-phase, Three-wire with Earthed Neutral (Fig. 2(b))

If the neutral point of an alternator is earthed solidly through a low resistance earth connexion, an earth fault on any line will not appreciably disturb the potential from earth of the remaining lines, which are tied down to a voltage above earth of $\frac{\text{line voltage.}}{\sqrt{3}}$

On the other hand, if the "earth" on the line is a very low resistance one, the fault current that flows will approach the short-circuit current of the alternator. If the neutral point is earthed through a resistance, the effect both in regard to potential of lines above earth and the value of fault current will lie between the extremes of the entirely unearthed neutral and the completely earthed neutral.

If the neutral point of an alternator is solidly earthed, when a severe "earth" occurs on any line, the very heavy current that will flow on the line will usually trip, not only the feeder circuit breaker involved but also the main alternator circuit breaker, unless very effective discriminative protection is provided, such as, by heavily time-lagging or otherwise restraining the alternator circuit breakers and so allowing the faulty feeder to be isolated from the system by its own circuit breaker. It is primarily to render this discriminative feature possible that current-limiting resistances are often inserted between the neutral point of the alternator and earth.

It will be realized therefore that should an "earth" occur on an essential circuit, the circuit will be isolated from its source of supply immediately, which might prove to be unfortunate.

When considering this scheme of distribution, it is worth while to refer to requirements regarding electrical steering gears, which are as follows: The circuit breakers are to be set for tripping at 200 per cent full-load and no overload trips are to be fitted in steering gear control equipment. This is to ensure that power is maintained even to the point of burning out the motors. It is obvious that if an earthed neutral system is adopted the above requirements for steering gear cannot be met.

Further, with the neutral earthed, a relatively high resistance fault can occur which may be a tracking or arcing fault, and hence a fire risk.

Three-phase, Four-wire System with Earthed Neutral (Fig. 2(c))

A four-wire system should never be installed unless the neutral is earthed, otherwise a combination of earth faults may occur whereby the line voltage of 400 volts can be applied to a section of 230-volt equipment.

With this system the neutral is brought to a fourth busbar of the main switchboard and is earthed, and the voltage between any phase and neutral is $\frac{\text{line volts}}{\sqrt{3}}$ which gives line to neutral voltage of 250, 230 and 220 for alternator voltage of 440, 400 and 380 respectively.

With this system, power circuits are connected across the three phases, or lines, and the 230-volt circuits across any one line and neutral, as shown in Fig. 2(c). The only transformers required are those for the lighting circuits, and not even these if the limitation of voltage to earth can be dispensed with. The saving in cost of transformers is to a great extent offset by the additional cost of cable and switch gear, the possible failure of supply to essential services, and attendant fire risks.

From the foregoing remarks it will be apparent that the system most favoured by the author is a three-phase three-wire system with unearthed neutral, with power circuits fed at 440 volts, and delta/delta connected transformers for all 230-volt circuits and without any earthing of transformer secondaries.

Such a choice of system gives the following advantages:—

1. Maximum reliability of supply to essential services.
2. Reduction of short-circuit faults to a minimum.
3. Magnitude of short-circuit currents reduced to a minimum, allowing a lower category of duty of protective devices to be fitted.
4. Easing to a minimum the time taken and trouble experienced by operational staff in locating earth faults, and so reducing fire hazards.

GENERATING PLANT

For ships' installations the alternators will normally be of the rotating salient pole type and in order to obtain the maximum standard of reliability it is recommended that such machines should have a comparatively low voltage (say 100 volts) excitation; they should be of the duct-ventilated type with filters in the inlet ducts.

Alternators today are not called upon to operate under overload conditions and therefore should be designed for C.M.R. (continuous maximum rating) instead of load plus sustained overload. The insulation should be Class "B", which allows a higher temperature rise, instead of the commonly accepted practice of Class "A". The combination of these two points results in a machine which is cheaper in first cost and is less in weight and occupies less space.

In assessing the alternator capacity for any particular installation it is only necessary to work on a similar basis as d.c. installations, that is, an estimation of the maximum sea and port loads. Having decided on the capacity of the generating sets in kW, one must take into consideration the question of power factor. If it is decided to adopt the generally accepted standard of 0·8 power factor, then the kW become in kVA 25 per cent more; that is, a 600-kW set can be quoted as 750 kVA at 0·8 power factor. This does not mean that the prime mover has to cope with an additional 25 per cent of power but that the alternator has, from a temperature rise point of view, to deal with an increase of 25 per cent in current.

This is a point about which one may be misled; generators as such have not to be larger for a.c. compared with d.c., which is a point that can be played upon. In discussing a proposed a.c. installation with a shipbuilder it was decided that 600-kW alternators were suitable; allowing for a power factor of 0·8 the alternator became 750 kVA, which is after all only another way of expressing the same thing. The shipbuilder then said it was necessary to increase the generating plant by 25 per cent. On being asked why, the reply was because it was an a.c. ship. The suggestion was utterly preposterous and was rejected but this again is one of the bogies that certain people raise.

A point which does require clarifying is the rating of marine Diesel engines for auxiliary purposes. The only reference in the Classification Rules is that:

The rated output in b.h.p. is to be the load required to drive the generators and all direct-coupled auxiliaries at their continuous maximum rating for a period of twelve hours when working with a barometric pressure of 30 inches of mercury and a surrounding air temperature of 62 deg. F.

Where such engines are coupled to generators for auxiliary purposes, the generators are rated for continuous day and night running with a surrounding air temperature of 113 deg. F. With the prime mover and the generator forming a combined unit, it is not logical to have such widely different conditions for rating purposes.

The specified conditions given in B.S. 649-1949 are that the rated output of the engine shall be the load in b.h.p. which it is capable of carrying for a period of twelve hours at rated speed when working with:

Mean barometric pressure of 29·5 inches of mercury.
Ambient temperature at intake of 85 deg. F.
Humidity, 0·6 inches of mercury vapour.

An engine rated under the above conditions would have to be derated for temperature, humidity and day and night running where adopted for marine purposes, and the deductions for a machine running more than 24 hours in an ambient of 113 deg. F. would be as follows:—

	Per cent
(*a*) Deduction for temperature ...	5·6
(*b*) Deduction for humidity ...	5·7
(*c*) Deduction for day and night running	10·0
Total deduction ...	21·3

This seems to be a realistic approach to the rating of marine auxiliary Diesel engines for it is often found in practice that marine engineers are loath to operate their generators at more than 70-75 per cent load due to the high exhaust temperatures obtained.

It is not proposed to discuss the operation of alternators in parallel, voltage regulation, the sharing of kVAr loading and such other matters, for these points have already been covered in an Institute publication(3).

Various developments have taken place to eliminate the voltage regulator. Compound-wound synchronous generators have been developed which are self-regulating but these have been of the stationary field type and of relatively small capacity. Another development has been the exciterless synchronous generator compounded through current transformers and rectifiers.

In discussing the reaction of the supply system to large variations of load, it should be noted that kW-load peaks will invariably produce a drop in the system frequency owing to the reduction in the speed of alternator prime mover, and the active power peaks of the alternator are eased by the induction motors connected to the system, which momentarily operate as generators and feed back.

At the same time voltage regulators are available, which, with the alternator unloaded (the most stringent condition), a load representing 50 per cent of the alternator full-load current at a low power factor can be thrown on and off, and the initial voltage variation will not exceed 10 per cent; and the voltage will be restored to within plus or minus 2½ per cent of normal in less than 0·5 second.

In view of what has been said above, the direct-on starting of even the largest squirrel cage motors met with on board ship, and voltage variations, do not present any difficulties.

SYNCHRONIZING OF ALTERNATORS

This is sometimes considered to be a problem, but is actually a simple operation, and only becomes a problem in the minds of those who are not conversant with the underlying principles. When two d.c. generators are being put in parallel, it is only necessary to equalize the voltages to enable the switch to be closed without causing the generator to deliver or receive any load. However, when paralleling two alternators, it is necessary to ensure that not only are the voltages equal but that they are also in phase with each other. This latter requirement may be met in two stages:—

(*a*) The two voltage vectors (incoming and running) must be rotating at exactly the same speed.
(*b*) The vectors must be in phase with each other; that is, the two voltages must be reaching their positive maximum values (or any other point in the cycle) at exactly the same instant.

These requirements must be obtained each time the sets are paralleled and to enable this to be easily determined a synchroscope is employed.

SELF-SYNCHRONIZING OF ALTERNATORS

If an alternator is to parallel with a relatively large system it may be sufficient to provide the alternator with low-resistance, pole face, damping windings and to arrange for the alternator to be switched directly on to the line when it has been brought by the prime mover up to approximately normal speed. Immediately after it has been switched to the line, the excitation must be applied and the alternator will synchronize. With a normal machine, relatively large currents will be drawn during this process, but by suitable design, the magnitude of these synchronizing currents may be limited, though the inherent voltage regulation would be impaired.

If the capacity of the system to which the alternator is connected is not sufficient to withstand the heavy synchronous currents drawn in this fashion, it may be desirable to arrange the switching to the line through a current limiting reactor or choke coil until the machine has been excited and synchronized, after which the reactor may be short-circuited. If, on account of synchronous current draw limitations, neither of these methods is acceptable, automatic synchronizing may be resorted to whereby the usual operations associated with manual paralleling are performed through the medium of automatic relays and switches. The technicalities of synchronizing is dealt with in more detail in an Institute publication(3).

MAIN SWITCHBOARDS

Alternator circuit breakers for the larger capacities should be electrically closed by means of a solenoid coil, though at the same time they should be arranged for hand operation in conjunction with one or more protective features whereby the circuit breaker is tripped out automatically when abnormal conditions arise. Protective features commonly employed in conjunction with circuit breakers controlling alternators include:—

Overload releases which, for small capacities, may be current actuated and function by operating directly on the circuit breaker mechanism or, for larger capacities, a separate current or power(watt)-operated relay may trip the circuit breaker through the medium of a shunt tripping coil.

A reverse power protective feature is usually fitted in the form of a separate relay operating the circuit breaker through the medium of the shunt tripping coil whenever two or more alternators are operating in parallel.

A preferential tripping device is required to ensure that, should the alternators become overloaded, the supply to non-essential services is shed, thus maintaining a supply to those services considered essential for the propulsion and safety of the ship. In d.c. installations the tripping relay is operated on a current basis, the power being directly proportional to the current value. In a.c. installations the relay should be power(watt)-operated, as in this case the power developed is proportional to current and power factor. With a power factor varying between 0·8 and 0·87 there would be a power variation in tripping of 8·7 per cent if the relay operated on current only.

Voltmeters. When two or more alternators are installed it is necessary to employ two voltmeters, one of which is permanently connected to the busbars to indicate the voltage of the running machines. The other instrument is so arranged that it can be connected by selector switch to the terminals of any machine at will.

Ammeters. These are also necessary; where the load is reasonably well-balanced the ammeter may be in one phase only of a three-phase machine. Where some small unbalance is expected, the ammeter should be equipped with a selector switch so that it may be connected into each phase in turn. Where, however, appreciable out-of-balance currents are anticipated, there should be an ammeter permanently connected in each phase.

A synchroscope is required where two or more alternators are to be run in parallel and as a standby to this instrument synchronizing lamps should be fitted and the "sequence method" of connexion should be employed.

Power factor meter and integrating wattmeters are not essential, but may be considered desirable.

Feeder circuits. The number of feeder circuits leaving the main switchboard is dependent upon the amount of current to be distributed; that is, the size and number of circuit breakers and size and number of cables required depends upon the current load, the greater the current load so more circuits have to be arranged. For 440-volt three-phase a.c. circuits the line current is only 36 per cent of that for equivalent 220-volt d.c. circuits.

TABLE II.—CURRENT VALUES OF MAIN SWITCHBOARD CIRCUITS FOR 220-VOLT D.C. AND 440-VOLT A.C. 3-PHASE

	D.C. 220 volts		A.C. 3-phase 440 volts	
Service	Connected load, amperes	Estimated maximum load, amperes	Connected load, amperes	Estimated maximum load, amperes
Engine room	2,619	1,934	942	696
Refrigeration	1,571	1,421	565	511
Ventilating fans	260	215	93	77
Deck machinery	2,983	994	1,073	358
Galley	469	383	168	137
Heating	1,003	903	361	325
Lighting	353	297	127	107

Table II gives the connected and estimated maximum loads for the various services on an existing ship. It is obvious from columns 2 and 4 that the number and size of circuits can be less for the 440-volt a.c. system than for the 220-volt d.c.

All feeder circuits should be protected by triple-pole circuit breakers, and their category of duty should be such as to be suitable for the maximum short-circuit current which can arise. One is prone to think the most important circuit breaker is the generator or alternator breaker, but as previously shown, a feeder circuit breaker may have far more onerous duties to perform.

The main switchboard being a very vital link in the safety of any modern vessel and also the point of greatest prospective short-circuit current, the fitting of distribution panels and plural or group starting of engine room motors as an extension to the switchboard is greatly deprecated. Such panels and starting equipment should be mounted away from the switchboard. The impedance of the interconnecting cables will then have the effect of reducing the short-circuit current values at the distribution and motor starting panels. At the same time ample space will be available at the main switchboard to ensure maximum clearances and insulation of the switchboard components.

SECTION AND DISTRIBUTION BOARDS

The protection of circuits connected to these boards can be provided by circuit breakers, h.r.c. fuse switches, or where applicable, miniature circuit breakers. Circuit breakers are essential for the protection of three-phase motors against single-phasing where efficient single-phase preventers are not fitted in motor control gear. Where such single-phasing protection is fitted, then the h.r.c. fuse will operate more efficiently than the normal circuit breaker. Miniature circuit breakers have a limited short-circuit capacity and a short-circuit current rupturing capacity of 1 kA. If the short-circuit current exceeds this value at any point of the system, then back-up protection must be fitted, which normally is carried out by means of h.r.c. fuses. This does not mean that every circuit breaker should have a fuse behind it; group back-up protection can be arranged. The fuse rating should not be too low otherwise it may blow in a region where the miniature circuit breaker would function satisfactorily; if too high, the fuse may not blow at currents in excess of the capacity of the breaker.

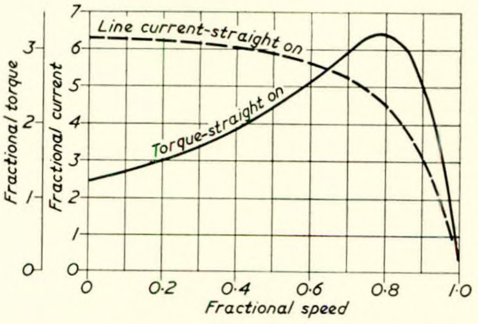
MOTORS

In order to maintain reasonable values of power factor and efficiency, care should be taken to ensure that over-sized motors are not fitted; in other words motor, fan and pump designers should eliminate their margins as far as possible, and it is therefore only logical that motors should be designed for C.M.R. (continuous maximum rating). Except in special cases they should be of the ventilated or deluge proof type and insulated with Class "B" insulation.

All motors for a marine installation can be of the squirrel cage type, and if the above mentioned factors are taken into consideration a motor will result which is low in first cost, efficient in running, low in maintenance cost, simple and robust, and hence inherently reliable.

Standard Squirrel Cage Motor

In this type of motor the squirrel cage winding is designed for minimum practicable losses (low slip) and minimum reactance. Such a machine exerts a comparatively poor starting effort. Reference to Fig. 4 shows that at standstill, in the example chosen, a comparatively high value of current is taken from the line. When the motor accelerates this current falls off, as indicated by the current curve. The curve actually shows a maximum line current of 6·3 times full-load value.



	Efficiency per cent	*Power factor*	*Slip per cent*	*Amperes*
Full load ...	91·0	0·89	2·5	66·7
Half load ...	90·2	0·775	1·2	39·7

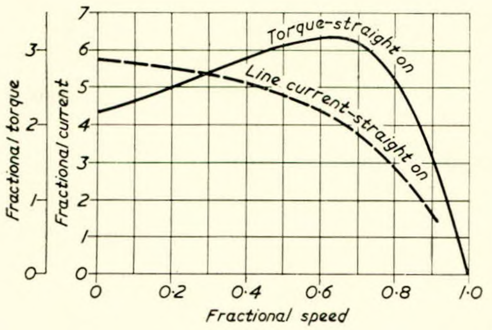
FIG. 4—*Starting current and starting torque curves of standard squirrel cage rotor induction motor*

Motor: Three-phase 50~400 volts, 50 b.h.p., 1,000/975 r.p.m.—ventilated—B.S.S. 168

The torque curve shows that the motor exerts a starting effort of 1·25 times full-load torque which, as the machine gathers speed, rises to over three times full-load value at approximately 80 per cent of full speed.

Special Squirrel Cage Motors

The high-resistance single squirrel cage winding provides a simple means of obtaining increased initial starting torque with a slight reduction of starting current. The disadvantage of such a winding is that the running efficiency of the motor is reduced by the increased resistance of the rotor windings (see Fig. 5).



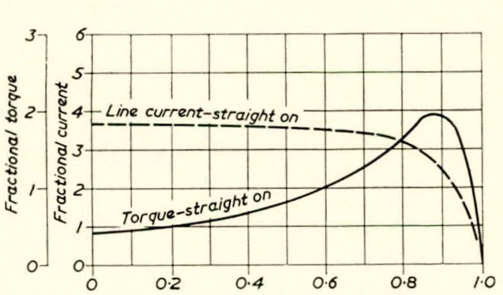
	Efficiency per cent	*Power factor*	*Slip per cent*	*Amperes*
Full load ...	88·0	0·89	5·6	69·0
Half load ...	88·7	0·78	2·8	39·0

FIG. 5—*Starting current and starting torque curves of high resistance squirrel cage rotor induction motor*

Motor: Three-phase 50~400 volts, 50 b.h.p., 1,000/975 r.p.m.—ventilated—B.S.S. 168

The high-reactance single squirrel cage winding is usually employed in cases where the main objective is a low starting current with high efficiency, starting torque and power factor being of secondary importance. The increased reactance is introduced by embedding the rotor conductors more deeply in the core and so increasing the magnetic leakage (see Fig. 6).

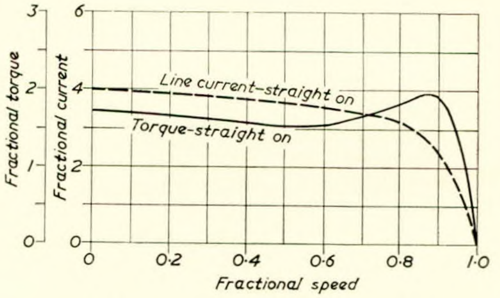
The double squirrel cage rotor combines, in proportions to some extent under control, the advantages of both high-resistance and high-reactance windings. In its usual form the double squirrel cage winding consists of two independent squirrel cages, each with its own separate end ring. One of these windings has a high resistance, and is arranged in the upper portion of the rotor slots, while the other, at low resistance, is embedded deeply in the core and therefore has a high reactance. Fig. 7 represents an average performance with the rotor designed for an initial starting torque of 1·7 times full-load torque and four times full-load current, when switched direct-on, with an overload capacity of approximately twice full-load torque at about 90 per cent of synchronous speed. The full-load slip and efficiency are practically the same as for the standard squirrel cage motor (Fig. 4), but the power factor is about 4 per cent lower.



	Efficiency per cent	*Power factor*	*Slip per cent*	*Amperes*
Full load ...	90·9	0·86	2·5	69·0
Half load ...	90·1	0·76	1·2	39·4

FIG. 6—*Starting current and starting torque curves of high reactance squirrel cage rotor induction motor*

Motor: Three-phase 50~400 volts, 50 b.h.p., 1.000/975 r.p.m.—ventilated—B.S.S. 168; straight-on starting



	Efficiency per cent	*Power factor*	*Slip per cent*	*Amperes*
Full load ...	90·9	0·85	2·55	70·0
Half load ...	90·1	0·76	1·27	39·4

FIG. 7—*Starting current and starting torque curves of double squirrel cage rotor induction motor*

Motor: Three-phase 50 400 volts, 50 b.h.p., 1,000/974 r.p.m.—ventilated—B.S.S. 168

POWER FACTOR CORRECTION

Power factor correction is an economic proposition for industrial installations but for marine installations such correction would be the exception rather than the rule. The majority of ships are fitted with electric cooking ranges, bakers' ovens, grills, etc., which form a useful basic load of near unity power factor, and which therefore raises the overall power factor of the system. Again, at times of maximum load, motors will in general be operating at their maximum power factor. If the connected load and the load cycle is known, then a near estimate of power factors can be made for the various loads to be expected, and it appears these will lie between 0·835 and 0·87. If the installation is designed for an overall power factor of 0·8 then it is obvious that power factor correction is not required.

CONTROL GEAR

Direct-on starting can be utilized for all motors on board ship, and, basically, any motor can be started by connecting it to the line through a triple-pole switch, but certain protective features are necessary in order to protect the motor. The simplest and most reliable form of direct-on starter is a triple-pole contactor fitted with overload trips on each pole and the contactor operating coil arranged to give the no-volt feature; further, it is desirable to give protection against single-phasing. Fig. 8 shows diagrammatically such a motor starter and its simplicity is obvious.

It may be argued that direct-on line starting has two disadvantages:—

(*a*) The current taken from the line will be five to eight times full-load current with a normal rotor, and this tends to cause dips in the line voltage of the supply system.

It has already been shown that such line currents can be limited to four times full-load current by suitable design of the motor.

(*b*) High torque and rapid acceleration may be a serious disadvantage. Again, it has been shown that torque and acceleration can also be controlled.

With squirrel cage motors and direct-on starting the motor and control gear manufacturers must work closely together. If such liaison is obtained, then the motor and its starter will

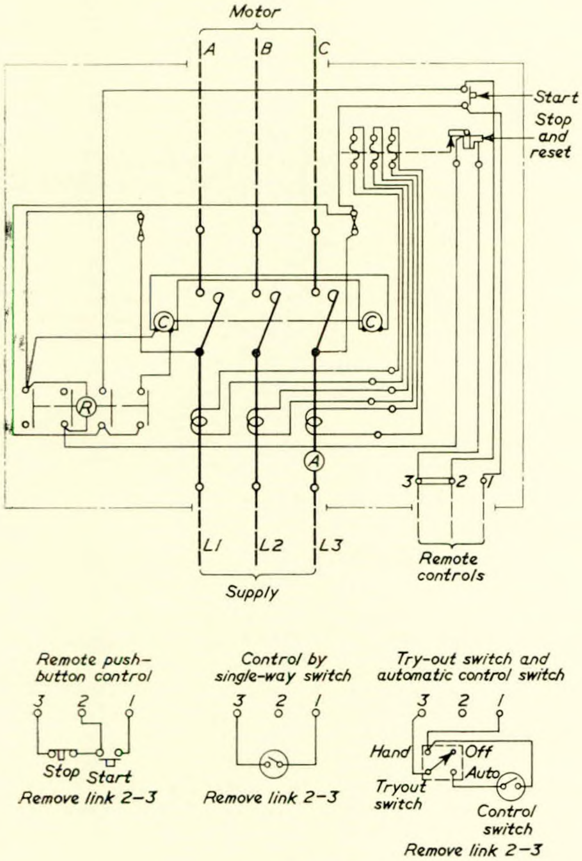


FIG. 8

be the simplest and most reliable combination one can obtain and, therefore, the cheapest to purchase and maintain.

For certain services such as refrigerating compressors, refrigeration fans, boiler fans, etc., it will be desirable to install two-speed motors, the speeds being "full" and "two-thirds" full speed. These can be direct-on started; the starting current when starting at either speed and the current when changing over from one speed to another can be restricted to a reasonable value and the start or change speed made without shock to the driven machinery.

There are also starters known as star/delta, primary resistor, reactor type and auto-transformer, but normally it is not necessary to consider any of these types for marine work.

The contactor operating coil can function quite satisfactorily from the 440-volt supply, but there are those who propose 110 volts as being more suitable and others who maintain that the coils should operate from a d.c. supply. Such suggestions entail the fitting of transformers and rectifiers, which naturally increases the cost of control gear.

Protection against Single-phasing

"Single-phasing" is caused by an open circuit occurring in one lead while the motor is running. Such an open circuit may occur through a broken lead, badly made joint, blowing of one fuse or failure of switch contact.

On the occurrence of an open circuit in one of the leads to a rotating three-phase motor, it will continue to run as a single-phase motor with an increased current in the other two supply leads. This increased current arises in the following way.

In general terms, the torque developed by an induction motor is proportional to the flux and rotor current. Upon the incidence of a "single-phase" the flux is decreased and, hence, to maintain the same torque and also because of the negative phase sequence torque which is set up, the rotor current and the stator current must increase. This increased current may be sufficient to operate the overload release but this is not always so, and furthermore the current in some of the internal circuits of the motor may increase in a greater ratio than the external leads.

For instance, there may be an appreciable increase in rotor current and whilst overload releases have sometimes been fitted in the rotor circuit to deal with such a condition, this measure cannot be applied to squirrel cage machines.

In the case of a star connected motor, the increased current taken by the sound phases will pass through the overload releases in the corresponding lines, as shown in Fig. 9, and if these overloads are set at a low enough value they will operate and give adequate protection.

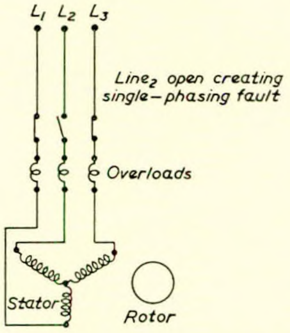


FIG. 9—*Single-phasing fault on star connected motor*

In the case of delta connected stators, the line currents are the vector sum of two of the phase currents. Under three-phase conditions, the line currents are all equal and are $\sqrt{3}$ times the balanced motor phase currents. A change in load causes the line and motor phase currents to vary almost proportionately. If, however, the current should fail in one supply lead, as shown in Fig. 10, the symmetry of the hitherto healthy three-phase circuit no longer obtains, and the motor circuit now consists of two parallel branch circuits, one branch having two motor phase windings, Y and Z, in series, whilst the other branch consists of the third motor phase winding X.

The curves in Fig. 10 show the effect of single-phasing, with L_2 open and the motor running on single phase; the curves indicate in percentages:

A The line current in unbroken lines L_1 and L_3.

B The current in windings Y and Z.

C The current in winding X.

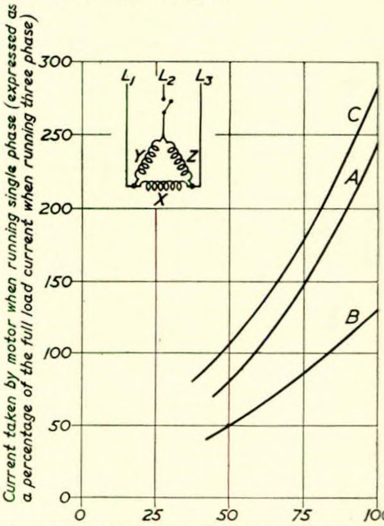


FIG. 10—*Current curves: single-phase faults on delta connected motor*

A study of the curves will show that on the opening of one of the supply leads to a delta connected motor, the current divides unequally between the windings of the stator. The increase on one pair of windings is not very great, but the increase in the third winding is very pronounced and is very much greater than the increase of the line current itself. For instance, at 75 per cent of full load the opening of one of the supply leads results in the line current rising to 147 per cent of full load and the current in the heavily loaded phase to 180 per cent of full load value. Thus an overload release designed to prevent the line current exceeding 50 per cent overload will actually permit one of the stator windings of the motor to undergo 80 per cent overload continuously. If the overload is set to trip at 25 per cent overload, it is possible for one phase to carry 50 per cent overload without protection.

If the economic advantages of continuous maximum rated motors are to be reaped it is essential to fit single-phasing protection in the motor control gear.

There are available motor starters in which the manufacturers fit a combined overload and single-phasing preventer as a standard fitment in their control equipment.

LIGHTING

An a.c. installation allows the fitting of fluorescent lighting throughout without the necessity of installing special motor/alternators. Table III gives the average lumens for both metal filament single-coil lamps and fluorescent tubes.

TABLE III.—COMPARATIVE LUMENS OF METAL FILAMENT LAMPS AND FLUORESCENT TUBES FOR EQUIVALENT WATTAGE

G.L.S. single-coil 230-volt lamps		Fluorescent tubes		
Lamp, watts	Av. Lumens	Tube, watts	Type	Av. Lumens
15	113	15 1½ feet	New Warm White	480
			Natural	420
			Deluxe Warm White	330
25	206	20 2 feet	New Warm White	800
			Natural	640
			Deluxe Warm White	460
		30 3 feet	New Warm White	1,380
			Natural	1,170
			Deluxe Warm White	840
40	330	40 2 feet	New Warm White	1,320
			Natural	1,080
			Deluxe Warm White	760
60	584	40 4 feet	New Warm White	2,160
			Daylight	2,040
			Natural	1,640
			Deluxe Warm White	1,360
			Colour Matching	1,600
75	785	80 5 feet	New Warm White	4,160
			Daylight	3,920
			Natural	3,120
			Deluxe Warm White	2,560
100	1,160		Colour Matching	3,040

It will be seen from this table that approximately three times the power is required for metal filament as compared with fluorescent lighting for the same intensity of illumination. It follows therefore that the fuel consumption will be three times as great and in an air-conditioned ship the fuel consumption for air conditioning relative to the lighting load will be in the same proportion. Again, the capital cost of air conditioning plant must be greater where metal filament lighting is installed. In order to demonstrate the effect lighting has on the air conditioning load, an example is quoted(4). This applies to a saloon.

Total volume of saloon, cu. ft. ...	40,000
Heat infiltration through structure (including sun radiation), B.t.u./hr.	80,000
Body heat, B.t.u./hr.	40,000
Lighting, etc., B.t.u./hr.	60,000
Fan heat, B.t.u./hr.	20,000
Total heat gain, B.t.u./hr.	200,000

If the lighting B.t.u./hr. is reduced from 60,000 to 20,000 by installing fluorescent lighting, the total heat gain becomes 160,000 B.t.u./hr., a reduction of 20 per cent. For a certain type of 18,000-ton vessel the total heat gain has been given as 6,000,000 B.t.u./hr. and such a ship would have some 300 kW of metal filament lighting load, which is the equivalent of 1,023,000 B.t.u./hr. If a diversity factor of 0·8 is taken for the lighting load, then the effective heat input is 818,400 B.t.u./hr. If a factor of one-third is taken for fluorescent lighting as compared with metal filament, then the heat input due to lighting becomes 272,800 B.t.u./hr., a reduction of 545,600 B.t.u./hr., or some 9 per cent of the total heat input. It is obvious therefore that the first cost for the air conditioning plant must be less. The question of fuel consumption for lighting must also be considered, and fuel consumption for air conditioning relative to the lighting load. If the metal filament lighting load is taken as 300 kW for an 18,000/20,000-ton vessel, then Table IV shows the relative fuel consumptions.

TABLE IV.—COMPARISON OF FUEL CONSUMPTION FOR METAL FILAMENT LIGHTING AND FLUORESCENT LIGHTING AND FOR AIR CONDITIONING RELATIVE TO LIGHTING

Lighting load, kW's.		Fuel consumption, lb./hr. at 0·6 lb./kW/hr.	
M.F.	Fluorescent	M.F.	Fluorescent
300	100	180	60
Lb./hr. for air conditioning at 80 per cent efficiency		225	75
Total fuel consumption, lb./hr.		405	135

If it is assumed that 60 per cent of the lights are switched on twelve hours per day, which incidentally is not unreasonable for marine installations, and take Diesel fuel at £10 per ton, this means a daily saving of

$$\left(\frac{405 \times 12 \times 0\cdot 6 \times 10}{2,240}\right) - \left(\frac{135 \times 12 \times 0\cdot 6 \times 10}{2,240}\right) = £8\cdot 7$$

or a yearly saving of some £3,220.

It does appear, therefore, that the capacity of the air conditioning plant can be reduced by 9 per cent plus an annual saving of fuel cost of £3,220.

DECK MACHINERY

This subject has already been ably dealt with in a previous Institute paper(5). The author would suggest, however, that closer attention should be given to fitting winches suitable to the duty cycle of the ship in question. Table V shows the somewhat haphazard fitting of winches in existing ships of a company's fleet.

If it is necessary to fit 3-ton winches at 130ft./min., then

TABLE V.—MOTOR H.P. REQUIRED FOR VARIOUS WINCH RATINGS

Tons lift	Ft./min.	Motor h.p.
3	80	23
3	100	26
3	130	34
5	65	30
5	80	31
5	100	43
5	130	55

obviously 3-ton winches at 80ft./min. are too slow, yet these latter winches have given twenty-five years' satisfactory service and maintenance has been less for the simple reason that the control gear is far less complicated. Similar remarks apply to the 5-ton winches at 65ft./min., and the vessel in which they are fitted can lift 10,000 tons of general cargo. Observations have been made of the weights lifted and the rate of working and for new construction which the author has in mind it has been decided that single-speed squirrel cage motor winches for lifting 3 tons at 100ft./min. will be quite suitable.

COSTS

Certain items of equipment in an a.c. installation will cost more than for d.c., others considerably less. The saving in first cost depends upon two factors: —

(*a*) Size and type of vessel.

(*b*) The attitude and exertions of the shipowner's technical representatives.

With regard to the first point, the larger the installation and the greater the number of motors fitted, then the greater the saving.

With regard to the second point, it should not be left simply to the shipbuilder to purchase and install the necessary equipment. It is essential that a qualified and experienced representative of the shipowner should get out and about, witnessing demonstrations of various manufacturers' equipment and examining it until he is in a position to select the equipment he considers suitable for his purpose. Having made his choice he should stand firm and not allow himself to be persuaded to modify this, and add that, and so find that what was an excellent piece of equipment for his purpose has now become "marine" equipment.

The next step to take is to compile a detailed and watertight specification.

It is impossible in a paper of this description to give detailed costs; furthermore such costs will vary from ship to ship, but an indication of the economies which can be made and the reduction in weight and volume of equipment is given.

TABLE VI.—COMPARATIVE COST OF CABLES

	220-volt d.c. P.C.P.–V.I.R.			440-volt 3-phase a.c. P.C.P.–V.I.R. 3-core			440-volt 3-phase a.c. P.C.P. Butyl 3-core		
kW.	Cable size	Length, yd.	Cost, £	Cable size	Length, yd.	Cost, £	Cable size	Length, yd.	Cost, £
10	7/·064	200	33	7/·036	100	33	7/·036	100	33
25	19/·083	200	122	19/·052	100	86	7/·052	100	49
50	37/·103	200	308	19/·083	100	180	19/·064	100	121
75	61/·103	200	507	37/·083	100	314	19/·083	100	179
100	91/·103	200	712	37/·103	100	435	37/·083	100	313
150	61/·103	400	1,014	37/·083	200	628	37/·103	100	435
200	91/·103	400	1,424	37/·103	200	870	37/·083	200	626
300	91/·103	600	2,136	61/·103	200	1,448	37/·103	200	870
400	127/·103	600	2,842	37/·103	400	1,740	37/·093	300	1,137
Total cost			9,098			5,734			£3,763
Percentage cost			100			63			41

TABLE VII.—COMPARATIVE WEIGHT OF COPPER IN CABLES

	220-volt d.c. system P.C.P.—V.I.R.			440-volt 3-phase a.c. system P.C.P.—V.I.R. 3-core			440-volt 3-phase a.c. system P.C.P.—Butyl 3-core		
kW.	Cable size	Length, yd.	Weight, lb.	Cable size	Length, yd.	Weight, lb.	Cable size	Length, yd.	Weight, lb.
10	7/·064	200	53	7/·036	100	25	7/·036	100	25
25	19/·083	200	242	19/·052	100	142	7/·052	100	52
50	37/·103	200	727	19/·083	100	363	19/·064	100	216
75	61/·103	200	1,199	37/·083	100	708	19/·083	100	363
100	91/·103	200	1,788	37/·103	100	1,090	37/·083	100	708
150	61/·103	400	2,398	37/·083	200	1,416	37/·103	100	1,090
200	91/·103	400	3,576	37/·103	200	2,180	37/·083	200	1,416
300	91/·103	600	5,364	61/·103	200	3,596	37/·103	200	2,180
400	127/·103	600	7,488	37/·103	400	4,360	37/·093	300	2,667
Total weight			22,835			13,880			8,717
Percentage weight			100			60			38

Cables

In order to obtain a fairly reasonable figure for cable cost, the author took for an example a 17,000-ton passenger cargo liner which had a 220-volt d.c. installation and a generating capacity of 2,100 kW's and converted it into a 440-volt three-phase system, the cable in each case being of P.C.P.-sheathed V.I.R. type, single core for the d.c. system and three core for the a.c. It was found that a saving of some 30 per cent could be achieved.

A new type of rubber insulation, known as "Butyl", is now coming on to the market, and Table VI gives an indication of the economy which can be effected by the adoption of a 440-volt a.c. system and the still further economy by the use of "Butyl" rubber insulated cables. The figures given are for transmitting various values of power a distance of 100 yards. It will be seen from this table that a saving of some 37 per cent in cost can be achieved by the adoption of a 440-volt system, and a further 22 per cent by the installing of "Butyl" rubber insulated cables. The saving in weight of copper installed is indicated in Table VII.

Motors and Generators

Figs. 11 to 22 show the relative dimensions, weights and costs for 220-volt d.c. and 440-volt 60-cycle a.c. motors and generators. In order to endeavour to give a fair comparison, constant-speed d.c. motors are compared with single-speed a.c. and variable-speed d.c. motors with two-speed a.c.

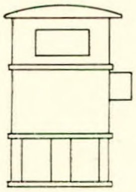
These figures may be criticized on the score of a different basis of rating and higher temperature rise for the a.c. machines. The answer to such criticism is that the a.c. machine is more suitable to such a rating and higher temperature rise and at no time has the machine manufacturer ever suggested that these should be adopted for marine d.c. machines.

A study of these figures show the appreciable saving in volume, weight and cost of the a.c. machine as compared with the d.c. It must also be appreciated that where these figures compare constant-speed d.c. with single-speed a.c., and variable-speed d.c. with two-speed a.c., in practice the comparison will be between variable-speed d.c. with single-speed a.c., which means a further saving.

An appreciable economy can be effected where turbo-generators are installed. For the larger capacity generators 750 r.p.m. appears to be the limit for 220-volt d.c. machines, whereas for the a.c. generator of similar capacity the r.p.m. can be more than doubled, that is, 1,800 r.p.m., and the saving in cost amounts to some 40 per cent, which is quite an appreciable sum when considering generators of 1,200 and 1,500 kW capacity.

Control Gear

Figs. 23 to 26 show the relative costs of d.c. and a.c. control gear. Again, constant speed d.c. is compared with single-speed a.c. and variable speed d.c. with two-speed a.c. Up to 80 h.p. d.c. the controllers are of the ratchet step-by-



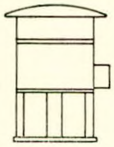
Direct Current Motor
Supply—220-volts d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A

Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.

Total weight—532lb.

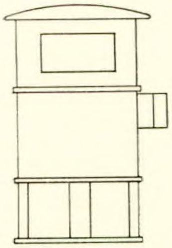
Active material weight:
Steel—260lb.
Copper—70lb.

Cost (relative)—100 per cent
Full load current—20 amperes
Efficiency—85 per cent



Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Winding—Squirrel cage rotor
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Windings—55 deg. C.
Total weight—178lb.
Active material weight:
Steel—41lb.
Copper—9lb.
Cost (relative to Lloyd's Class A d.c. motor)—43 per cent
Full load current—7 amperes
Efficiency—80 per cent

FIG. 11—*Comparison of size, weight, cost, etc., of direct current motors and alternating current motors, 5 b.h.p., 1,730 r.p.m. approximately, for service in ocean going ships*



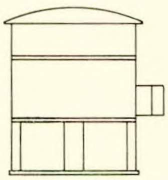
Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A

Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.

Total weight—840lb.

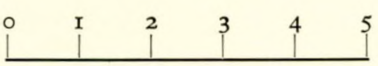
Active material weight:
Steel—300lb.
Copper—110lb.

Cost (relative)—100 per cent
Full load current—80 amperes
Efficiency—85 per cent



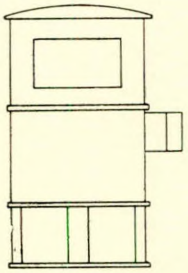
Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Winding—Squirrel cage rotor
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Windings—55 deg. C.
Total weight—448lb.
Active material weight:
Steel—141lb.
Copper—51lb.
Cost (relative to Lloyd's Class A d.c. motor)—42 per cent
Full load current—24·9 amperes
Efficiency—88 per cent

FIG. 12—*Comparison of size, weight, cost, etc., of direct current motors and alternating current motors, 20 b.h.p., 1,730 r.p.m. approximately, for service in ocean going ships*

Scale:


feet

Scale ⅜ inch to one foot



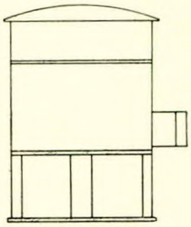
Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A

Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.

Total weight—1,680lb.

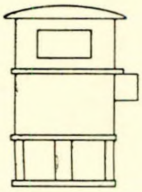
Active material weight:
Steel—650lb.
Copper—260lb.

Cost (relative)—100 per cent
Full load current—190 amperes
Efficiency—89 per cent



Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Winding—Squirrel cage rotor
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Windings—55 deg. C.
Total weight—784lb.
Active material weight:
Steel—270lb.
Copper—85lb.
Cost (relative to Lloyd's Class A d.c. motor)—43 per cent
Full load current—61·3 amperes
Efficiency—89·5 per cent

FIG. 13—*Comparison of size, weight, cost, etc., of direct current motors and alternating current motors, 50 b.h.p., 1,730 r.p.m. approximately, for service in ocean going ships*



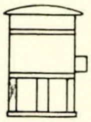
Variable Speed Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A

Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.

Total weight—532lb.

Active material weight:
Steel—260lb.
Copper—70lb.

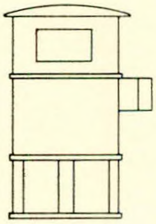
Cost (relative)—100 per cent
Full load current—20·2 amps.: 6·8 amps.
Efficiency— 84 per cent: 75 per cent



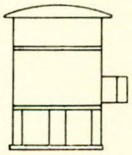
"Two-speed" Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Stator winding—Two windings
Rotor—Squirrel cage
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Windings—55 deg. C.
Total weight—280lb.
Active material weight:
Steel—80lb.
Copper—41lb. .
Cost (relative to Lloyd's Class A d.c. motor)—61 per cent
Full load current—7·75 amps.: 3 amps.
Efficiency— 76 per cent: 65 per cent

FIG. 14—*Comparison of size, weight, cost, etc., of variable speed direct current motors and "two-speed" alternating current motors for centrifugal pump duty in ocean going ships*

Output: 5 b.h.p., 1,730 r.p.m. approximately
1·5 b.h.p., 1,150 r.p.m. approximately



Variable Speed Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.
Total weight—1,200lb.
Active material weight:
Steel—450lb.
Copper—165lb.
Cost (relative)—100 per cent
Full load current—79 amps.: 26·4 amps.
Efficiency— 86 per cent: 77 per cent

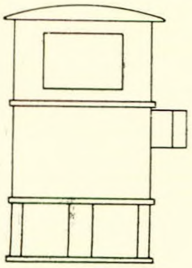


"Two-speed" Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Stator winding—Two windings
Rotor—Squirrel cage
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Windings—55 deg. C.
Total weight—728lb.
Active material weight:
Steel—220lb.
Copper—100lb.
Cost (relative to Lloyd's Class A d.c. motor)—71 per cent
Full load current—26·4 amps.: 10·2 amps.
Efficiency— 86 per cent: 74 per cent

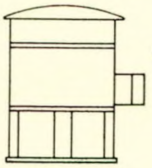
FIG. 15—*Comparison of size, weight, cost, etc., of variable speed direct current motors and "two-speed" alternating current motors for centrifugal pump duty in ocean going ships*

Output: 20 b.h.p., 1,730 r.p.m. approximately
6 b.h.p., 1.150 r.p.m. approximately

Scale ⅜ inch to one foot



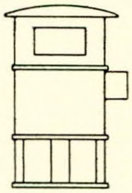
Variable Speed Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
  Windings—35 deg. C.
  Commutator—40 deg. C.
Total weight—1,792lb.
Active material weight:
  Steel—720lb.
  Copper—280lb.
Cost (relative)—100 per cent
Full load current—190 amps.: 62 amps.
Efficiency— 89 per cent: 82 per cent



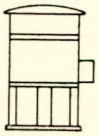
"Two-speed" Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Stator winding—Two windings
Rotor—Squirrel cage
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
  Windings—55 deg. C.
Total weight—1,064lb.
Active material weight:
  Steel—400lb.
  Copper—144lb.
Cost (relative to Lloyd's Class A d.c. motor)—87 per cent
Full load current—64·5 amps.: 24·4 amps.
Efficiency— 88 per cent: 77 per cent

FIG. 16—*Comparison of size, weight, cost, etc., of variable speed direct current motors and "two-speed" alternating current motors for centrifugal pump duty in ocean going ships*

Output: 50 b.h.p., 1,730 r.p.m. approximately
15 b.h.p., 1,150 r.p.m. approximately



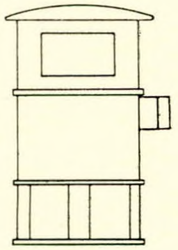
Variable Speed Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
  Windings—35 deg. C.
  Commutator—40 deg. C.
Total weight—532lb.
Active material weight:
  Steel—260lb.
  Copper—70lb.
Cost (relative)—100 per cent
Full load current—20·2 amps.: 13·6 amps.
Efficiency— 84 per cent: 83 per cent



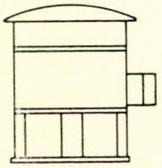
"Two-speed" Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Stator winding—Two windings
Rotor—Squirrel cage
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
  Windings—55 deg. C.
Total weight—364lb.
Active material weight:
  Steel—102lb.
  Copper—50lb.
Cost (relative to Lloyd's Class A d.c. motor)—62 per cent
Full load current—7·4 amps.: 5·7 amps.
Efficiency— 80 per cent: 76 per cent

FIG. 17—*Comparison of size, weight, cost, etc., of variable speed direct current motors and "two-speed" alternating current motors for constant torque drives in ocean going ships*

Output: 5 b.h.p., 1,730 r.p.m. approximately
3·33 b.h.p., 1,150 r.p.m. approximately



Variable Speed Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
  Windings—35 deg. C.
  Commutator—40 deg. C.
Total weight—1,200lb.
Active material weight:
  Steel—450lb.
  Copper—165lb.
Cost (relative)—100 per cent
Full load current—79 amps.: 53·5 amps.
Efficiency— 86 per cent: 85 per cent

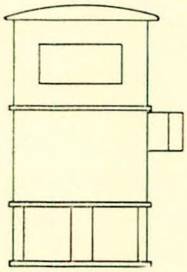


"Two-speed" Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Stator winding—Two windings
Rotor—Squirrel cage
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
  Windings—55 deg. C.
Total weight—896lb.
Active material weight:
  Steel—300lb.
  Copper—116lb.
Cost (relative to Lloyd's Class A d.c. motor)—71 per cent
Full load current—26·1 amps.: 20·6 amps.
Efficiency— 87 per cent: 81 per cent

FIG. 18—*Comparison of size, weight, cost, etc., of variable speed direct current motors and "two-speed" alternating current motors for constant torque drives in ocean going ships*

Output: 20 b.h.p., 1,730 r.p.m. approximately
13·33 b.h.p., 1,150 r.p.m. approximately

Scale ⅜ inch to one foot



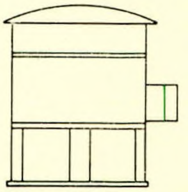
Variable Speed Direct Current Motor
Supply—220-volts. d.c.
Winding—Light compound
Rating—Lloyd's Rules
Insulation—Class A

Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.

Total weight—1,792lb.

Active material weight:
Steel—720lb.
Copper—280lb.

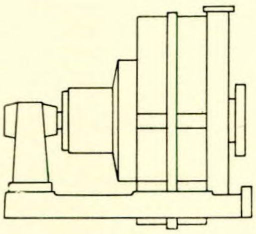
Cost (relative)—100 per cent
Full load current—190 amps.: 129 amps.
Efficiency— 89 per cent: 88 per cent



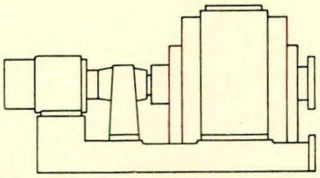
"Two-speed" Alternating Current Motor
Supply—440 volts, 60 cycles, 3-phase
Stator winding—Two windings
Rotor—Squirrel cage
Starting—Direct on the line
Starting current—4 × full load current
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Windings—55 deg. C.
Total weight—1,780lb.
Active material weight:
Steel—640lb.
Copper—205lb.
Cost (relative to Lloyd's Class A d.c. motor)—87 per cent
Full load current—63·8 amps.: 50·3 amps.
Efficiency— 89 per cent: 83 per cent

FIG. 19—*Comparison of size, weight, cost, etc., of variable speed direct current motors and "two-speed" alternating current motors for constant torque drives in ocean going ships*

Output: 50 b.h.p., 1,730 r.p.m. approximately
33·3 b.h.p., 1,150 r.p.m. approximately



Direct Current Generator
Output—750 kW, 220 volts, 750 r.p.m.
Winding—Level compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
Windings—35 deg. C.
Commutator—40 deg. C.
Total weight (including bedplate)—180 cwt.
Active material weight:
Steel—7,500lb.
Copper—3,400lb.
Cost (relative)—100 per cent
Full load current—3,410 amperes
Efficiency—93·1 per cent

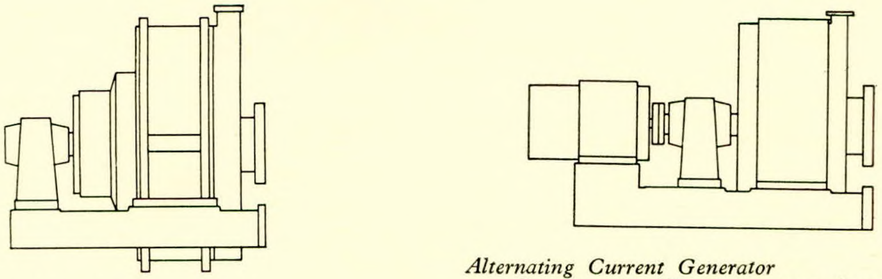


Alternating Current Generator
Output—750 kw, 0·8 power factor, 937·5 KVA
440 volts, 60 cycle, 3-phase, 1,800 r.p.m.
Winding—Salient pole
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
Stator windings—55 deg. C.
Rotor windings (exposed)—70 deg. C.
Total weight (including bedplate)—90 cwt.
Active material weight:
Steel—3,500lb.
Copper—900lb.
Cost (relative to Lloyd's Class A d.c. generator)—60 per cent
Full load current—1,230 amperes
Efficiency (at 0·8 power factor)—94·36 per cent

Generator capacity—750 kW
Drive by geared steam turbine

FIG. 20—*Comparison of size, weight, cost, etc., of direct current and alternating current generators for supply of electricity to auxiliary service in ships*

Scale ⅜ inch to one foot



Direct Current Generator
Output—500 kW, 220 volts, 300 r.p.m.
Winding—Level compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
    Windings—35 deg. C.
    Commutator—40 deg. C.
Total weight (including bedplate)—260 cwt.
Active material weight:
    Steel—8,400lb.
    Copper—3,900lb.
Cost (relative)—100 per cent
Full load current—2,270 amperes
Efficiency—92 per cent

Alternating Current Generator
Output—500 kW, 0·8 power factor, 625 KVA
440 volt, 60 cycles, 3-phase, 300 r.p.m.
Winding—Salient pole
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
    Stator windings—55 deg. C.
    Rotor windings (exposed)—70 deg. C.
Total weight (including bedplate)—150 cwt.
Active material weight:
    Steel—5,170lb.
    Copper—2,050lb.
Cost (relative to Lloyd's Class A d.c. generator)—87 per cent
Full load current—820 amperes
Efficiency—92·5 per cent

Generator capacity—500 kW, 300 r.p.m.
Drive by oil engine

FIG. 21—*Comparison of size, weight, cost, etc., of direct current and alternating current generators for supply of electricity to auxiliary service in ships*

Direct Current Generator
Output—120 kW, 220 volts, 514 r.p.m.
Winding—Level compound
Rating—Lloyd's Rules
Insulation—Class A
Temperature rise:
    Windings—35 deg. C.
    Commutator—40 deg. C.
Total weight (including bedplate)—85 cwt.
Active material weight:
    Steel—4,200lb.
    Copper—1,350lb.
Cost (relative)—100 per cent
Full load current—545 amperes
Efficiency—92 per cent

Alternating Current Generator
Output—120 kW, 0·8 power factor, 150 KVA
440 volts, 60 cycles, 3-phase, 514 r.p.m.
Winding—Salient pole
Rating—Continuous maximum
Insulation—Class B
Temperature rise:
    Stator windings—55 deg. C.
    Rotor windings (exposed)—70 deg. C.
Total weight (including bedplate)—49 cwt.
Active material weight:
    Steel—1,350lb.
    Copper—670lb.
Cost (relative to Lloyd's Class A d.c. generator)—123 per cent
Full load current—197 amperes
Efficiency (at 0·8 power factor)—90·4 per cent

Generator capacity—120 kW, 514 r.p.m.
Drive by oil engine

FIG. 22—*Comparison of size, weight, cost, etc., of direct current and alternating current generators for supply of electricity to auxiliary service in ships*

Scale ⅜ inch to one foot

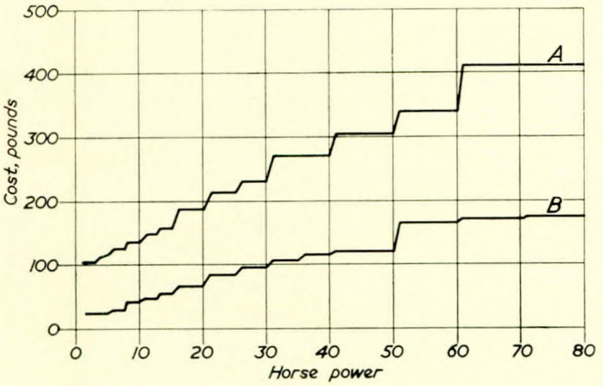


FIG. 23—*Comparison of costs between:*

A—220-volt direct current cam operated starters for constant speed motors

B—440-volt alternating current direct-on starters with single-phasing preventers, 1-80 h.p.

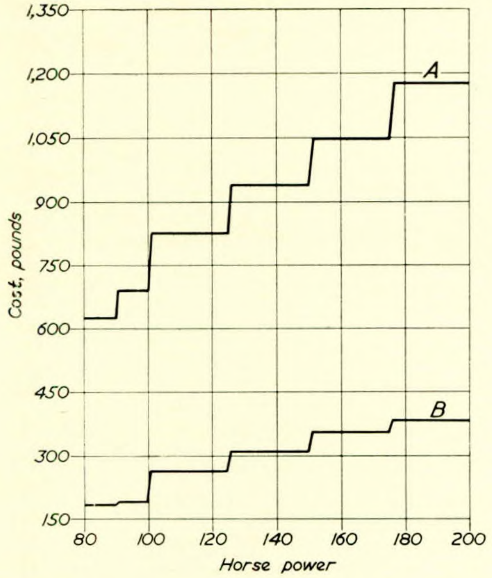


FIG. 24—*Comparison of costs between:*

A—220-volt direct current automatic contactor panels for constant speed motors

B—440-volt alternating current direct-on starters with single-phasing preventers, 81-200 h.p.

TABLE VIII.—COMPARATIVE WEIGHTS (LB.) AND CUBAGE (CU. FT.) FOR 220-VOLT D.C. AND 440-VOLT A.C. MOTOR STARTERS: CONSTANT SPEED—D.C.; SINGLE SPEED—A.C.

H.P.	220-volt d.c.		H.P.	440-volt a.c.	
	Weight	Cu.Ft.		Weight	Cu.Ft.
1–12·5	110	9·0	1–7·5	26	1·5
—	—	—	8–15	48	2·5
13–25	210	14·0	16–25	61	4·0
26–50	432	23·0	26–50	64	6·5
51–80	562	32·0	51–80	114	7·5

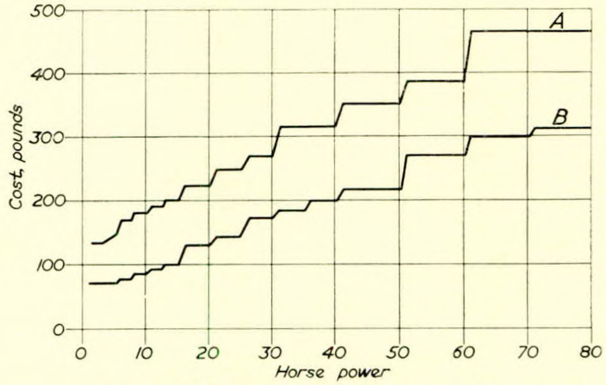


FIG. 25—*Comparison of costs between:*

A—220-volt direct current cam operated starters for variable speed motors

B—440-volt alternating current two-speed direct-on starters with two sets of overloads (and single-phasing preventers), 1-80 h.p.

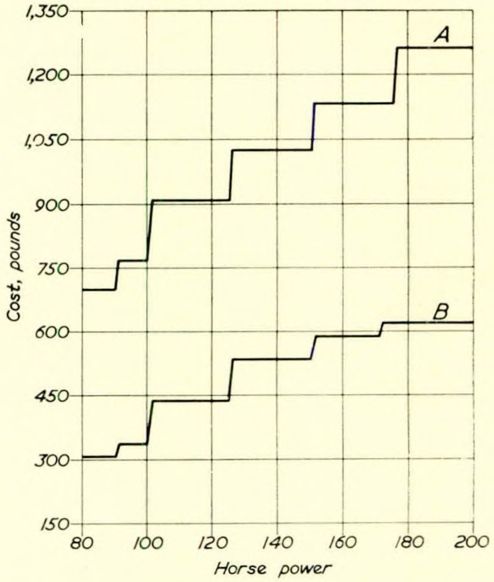


FIG. 26—*Comparison of costs between:*

A—220-volt direct current automatic contactor panels for variable speed motors

B—440-volt alternating current direct-on two-speed starters with two sets of overload and single-phasing preventers, 81-200 h.p.

TABLE IX.—COST, DIMENSIONS AND WEIGHT OF SINGLE-PHASE, AIR COOLED TRANSFORMERS

25 kVA	£116	Class A insulation	50 deg. C. rise
50 kVA	£188	Class A insulation	50 deg. C. rise
75 kVA	£250	Class A insulation	50 deg. C. rise
100 kVA	£290	Class B insulation	75 deg. C. rise
150 kVA	£345	Class B insulation	75 deg. C. rise

	Approximate length, inches	Width, inches	Height, inches	Weight, lb.
25 kVA	24½	18	34½	500
50 kVA	30½	20	48	920
75 kVA	35	24	56	1,350
100 kVA	36	26	57	1,900
150 kVA	42	57	63	2,500

Owing to the heavy current in the secondary, there would be a copper busbar arrangement on the 100- and 150-kVA sizes.

step type complete with isolator and ammeter, and above 80 h.p. they are of the automatic contactor type. Every endeavour has been made to quote for control gear which over the years has been fitted in conjunction with 220-volt d.c. installations.

The a.c. equipment quoted is of the heavy industrial type, being suitable in all respects for ship work, the prefix "marine" being omitted in order to bring the cost down to a reasonable figure without sacrificing performance.

Table VIII shows the relative volumes and weights of such equipment.

Transformers

Table IX gives the cost, volume and weight of various capacities of transformers. These figures are for single-phase units, and such figures must be multiplied by three for three-phase equipment.

Deck Machinery

This equipment will cost more than d.c. equipment; how much more depends on how closely the shipowner wishes to emulate d.c. performance. Suitable deck machinery can be provided and, incidentally, is being fitted, at a reasonable cost, bearing in mind the overall economy which can be achieved with an a.c. installation. It is the general opinion that a fall in cost of this machinery will take place when production is really underway.

Main Switchboards

This is another item which will be more expensive for a.c. than for d.c., but by careful planning, not only can the cost be held down to a reasonable figure, but the safety factor can be improved; to supply numerous small circuits from the main board is not only expensive but potentially dangerous.

Galley Ranges

The main galley ranges will also be greater in cost for a.c. than d.c., but this will be offset, particularly in the long run, by the ability to fit standard pieces of hotel equipment which are primarily designed for a.c. supply.

CONCLUSIONS

The overall cost of an a.c. 440-volt three-phase installation is less than its equivalent 220-volt d.c. system for the passenger and passenger/cargo type of vessel. It is also perfectly obvious that maintenance costs will be considerably less.

In a properly planned and installed a.c. system the safety and reliability factors will be improved.

The achievement of these advantages will, however, depend upon the initiative of the shipowners' representatives.

ACKNOWLEDGEMENTS

The author has to acknowledge with appreciation the assistance rendered to him by Mather and Platt, Ltd., The Electrical Apparatus Co., Ltd., and British Insulated Callender's Cables, Ltd.

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Discussion

Mr. G. Auterson, B.Sc. (Member) said Mr. Savage had left no doubt at all that after due consideration of all the issues involved he was finally convinced—at least as far as passenger cargo ships were concerned—that the conventional d.c. 220-volt electrical installation had had its day and must abdicate in favour of the 440-volt 3-phase a.c. installation. This, he claimed, promised increased safety, enhanced reliability, lower first cost and reduced maintenance costs. The validity of some of these claims had still to be proved, although the expectation was that they might be realized.

Incidentally, one also learned that the way of the innovator—to put it mildly—was not made easier by those who for one reason or another adhered doggedly to the concept of d.c. for ship installations.

In his reference to short-circuit protection the author had produced in Table I figures for initial short-circuit currents based on the assumption that the short-circuit current was limited only by the internal impedance of the participating generators and motors; whereas in practice the impedance of the connexions between the machines and the switchgear played its part to bring about a substantial reduction in the prospective short-circuit current. The lower the system voltage the greater generally was the ameliorating effect of circuit impedance. He would therefore suggest that, particularly in the d.c. case quoted, the prospective short circuit current would be very considerably less than the value of 133,080 amperes given in the table. He would also suggest that in the a.c. case the contribution of induction motors to the fault current could, in most cases, be safely ignored in calculating the initial symmetrical short-circuit current. This assumption would accord with the guidance notes given in Appendix C of B.S. 116 in which the following statement appeared:—

> "*Synchronous* machinery normally taking power from a network feeds back into it for a short period if the voltage or the frequency drops, as happens under short-circuit conditions, and *large induction motors* with *considerable flywheel effect* also act as generators if the frequency falls."

From this it might be concluded that the fault current contribution of an induction motor was negligible unless the occurrence of a fault entailed an appreciable fall in frequency and the induction motor and/or the machine to which it was coupled had considerable flywheel effect. If these considerations were taken into account, there would—he thought—be a substantial reduction in the figures in the table.

The figure of 78,720 R.M.S. asymmetrical amperes, for example, in the third column of the table was based on a doubling factor of 2·0, whereas 1·8 was the accepted maximum and 1·6 would perhaps be more appropriate to a 440-volt system.

In passing these comments, he was not attempting to belittle the importance of short-circuit protection; but he felt they must not allow themselves to be awestruck by figures derived from data which did not take into account all the factors involved. Mr. Savage, in his resumé of the paper, had already dealt to some extent with this subject.

Concerning the ability of fuses in installations in which the prospective short-circuit current exceeded the value of 33,000 amperes associated with Category of Duty 4, it had been stated authoritatively that the mode of action of the fuses under these conditions was such that successful performance might be expected, this being due to the current limiting feature of the fuse and the occurrence of cut-off.

On page 223 the author referred to a Classification Society Rule which could readily be identified with paragraph 405 of Chapter L of Lloyd's Register's Rules for Electric Propelling Machinery. These Rules had not been revised for many years, and the paragraph quoted was in the nature of an anachronism and would be omitted from future editions. Thanks were due to Mr. Savage for having pointed out this anomaly.

The author's suggestion that except in special cases all motors should be Class B insulated seemed rather strange, because Class B insulation would not appear to be ideal from the manufacturing point of view for a small induction motor with a mush wound stator and semi-enclosed slots.

The comparisons made on pages 229 to 233 between d.c. and a.c. motors and generators were somewhat misleading, since the d.c. machines were Class A insulated with a rating permitting overloads, whereas the a.c. machines were Class B insulated and had continuous maximum ratings. Mr. Savage had explained in his resumé, however, that he was not setting out to argue about a.c. *versus* d.c. but was illustrating what would be fitted normally and what could or would be fitted in the case of an a.c. ship.

Mr. L. W. Groom said that the field covered by the author was extremely wide; nevertheless, he appeared to have covered most of the essential points. Over such a wide range, there was unlikely to be complete agreement, but in general he (Mr. Groom) found himself in agreement on the major points at issue.

The demand for electrical power had increased, and it was increasing at a fantastic rate in ships for the Royal Navy. This made the examination of weight and space occupied by equipment an increasingly critical requirement. With some of the older d.c. ships there was a tendency to fit heavy solid equipment with little regard for its weight. In recent years on a.c. ships considerable attention had been given to this problem and much lighter equipment was being fitted, although there was still room for improvement. The problem of making equipment proof against severe shock and vibration had been solved by careful attention to design and eliminating brittle materials such as cast iron. In fact, it was now more readily appreciated that the answer to these problems was ingenuity in design and lightness of construction. He felt, therefore, that normal industrial equipment would never be suitable for naval use and that the Navy would always be faced with having to fit more expensive equipment. This question was really one of production, and if marine and naval requirements were similar, there could be a corresponding saving for both.

Considerable thought was given to the satisfactory operation and protection of electrical equipment in naval vessels. In d.c. ships a ring main system was generally used, and the system was split up so that large fault powers at any point were not possible. The typical arrangement quoted just below Table I showed evidence of a poorly designed system. Fault powers of the order quoted became possible and whilst fuses were available to deal with them, the question of suitable feeder breakers became a very difficult and almost impossible one.

The question whether to adopt symmetrical or asymmetrical current values referred to in the paper was bound up with the tripping times of breakers. If the times were relatively long then symmetrical values were appropriate, but the rating of the cables had to be considered. In general, short tripping times gave the best overall saving.

In a.c. ships use was made of the switchboard system with interconnector breakers between boards and busbar linking breakers or switches between sections of the boards. The worst duty of any of the switchgear resided in the feeder breaker and for the largest ships with a properly designed system the fault power was generally less than 25 MVA. This duty was quite commonly met by switchgear manufacturers and with careful design the switchgear could be made quite compact.

The author did not mention one problem which he himself had found to be extremely difficult: the physical problem of getting the large currents generated into the switchboards. The author did touch on the vexed question of whether for large powers 440 volts was the appropriate voltage. It was doubtful whether 660 volts would give a worth while advantage. Raising the voltage to 3·3 kV would necessitate the use of large numbers of transformers. Air break switchgear was preferred, and although the current handling problem would be eased the switchgear would be larger. A very thorough analysis would be necessary to supply the answer to this question.

The case of the *Flandre* was a very bad example of a poorly designed system as well as of poor equipment.

The author gave three reasons for lagging behind in the development of a.c. ship installations. He did not feel competent himself to deal with these reasons completely, but he found the first reason difficult to follow. The difficulties raised by the author did not appear to apply to shore installations, and in any case surely the manufacturer would make what was wanted. In connexion with the second reason, alterations to specification were always expensive, and surely more effort should be devoted to getting this right in the first instance. With reference to the last reason, he had not heard of these objections; this was probably because the Admiralty Electrical Engineering Department did the major portion of the designing of a system and had largely decided the design of the equipment to go with it. They knew a good many of the problems and some of the answers. However, it would be fair to say that if these objections had been raised they were quite unfounded.

With regard to the distribution system, while he would not go into details, much the same conclusion had been reached as by the author: that the 440-volt 3-phase 60-cycle 3-wire unearthed system was the best. There were one or two points of difference. For example, lighting was supplied from transformers at 115 volts and heating and galley equipment was generally 440 volts. The author had not stated clearly that he favoured 60 cycles for the supply, and he would like to hear Mr. Savage's further remarks on this point.

With reference to switchboards, it was essential that power operation of breakers should be employed when the fault currents concerned were fairly large, say over 10 kA. Preferential tripping was not used since, from the nature of a warship, it was necessary to have adequate power available even when some sources of power had been lost under action conditions. Discrimination in fault clearing was very important, and considerable effort was devoted to ensuring that when a fault occurred it was cleared without interfering with the remainder of the system. Group starting was not employed, again for a very good reason: that under action conditions one wanted the minimum disturbance due to damage. All important services could be supplied from alternative sources via automatic changeover switches or hand changeover switches, and in addition emergency supplies could be quickly rigged. Quite often engine room auxiliaries could obtain emergency supplies from their local generators without going through the switchboard.

Direct on-line starting was employed wherever possible for the control of motors. Control circuits were at 440 volts, and two overload trips were provided with fixed settings at 125 per cent full load. It was agreed that single-phasing protection would be a desirable feature, but no satisfactory shockproof and simple device existed. However, with the overload setting used and with star connected motors the risk of damage due to single phasing was negligible. Trouble was only likely to arise with delta wound motors and occurred with a loading of about 60 per cent of full load over a small range. Contactors would easily open circuit on stalled motors with over eight times full load, and back-up fuses would take over at about twelve times full load and clear short circuits. In order to minimize maintenance on control gear, silver-faced contacts and sealed-type silicone fluid dashpots had been introduced.

Fluorescent lighting was used and was very satisfactory. Deck machinery had been a problem and he was not sure the best solution had been arrived at yet. Users had been so used to the wide range of control easily attained with d.c. that it was necessary to explain and demonstrate that simpler controls were adequate. Recently there was a demonstration of a winch control using a squirrel cage motor with a star/delta lever and foot brake, and exceptionally good control was achieved. It was hoped that this scheme might have wide application.

P.C.P. cables had been used to reduce weight and cost and silicone cables were being introduced to achieve further saving in weight and allow higher temperature rises. It was sometimes overlooked that voltage drop and short-circuit capacity might be determining features in the amount of copper used in a cable.

In warships there was still a requirement for a certain amount of d.c., mainly at 220 volts and 24 volts, and selenium rectifiers provided a satisfactory answer. It was thought that there might be a use for silicon rectifiers, but this was not likely to occur in the very near future.

Safety precautions to protect the persons operating equipment had been a major consideration, and the reduction of maintenance effort had been attempted with some success. It was essential to reduce watchkeeping effort, and this had been achieved by the use of automatic watchkeepers. These had demonstrated their value on small ships and were being extended to cover all types of prime mover and generator.

A comparison of the costs of a.c. and d.c. installations was not easily obtained. The *Daring* class were the only ships readily available for comparison. These included the first a.c. ships for the Navy, and considerable improvement had been effected since then. Even so, there were savings in weight and maintenance on these ships. There was little doubt now that a.c. installations scored over d.c. on all counts, and his information was that the Navy had taken to the a.c. ships and liked them very much.

Finally, it was desired to support the author's opening remarks in which he referred to the necessity for shipowners to have fully competent electrical advisers. The Admiralty had built up a useful fund of knowledge and one wondered whether this could not contribute in some way to a more efficient marine service.

MR. M. P. HOLDSWORTH, M.Eng. (Member) said the marine electrical engineer in the past had been largely concerned with d.c. and had been on his own. There had been no large industrial d.c. installation of a comparable size from which he could obtain guidance. Perhaps because he had been on his own so long he tended to forget, now that he had taken up a.c., that this was no longer so. He might do better and get along far more quickly in the solution of problems real and imaginary if he realized that industry ashore had some fifty years' experience in the same field.

To a stranger this might seem an unnecessary statement, but after reading Mr. Savage's paper and examining his own outlook he felt it was worth while to remind themselves of its truth.

Three points from the paper would illustrate what he thought was this tendency to "go it alone".

First—short-circuit protection. Mr. Savage rightly pointed out that the a.c. system was very much better from this aspect than the equivalent d.c. system; but he had not shown the a.c. system to its true and full advantage. Mr. Savage suggested that even the a.c. breaker and its fault operating conditions were doubtful quantities. On page 218 he wrote: "It is suggested that the values should be accepted in estimating short-circuit values until *more detailed research has been carried out. . . . .*". And again at the bottom of page 219: "There is a divergence of opinion as to whether the asymmetrical current should be considered at all, *but until more is known about operating efficiencies of circuit breakers,* then the worst possible circumstances should be taken." It was a frightening picture. They were on the brink, one might imagine, of a fearful amount of thought and research but, he would submit, this was not true at all. There were few aspects of electrical engineering which had received such co-operative attention and research from manufacturers as circuit breaker design and testing, and power system prospective fault determination. The existence of two British Standard specifications, namely B.S. 116 and B.S. 936, might make for some confusion, since neither was applicable directly to the marine a.c. air breaker, though selected abstracts from both must be used pending the issue of a fully appropriate specification. The testing procedures in these specifications were different, B.S. 936 covering symmetrical currents and B.S. 116 covering asymmetrical currents. Nevertheless he felt sure there was no divergence of specialist opinion as to the amount which the asymmetric component should be considered in evaluating the necessary switch gear rating for marine a.c. breakers. Because of the compact nature of a marine installation the a.c. component of a fault could be comparatively slow to die away. Modern a.c. air breakers, as already used in ships, had a very short operating time. As a result of these two factors asymmetric current certainly should be taken into account. Not, however, in the way Mr. Savage had done, for his figures greatly exaggerated its importance.

There was no real mystery about this type of problem which to land industry was an everyday matter.

The second example concerned single phasing. He wondered whether they were getting this problem a little out of perspective. Two papers(5) had been given to the Institute concerning the fundamentals of a.c. on ships. Both papers had contained a detailed section on single phasing. This problem, however, was not in any way peculiar to marine installations; and it was reasonable to ask what shore industries had done about it in their fifty years of development. Throughout the whole of British industry there were only two devices which specifically aimed at protecting against this condition. One device was a most elegant and expensive induction type meter; the other, mentioned by Mr. Savage, was an ingenious and relatively inexpensive device operating on thermal bimetallic principles. Both were excellent and he had no quarrel with them. His only feeling was that before the marine industry accepted that such protection was necessary for their motors they should refer back to land industry and examine the reasons why such devices had in general been found to be an unnecessary refinement.

The last example concerned squirrel cage rotors. On page 225 Mr. Savage appeared to be arguing for the wholesale adoption of special double squirrel cages giving low starting current and controlled torque characteristics. He thought that was so from the paper and from Mr. Savage's remarks it did seem to be the case. This impression was further strengthened by the reference to four times full-load current as the starting current in every case of the comparative alternating current motor characteristics on pages 229 to 232. He might be doing Mr. Savage an injustice here but such a view had wide currency a few years ago. The truth surely was—and it was the same on land—that special cage motors could contribute to a well-integrated installation. Their usefulness, however, was only at the top of the motor size range, where considerable alleviation of voltage dips could be given. For the majority of motors there was no problem of voltage dip. So why fit a motor which was unnecessarily complex, had a lower working power factor and, ultimately, on a fair pricing basis, would cost some 15 per cent more, as it now did on land?

He must make it quite clear that he was not advocating the use, willy nilly, of land equipment on shipboard. The marine environment demanded in many cases special materials and often higher standards all round. But there was on land a solid background of advanced ideas and a knowledge of a.c. engineering which the marine electrical engineer would be remiss to ignore.

MR. R. ATKINSON, D.S.O., R.D., B.Sc. (Member) thought the author was to be congratulated on an excellent paper and it would be difficult not to agree that his outspoken comment was both constructive and fair. His suggestion that the shipowner must have on his staff a properly qualified person was unquestionably good. He thought he might expand on this point, however; presumably he meant an electrical engineer but how many ships did an owner need to have before this course was seriously recommended?

Very early in the paper the author discussed short-circuit and protection gear. Once again they must agree that this required serious consideration. The author gave the impression that very little was known and that certain short-circuit values had to be assumed; he spoke of "astronomical short-circuit current values" and then of "further research". Now he thought this was a pity as it tended to frighten from a.c. those who were now giving it serious consideration. If short-circuit current was to be limited to a value within the capabilities of the circuit breaker then protective reactors should be inserted in the system and the size of these reactors must be calculated. Hence, it was necessary to know the maximum short-circuit current that could occur at the various points in the system. It was hardly possible to select a circuit breaker which would withstand the current and isolate the faulty section if the maximum short-circuit current was not known. Would the author agree that it was possible to calculate the value of the short-circuit current for design purposes? Would he also agree that by careful placing of reactors the short-circuit currents could be much reduced in magnitude? After all, if installations were growing so big, were not reactors worth considering?

An important point not made by the author was the limit on size of the d.c. plant. When considering an electrical installation for a passenger liner, they were almost forced to employ a.c. Considering a possible plant capacity of 2,400 kW, the employment of d.c. would cause definite difficulties. Marine d.c. voltages seemed to have been standardized at about 240 maximum because higher voltages were dangerous to personnel. At this relatively low voltage level, the rate of current output of a 2,400-kW plant would be about 10,000 amperes and the short-circuit current which could be produced by the generators alone would be about 100,000 amperes. On the assumption that half the rate consisted of motors and that their current contribution to the generators under faulty conditions was added, a fault current resulted of approximately 130,000 amperes. As far as he was aware there were no air circuit breakers in existence with an interrupting capacity in excess of 100,000 amperes so adequate circuit breakers for a 2,400-kW d.c. plant could not be obtained.

If the maximum rating of circuit breakers was assumed at 100,000 amperes interrupting capacity, a maximum plant size of 1,800 kW for the 240-d.c. installation was arrived at. These figures were calculated by the use of the approximate rule incorporated in A.I.E.E. No. 45, "Recommended Practice for Electrical Installations on Board", and whilst they were not necessarily exact, they did nevertheless serve to illustrate the fact that there was a definite upper limit to the capacity of a contemplated d.c. system.

Higher d.c. voltages would, of course, obviate this condition, but this led into other difficulties. As mentioned above, d.c. voltages in excess of 240 line to line, or 120 volt to ground were rightfully considered dangerous to the operating personnel. Secondly, very little general purpose industrial equipment was built for voltages in excess of 240, so that marine d.c. equipment for the higher voltages were of a special nature and thus more expensive. Finally, there was the question of higher voltage equipment requiring high class makers of a higher order than that generally given to the lower voltage equipment.

In sharp contrast to this rather rigid limitation of the d.c. system, the a.c. plant was practically unrestricted in size, by which he did not mean the 440-volt a.c. plant could be expanded without limit. In enlarging such a power plant, once again the circuit breakers were the limiting factor but at a considerably higher power level.

Consider an a.c. plant of 5,000 kW with a connected motor load of about 50 per cent and by virtue of the same method of calculation described above, with a similar motor contribution, it was found that such a power plant rating fell within the capabilities of the 100,000 amperes rating of the circuit breakers where a fault occurred. If the generator short-circuit characteristics were such that the generator contribution to a fault was less than the "ten times" assumed, then it was possible to increase the a.c. plant rating to about 6,000 kW. Furthermore, by the use of current limiting reactors previously mentioned, it was possible to keep fault currents within breaker capabilities, but for a large increase in operating plant rating about 6,000 kW it would be necessary to operate under split plan condition or to raise the generated voltage to 2,300 or 4,161 volts. The method would then be to distribute this voltage to appropriate parts in the ship. At selected points transformers would be installed to reduce the generated voltage to 440 for use with the majority of auxiliaries. It was quite probable that in such a marine power plant some of the larger auxiliary motors would be operated from the high voltage line.

The author's comments on page 220 on a.c. installations were interesting and indeed applicable. He recently took out some figures in respect of a ship's supply of pumps and compressors. On average a.c. equipment cost 70/71 per cent of the equivalent d.c. These were indisputable facts..

The author had not made any recommendations on variable speed or constant speed motors, except a passing reference on page 226. There had been a development towards constant speed and as it had a great influence on price, he would have thought the author might have found it appropriate to make recommendations. Would he agree that there was now very little need for anything but constant speed? He submitted a table of proposals for the author's comments:—

TABLE X

Number	Application	Enclosure	Usual arrangement of d.c. motors		Proposed arrangement of a.c. motors	
			Winding	Speed	Winding	Speed
1	Air compressor	Drip proof	Shunt	Constant	Squirrel cage	Constant
2	Auxiliary circulating pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
3	Auxiliary circulating pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
4	Auxiliary condenser pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
5	Ballast pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
6	Bilge pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
7	Boat winch	Waterproof	Compound	Variable	Squirrel cage	2-speed
8	Boiler feed pump	Drip proof	Shunt	Constant	Squirrel cage	Constant
9	Butterworth pump	Drip proof	Shunt	Constant	Squirrel cage	Constant
10	Capstan	Waterproof	Compound	Variable	Wound rotor	Variable
11	Cargo winch	Waterproof	Compound	Variable	Squirrel cage	Multi-speed
12	Circulating pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
13	Drinking water pump	Drip proof	Shunt	Constant	Squirrel cage	Constant
14	Emergency bilge pump	Submersible	Shunt	Constant	Squirrel cage	Constant
15	Fire pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
16	Fire and salt water pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
17	Forced draught fan	Drip proof	Shunt	Adjustable	Squirrel cage	4-speed
18	Fresh water pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
19	Fuel oil transfer pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
20	Fuel oil service pump	Drip proof	Shunt	Adjustable	Squirrel cage	4-speed
21	Hot water pump	Drip proof	Shunt	Constant	Squirrel cage	Constant
22	Hull ventilation	Drip proof and waterproof	Shunt	Constant and adjustable	Squirrel cage	Constant or 2-speed
23	Lubricating oil pump	Drip proof	Shunt	Constant	Squirrel cage	Constant
24	Lubricating oil purifier	Drip proof	Shunt	Constant	Squirrel cage	Constant
25	Machinery space ventilator	Drip proof	Shunt	Adjustable	Squirrel cage	Constant or 2-speed
26	Main circulating pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
27	Main circulating pump	Drip proof	Shunt	Adjustable	Squirrel cage	2-speed
28	Main condenser pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
29	Priming pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
30	Refrigeration compressor	Drip proof	Shunt	Adjustable	Squirrel cage	2-speed
31	Refrigeration condenser	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
32	Salt water circulating pump	Drip proof	Shunt	Adjustable	Squirrel cage	Constant
33	Sanitary pump	Drip proof	Shunt	Constant	Squirrel cage	Constant
34	Shaft turning	Drip proof	Compound	Constant	Squirrel cage	Constant
35	Steering gear, hydraulic	Drip proof	Shunt	Constant	Squirrel cage	Constant
36	Windlass	Waterproof	Compound	Variable	Wound rotor	Variable

Under "Control Gear" the author stated categorically that direct-on starting could be utilized for all motors on board ship. Surely the author did not mean this. Was he (Mr. Atkinson) right in saying that this matter was a function of the generator capacity and if a motor was greater than 12½ per cent of the generator capacity then direct-on starting was quite unsuitable, giving way to auto-transformer type starters?

Under "Lighting" the author spoke of allowing the fitting of fluorescent lighting throughout. Did he recommend this? Had he ever done it? Was it not dangerous in an engine room? He had heard of factory accidents being traced to this very point; he believed it was called stroboscopic effect, and occurred if the frequency of the lighting synchronized with the speed of rotation of a piece of machinery, whence it was quite easy to be unaware that the machine was in fact rotating. Hence a mixture of incandescent and fluorescent lighting had been recommended for such machinery spaces. Would the author comment on this?

The author paid little attention to the disadvantage of the squirrel-cage motor for winches. Did he merely accept low starting torque and high starting current? In the past this had always been considered a serious stumbling block. Would he not consider that in a ship of the dry cargo type d.c. was really necessary as well as a.c. and that conversion apparatus of the static type was justified?

The author seemed to favour the low speed winch which was contrary to development trends. Records showed that about 50 per cent of the cost of operating a cargo vessel originated in the time and expense of loading and discharging on lay days. Anything which decreased this expense must have a direct bearing on shipowning profitability, and these were the arguments that interested shipowners. Cargo time was perhaps not so important in the case of a passenger ship. Was the author really speaking of passenger vessels?

With temerity he suggested that the author could with advantage have been less general and more definite in his advice. Was it wise or possible to group all ships together and then pronounce for a.c. or d.c.? Would the author agree that the case for a.c. was much stronger with different types of tonnage? Would he criticize the following reasoning?

It seemed to him that the case for a.c. could be shown as follows:—

TABLE XI

General Cargo Vessel

Recommendations	*Reasons*
Probably a case for d.c., but in any case marginal.	(a) Without great expense no one seems to have devised a.c. winches giving d.c. characteristics. (b) The large amount of d.c. required and conversion being expensive reduced seriously the financial advantage of a.c. (c) Situation would change overnight if reliable, cheap rectifier were available.

Refrigerated Vessel

Recommendations	*Reasons*
A.C. favoured.	(a) If ideal conditions were sought, variable speeds were required to prevent starting and stopping of compressors and this gave the best economy. (b) If a small percentage of operating efficiency could be sacrificed several constant speed refrigerating units driven by a squirrel cage motor could be supplied. Units in service could thus be varied according to demand. (c) Same as (b) except that larger units should be driven by a two-speed squirrel cage motor. This was American practice. (d) An increased number of constant speed units were a natural advantage to a.c.

Dry Bulk Carrier

Recommendations	*Reasons*
A.C. recommended.	(a) This type of ship seldom used winches, especially the new trend of a regular shuttle service on ore. (b) Excluding, therefore, consideration of cargo handling, very few auxiliaries needed two-speed drives and only fuel oil service and forced draught fans required four-speed motors. (c) Self-unloaders might be included in this contingency. Unloading equipment was frequently of the slip ring induction motor type with speed adjusting features.

Passenger Vessels

Recommendations	*Reasons*
A.C. recommended.	(a) Because of larger power requirements d.c. was precluded on grounds of protection as previously described. (b) Such a vessel often had large refrigerated capacity for air conditioning and where constant speed centrifugal compressors were satisfactory. (c) All other loads including hotel services were natural a.c. applications.

Tankers

Recommendations	*Reasons*
A.C. recommended.	(a) Almost all auxiliaries were suitable for constant speed squirrel cage motors. (b) No winch problems. (c) Cargo pumps had to be considered specially, but these were normally turbine driven because very high capacities required to reduce time in port, and in any case, normally steam was available in port. Nevertheless, they could be motor driven and constant speed. (d) Cargo stripping pumps of variable a.c. multi-speed required.

MR. A. R. TULLEY said that he wished to add some remarks to those of Mr. Groom.

The author seemed to have been unnecessarily unkind to the d.c. machine in thinking of it only in terms of Class A insulation and low temperature rise, and in slow speeds for generators. The Admiralty were proposing the exclusion of Class A material and adopting the recently agreed increased temperature rises of B.S. 2613 and B.S. 2757, in which the Class B insulated windings of both d.c. and a.c. machines were permitted 65 deg. C. rise measured by thermometer above an ambient temperature of 50 deg. C. They had also a number of d.c. main generators running at 900 and 1,000 r.p.m. satisfactorily.

The advantages of the squirrel cage induction motor in respect of maintenance were indisputable. As the number of machines in a large warship could approach one thousand, it would be appreciated that the reduction in maintenance requirement due to the adoption of an a.c. system permitted the limited effort available to be redirected to the more complex equipment of fire control, radar, and so on, which steadily grew.

The alignment of marine and naval requirements, as far as construction was concerned, was aimed at in the Defence of Merchant Shipping Memorandum No. 32, in which the Admiralty recommended measures considered to render merchant ships and their equipment less vulnerable to underwater shock. Whilst, for the performance of main generators, naval and marine requirements were probably necessarily different, a good measure of agreement on performance of motors and their control gear should be obtainable without much difficulty.

There were a number of special requirements for the main a.c. generators for H.M. ships. The principal ones were: firstly, accurate steady state voltage control, which was restricted to ± 1 per cent, thereby greatly assisting in the minimizing of cable weights. Mr. Groom had pointed out that the selection of cable size might depend on voltage drop, and the less the generator regulation took of the guaranteed range of 455 to 435 volts the better. Secondly, limitation of voltage disturbance due to load changes. Disturbance had to be kept to a low level as a number of users had been persuaded to use the general supply system instead of having a privately generated supply. Thirdly, satisfactory short-circuit performance. The initial short-circuit current was limited to ten times full load current (symmetrical) for generators up to and including 500-kW capacity. This agreed with the author's suggested figure. But for larger generators the peak was limited to six times full load current, this easing the duty of the switchgear. In order to give the protective devices a chance to disconnect a faulty section and allow the remainder of the supplied equipment to continue to enjoy or be reconnected to a healthy supply, a minimum sustained short-circuit current of three times the full load current was called for. On removal of the fault the voltage must return to normal automatically. This latter requirement precluded the use of many self-excitation schemes.

All large main generators had closed air circuits with air-to-water heat exchangers mounted over the machines. Ducting to and from the upper deck was not acceptable for warships for more than one reason, the newest reason being a dislike of the type of atmosphere which might be encountered in any future conflict. The problem of carbon dust in large d.c. generators had led to the fitting of wet or dry type filters in the air stream, and the reversal of the direction of air flow so that the dust-laden air from the commutator passed direct to the filter instead of past the armature. Though on the first a.c. generators the slip rings were kept outside the enclosure, the fouling due to oily and wet engine room and boiler room atmospheres had led to their being resited inside on later machines.

MR. G. J. TUKE (Associate Member) wished to offer his congratulations to Mr. Savage on delivering his paper at this time In view of the number of vessels other than tankers which had recently been ordered with a.c. installations, the paper was most opportune.

He found himself very largely in agreement with the author, although not completely, and would prefer to dwell on, and develop, some of those points in which they were in agreement, rather than to take up the cudgels on points of variance.

The first main point concerned co-ordination of the ships' electrical system. The days when the electrical system of a ship was deemed to have elastic properties, when the addition of an extra piece of equipment merely resulted in an extra switch fuse on the main switchboard, or extra outlets at the distribution end, had, or should have, ended completely.

It was essential that the system be considered as a whole, from generator to final distribution, in the greatest possible detail *before* any decisions were made regarding numbers of generators and type of distribution system to be adopted. For a successful and well designed ship, it was as important to have a correctly designed electrical system as it was to have a carefully investigated heat balance—a point which, he was glad to say, mechanical engineers had appreciated to a greater degree in the last few years. It was also essential to maintain a correct perspective for electrical installations. The system was essentially one of conversion and distribution of the horse power developed by the auxiliary prime movers, and as such should have the characteristics of a good servant, completely reliable, as inconspicuous as possible and quietly efficient. To what extent did they achieve this objective in practice?

He believed that the reason for much of their difficulty was that neither the owners nor the shipbuilders had placed sufficient stress on co-ordination and had merely added bits and pieces here and there as was found necessary to meet the requirements of engine room and deck services.

It must also be admitted that electrical co-ordination necessitated extra effort on the part of owners and builders, probably causing more load on already overloaded drawing offices, but that effort produced results for the twenty-odd years of a ship's life, and their experience was that it was well repaid. Unfortunately it conflicted with the very natural desire of the shipbuilder to complete his designs with the least effort and upheaval—and this again emphasized the fundamental necessity of the closest co-operation between the shipbuilders' electrical department and the owners' electrical superintendent.

The company with which he was associated had been operating a large fleet of tankers with a.c. systems for a number of years and it would seem appropriate to recall some of their practical experiences in relation to points Mr. Savage had made. Before doing so, however, they could hardly let this opportunity pass without paying tribute to the remarkable achievement of the American-built T.2 tankers, and there were, he believed, about 600 of these turbo-electrically propelled ships built with all a c. auxiliaries and transformer interconnexion so that electrically driven cargo pumps could be supplied by either the main propulsion alternator or the auxiliary turbo-alternators. When one paused to consider the circumstances and unprecedented strategic urgency prevailing at the time these vessels were designed and built, their conception was indeed a bold step. The fact that his company—in common with many other owners—were still operating very satisfactorily a number of these vessels, some of which were now fifteen years old, was a measure of their success.

He would agree with Mr. Savage wholeheartedly in his condemnation of those who developed technically inaccurate arguments against the use of a.c. It would be idle, of course, to claim that a.c. was the answer to all problems, but let them ensure that in reaching their decisions, they had got their facts right.

Mr. Savage quoted the case he encountered of the proposal to increase the horse power rating of the prime mover of the auxiliary generator because the system chosen was a.c. They too had encountered this. Whoever gave rise to this surprisingly widely circulated misconception was either technically dishonest or very ill-informed. There was not time to deal with all aspects of this problem, but let them dismiss it with the categoric statement that a motor of rating equal to 75 per cent of that of the alternator supplying it could, if need be, be started direct on line with no harmful effects whatever, provided that the machine designer understood the requirements and made suitable provision with his alternator sub-transient reactance and the impedance in the rotor of the motor. Oscillograph records of such a test carried out by a well-known Continental manufacturer had been published.

Turning now to the vexed question of speed variation, it was true, of course, that d.c. motors afforded speed variation more readily than a.c. motors, but should they really be content to accept designs of auxiliary mechanical units which were so loose that they depended on what was virtually an infinitely variable gearbox in the form of a d.c. motor to give the required speed tolerance?

The manufacturers of the auxiliary mechanical units naturally preferred d.c., but if each of the drives for which speed variation had been considered traditionally as essential was examined in detail it was surprising how few really required speed variation to meet varying operating conditions, rather than speed variation to compensate for loose design.

In 1955, his company put into service three Diesel-driven tankers with an all a.c. electrical system. The problem of speed variation was investigated in great detail for engine room auxiliaries. For certain of these drives two-speed change-pole motors were used, and in one case only—the main lubricating oil pumps—it was decided to fit a recirculating line across the pump. These ships were operating very satisfactorily.

In tankers generally, experience over the last ten years had proved a.c. to be the better system. He would have thought that for very similar reasons the passenger liner with the large hotel load would also benefit from a.c. The dry cargo boat winch load, however, was an important exception, and in spite of modern a.c. developments for cargo winches the characteristics of the converter and Ward-Leonard system still had much to commend them.

His company's practice for tankers had been that a.c. systems were adopted for all installations where the normal sea load exceeded 120 kW.

As developments continued, ever increasing stress must be laid upon continuity of supply. On a modern vessel total electrical failure meant no engines and no steering, and the vessel was literally helpless. It was essential that some check was maintained on individual component protection. The manufacturer naturally liked to arrange that his component in the ship's system put itself out of action when conditions arose which were not perhaps entirely to its liking. The fact of that component putting itself out of action, however, could interrupt a vital link and completely disorganize the main cycle. Once again components must be co-ordinated into the whole system, and in many cases it paid to sacrifice a small measure of individual component protection in the interests of preserving the system as a whole—particularly as some component protective devices were so eager to perform that they shut down the component when no fault existed. One of the best examples of this was the circulating pump motor for the auxiliary turbo-generator condenser. If the relay protecting this motor tripped, the turbine lost vacuum and the turbine low vacuum trip operated with the result that all power was lost. This process required approximately 25 seconds from beginning to end. There were various ways round this difficulty, their particular solution being to dispense with condensers and use back pressure turbines for driving the generators.

This same point had been referred to by Mr. Savage in the choice of the system. Surely an earthed neutral system with protective devices to isolate components in the event of an earth fault developing must be confined to circuits of a non-essential nature in spite of the fact that an earthed system was recently adopted for a large vessel built in this country.

Happily for the tanker owners, electrical loads had not yet reached such values that the prospective short circuit under the worst fault conditions exceeded values of 25 m.V.A. As there was a wide range of fuses and circuit breakers tested and certified to deal with 25 m.V.A. their problem was simple.

They felt, however, a certain amount of sympathy for their colleagues in other fields who, as Mr. Savage suggested, were faced with a very serious problem. Surely the answer was to adopt 3,300-volt systems of power distribution to main auxiliaries and transform down to lower voltages for smaller auxiliaries and domestic loads. One could almost visualize the raising of hands in horror and the shaking of wise heads at this suggestion—but three points were worth considering:—

(1) Any a.c. voltage above 50 could be lethal.

(2) Of the very large number of electrically propelled vessels whose propulsion system operated at 2·3 and 3·3 kV—how many fatal accidents had occurred? High voltage here had solved an otherwise insoluble problem.

(3) Was this problem not akin to that of shore installations—and should it not be solved by the same method?

COMMANDER P. A. WATSON, R.N., pointed out that Mr. Groom and Mr. Tulley had spoken of considerations concerning the design of the a.c. installations now universally adopted in the Royal Navy for all new construction.

The Electrical Branch of the Royal Navy, of which he was a member, was responsible at sea for the handling and maintenance of the electrical systems, and he thought that a few words on this aspect might be of interest.

As the meeting had heard, the first ships to join the Fleet with a 440-volt a.c. installation were four of the eight *Daring* class, which were equipped with exactly similar electrical layouts to their four 220-volt d.c. sister ships. This feature had enabled the relative advantages of the two systems to be compared closely as regards reliability, maintenance effort and ease of handling.

The greatest saving, without doubt, had been brought about by the substitution of the induction motor and its direct "on line" starter for the commutator motor with its comparatively complex starter. This was the principal factor in the reduction of the maintenance load, which had enabled them to make a 20 per cent saving in the number of maintenance ratings required for the main generating and distribution system in the a.c. as opposed to the d.c. ships.

There were some qualms about the ability of the ratings to adapt themselves to the new system, but in the event they took to the complexities of electronic automatic voltage regulators, synchronizing and so on, easily and with confidence. Each ship, however, carried an electrical officer who was a fully qualified electrical engineer, and the senior ratings were given extensive electrical training. Their responsibilities, of course, included the maintenance of radar, wireless, asdics, complex electronic fire control systems and so on.

The question of safety of people from the higher voltages used had given no worry at sea, largely because all 440-volt equipment had been designed with this danger in mind, and it was all "dead front" and very adequately protected.

It was reasonable to expect the introduction of an entirely new system to have some attendant shortcomings, and the only feature of the new installations which was giving real cause for concern was the failure of some squirrel cage motor stators due to single phasing. The larger motors had been fitted with thermal or other protective devices, but such protection was originally thought unnecessary in the fractional horse power sizes. Failures had been suffered in this way. However, the matter was being energetically pursued by the Director of Electrical Engineering, and suitable solutions would no doubt be provided.

To sum up, he could confirm that the introduction of a.c. had given the operators and maintainers fewer troubles than were anticipated and had shown a really worth while improvement in reliability and the reduction of maintenance man hours. Sailors of the "Grey Funnel Line" heartily commended the adoption of a.c. to their brothers at sea.

MR. H. R. OGLE said the author has inferred in the introduction that manufacturers were interested in maintaining the *status quo*. Other speakers would, no doubt, have their own views on this statement, but as far as his own organization was concerned they had at all times endeavoured to give the builder and owner what had been requested, no matter whether a.c. or d.c. Also they had endeavoured to help those of their customers who had not had a.c. experience by technical articles designed to bring out some of the important a.c. characteristics. To quote a particular case, they were extremely pleased to contribute a major portion of that section of the Institute's publication(3) which dealt with the parallel operation of alternators. This policy, which he was sure was similar to that followed by other manufacturers, certainly did not indicate a bias against a.c. where it was economically and technically sound.

He was interested to note the reference to the assured source of income based on the demand for spare gear. He would say without hesitation that they would shed few tears if this part of their business proved redundant, amounting as it did to a very small percentage of their total turnover.

Turning now to technical matters, there were several interrelated comments he would like to make.

It was perfectly true, of course, that for a given installation the generating capacity must be greater for a.c. than for d.c., if by generating capacity they meant the generator size required to deliver a given current and voltage. This was due to the effect of a power factor less than unity as a result of the demand by induction motors for wattless magnetizing current in addition to the power current. A decreasing power factor had a cumulative effect on the size and cost of an alternator. Not only was the size increased as a result of increased kVA but for a given kVA the size increased somewhat as the power factor decreased. For this reason as well as for the effect upon cable and switchboard capacity the overall load power factor should be as high as possible. To attain this end it was necessary that all motors should be designed for maximum power factor.

In the past too much emphasis had been placed upon the need for reduced starting current motors since any motor design which decreased the starting current inherently reduced the running power factor. This was independent of the particular manner or design by which the reduced current was obtained. Incidentally, a reduction of starting current also decreased the maximum torque and tended to increase the motor size and cost. Naturally the larger motors must in general have a limited starting current, but there was no excuse for a specification calling for all motors to be of this type. The logical approach was to determine the maximum transient current which could be accepted by the generating plant and to give this value in the motor specification. This method would ensure that the maximum overall power factor was obtained.

The author briefly dismissed power factor correction as being unnecessary if the load power factor exceeded the rated alternator power factor, which was usually a nominal 0·8. Surely a sensible attitude was to investigate whether or not a measure of correction would give an overall economy by permitting the rated power factor to be raised, bearing in mind the reduction in size, weight and cost of alternators, cables, switchgear and transformers resultant upon higher rated power factors.

Returning to the question of motor starting performance, and in reference to Figs. 4 to 7, he would strongly urge the greater use of single cage motors with, if necessary, a special rotor bar shape for those duties where reduced starting currents were required. Much propaganda had been broadcast concerning the merits of the double or triple cage design but the fact was that, although such a machine could be designed to give the exceptionally high starting torques which were occasionally required, it held absolutely no advantage where reduced starting current was the primary requirement. Therefore, since starting torques above normal were unnecessary for the majority of marine duties, particularly centrifugal drives, it was obvious that full advantage should be taken of the greater simplicity and robustness of the single cage design.

Might he also plead for the abolition of such vague terms as "high torque" and "low starting current" which were commonly found in enquiries received by motor manufacturers. A more precise statement at this stage would enable the manufacturer to offer a motor best suited to the particular duty.

An important effect of motor starting current was the resultant transient dip in alternator voltage. The author suggested that the magnitude and duration of such transient dips were a function of the automatic voltage regulator. He would point out that it was the alternator and exciter characteristics which primarily determined the dip and recovery time for a given transient load, and the automatic voltage regulator, so long as it operated satisfactorily, had but a secondary effect. In this connexion it would be of interest to learn the user's experience as to what transient voltage dip was acceptable in service. Various sources of information had indicated that 20 per cent was a reasonable limit, but further comment would be very welcome.

Mr. T. G. C. Harrop congratulated Mr. Savage on his paper and said that by and large he agreed with him. But there were a few points he must make and he would deal with them under the headings given in the paper.

He agreed that this was a specialized subject, as stated in the introduction to the paper. It was in the shipowner's interest to have an electrical expert on his staff and if the latter was given the necessary status and authority he would be welcomed by all shipbuilders.

If "marine" meant a 30 per cent increase in cost for equipment similar to that destined for land use, surely this was due to marine requirements developed over a period of years and specified by the various classification societies. In other words, the equipment was special, and the price did not go up because it was marine.

He did agree, however, that in most circumstances standard equipment to the various British Standard specifications was suitable.

Under d.c. development, the original electrical installations were simple, and one of the main selling points of the earlier electrical engineer was that the installation could be fitted into an existing ship without disturbance to anything. In these days, however, the electrical installations must be properly planned and equipment must be placed in suitable positions. Each electrical installation on a ship at the present time was an engineering job, and equipment and cabling could not be put in any hole or corner available.

On maintenance and repair costs, the cost of repairs in remote spots was undoubtedly high, as was known by experience. He would like to see more consideration given to the better siting of machines, and this had been dealt with by previous speakers.

Under the heading "A.C. Installations", he was really amazed at Mr. Savage's remarks regarding shipowners, shipbuilders and manufacturers. Perhaps it was a leg pull! Mr. Savage stated that manufacturers did not favour a.c. because of the possible loss of business in spare gear. In his own experience, the obtaining of spares was a very expensive and tedious business. The manufacturers regarded spares as a nuisance and preferred not to be humbugged with them. In many instances, it was quicker and cheaper to deal with them in the shipyard.

Although he must agree that the shipbuilder could kill a project on price if he desired, the rapid advance in design and everything connected with ships surely indicated that shipbuilders were progressive.

He was surprised at the inference behind the remarks on a.c. installations. He would have thought that by now all major shipbuilders had carried out at least one a.c. installation for the Admiralty. Having had experience, they would have no qualms in giving the shipowner what he required. He could assure Mr. Savage that he knew of one shipbuilder who would welcome the opportunity of developing an a.c. installation for his liners and preparing the working drawings, although he could not build the ships. Furthermore, he would embody in the system all Mr. Savage's ideas which were—he felt sure—quite sound.

He agreed wholeheartedly with the remarks on the shipowners' representatives but no doubt Mr. Savage knew that better than he did.

Generating plant, as Mr. Savage had said, was available to permit direct-on starting of even the largest squirrel cage motors found on ships without any difficulty.

In practice, the synchronizing of alternators had presented no difficulty among the usual run of workmen accustomed to d.c. paralleling in shipyards. He would put in a plea to everyone not to complicate the system by introducing automatic synchronizing equipment or anything else which might result in the maintenance problem being made more difficult than the problem it was intended to overcome. On costs he agreed that the shipowner should stand firm. He should stick to the equipment he had decided upon. Further, in the interests of standardization he should not allow different makers' products to be introduced into one ship. In the past, shipbuilders had insisted on one make of motor to comply with owners' requirements. But the auxiliary manufacturers had been able to get round the shipowners' representatives to accept another make, and the shipbuilders' ground had been cut from under them.

It was curious that an a.c. galley should cost more than a d.c. galley. His own experience was the reverse.

He could see a big future for "Butyl" cable and he hoped shipowners would agree to its introduction in their vessels.

So far as costs were concerned, on one particular project, which was a destroyer for a foreign owner, it was found that a 13·5 per cent increase in the cost of the electrical installations would occur if a.c. were used in preference to d.c. This was partly accounted for by the fact that in those days the type of equipment for a naval vessel was under development, and the shipbuilder had to bear the cost of development. The number of motors fitted was very small compared with passenger liners and he would expect the material costs of a liner would work out at more or less the same for a.c. as for d.c. He would expect a reduction on the installation labour costs, however, and the balance should be slightly in favour of an a.c. vessel.

An overall saving of weight on a 440-volt a.c. system as compared with 220 volts could amount to many tons. The saving on an a.c. system could be considerable and it was well worth while taking into account, on considering the saving in cabin accommodation and so on, due to fewer electricians being required on board.

From his own experience he felt the most troublesome aspect of a.c. installations would be the burning out of motors from single phasing, but that would be the fault of the maintenance people. The fitting of an a.c. installation on a ship was a technical rather than a practical problem; and provided sufficient thought was given to the design of the installation in the drawing office, no difficulty should occur. If the Government were to set up a new Ministry, the one with the greatest value to this nation would be a Ministry of Simplification. So far as electrical installations on ships were concerned, a.c. had a grand opportunity of introducing the use of more simple vital components in a ship. The day was not far off when everyone concerned with ships would grasp it with both hands. The Admiralty, whom no one could accuse of being irresponsible, had adopted a.c. on the score of greater reliability, reduced maintenance and economy in the production of electrical equipment. They had taken advantage of modern developments which were mainly on the a.c. side and he felt sure shipowners and shipbuilders would find it in their own interest to follow suit.

MR. R. CLARKE, O.B.E. (Member) observed that Mr. Savage had stated his case in no uncertain fashion. He himself had fortunately an interest in both camps, as it were. As a manufacturer of both a.c. and d.c. marine electrical machinery, he could perhaps state an opinion without undue bias either way.

First, it should always be remembered that owners wanted a good ship, a ship that would sail the seas and pay them a dividend for many years. That should be at the back of the minds of designers for the Merchant Navy. Such a ship must have the most efficient auxiliaries possible.

If, for example, for the sake of fitting a simple constant speed direct-on started a.c. motor to an auxiliary that performed more efficiently coupled to a variable speed motor, to supply a constant speed machine was in his opinion quite wrong.

He was tempted to suggest that Mr. Savage had produced his paper with his tongue in his cheek, being determined to provoke a lively discussion. Some of the statements in the paper were beyond his own powers of comprehension, some he was taking up in his reply, and with some he was in complete agreement.

His first point was the author's statement in his introduction that the term "marine" was often misapplied and that "In some costing departments the word 'marine' seemed to mean an automatic 30 per cent increase above the prices for similar equipment destined for land use". As far as electrical machinery was concerned, nothing could be further from the fact. His own company considered that an industrial machine built to an industrial specification was not a machine they recommended for shipboard use, where the conditions, both climatic, atmospheric and physical, were far worse than would be found on land. Mechanically, the marine machine bore no resemblance to its industrial brother; for example, there were split yokes and brackets on medium and large machines, special bearings to ensure good lubrication despite the worst tilt and roll of a ship, non-corrosive bolts and nuts, and electrically non-hygroscopic non-inflammable insulating materials. Many owners' specifications called for the provision of these points, and no doubt they had been found necessary from years of experience.

Mr. Savage stated on page 229 that his bias of comparison of d.c./a.c. took into account 35 deg. C. temperature rise for d.c. machines and 55 deg. C. for a.c. machines. He gilded the lily by further stating that the reason for this was that the a.c. machine was more suitable for this higher temperature rise, and at no time had a manufacturer ever suggested that this rise should be adapted for d.c. marine machines.

He overlooked the fact that manufacturers had to comply with the requirements of the various classification societies who determined the maximum permissible rise and also the various owners' specifications.

In fact, Bureau Veritas permitted 55 deg. C. rise for d.c. machines and his company had long supplied such machines without hesitation. The author was aware that the new B.S. marine specification allowed higher rises than the current Lloyd's Register regulations.

The author rightly stated the use of induction motors, direct-on started, was the simplest, lightest and cheapest form of a.c. drive. With this he himself agreed, providing that (1) the starting current, particularly of the larger machines, was kept to a minimum; (2) the a.c. generator was so designed and controlled that it could accept the maximum starting current without undue disturbance, i.e. transient voltage drop; and (3) the prime mover driving the a.c. generator could accept the largest starting load without undue transient speed drop.

As far as induction motor design was concerned, machines were available with performance as good as, and even better than, the examples given on page 225 and at much larger outputs than the largest mentioned.

The limitation to the size of induction motor which could be directly switched to the line was the transient voltage regulation of the alternators. A voltage regulator, contrary to Mr. Savage's opinion, could only have a secondary influence on the transient voltage which was essentially a matter of alternator design.

It was the transient voltage regulation of the alternator itself when switching which was the critical factor affecting, as it would, fluorescent lighting, control equipment and safety devices. The recovery time was far less important. The aim should be, therefore, to reduce the initial voltage variation for any given switching load and thus increase the size of motor which could be directly switched.

It should be made clear that the new marine specification permitted a 20 per cent voltage drop for 50 per cent load switching, but even this relaxation drastically limited the switching load which could be imposed. Alternators were now available with a switching capacity of 120 per cent of alternator full load for the same voltage drop. This obviously went much further to meet the author's claim that direct-on starting of even the largest squirrel cage motors did not present any difficulty.

For certain drives (draught fans, circulating water pumps and air conditioning) truly variable speed motors should be given consideration. As those drives were likely to be some of the largest used in the installation, the starting current problem would be considerably eased.

The fact that these variable speed motors had commutation was not a valid argument against them. From the many thousands of commutator machines, both a.c. and d.c., that they had supplied over the years, very little commutation trouble had arisen.

Regarding deck machinery, out of approximately 1,800 lines composing the paper, Mr. Savage had devoted 7½ to that subject. Nevertheless he suggested that in an a.c. ship, if efficient deck machinery were required, very careful thought should be given to it. From the latest information he had received he could say with certainty that a number of Continental owners fitting a.c. winches in the past were changing to d.c. on the score of performance current kicks, speed, and reliability.

MR. E. L. N. TOWLE, B.Sc. (Member) said he proposed only to mention the salient points in what he had intended to say. Mr. Savage had investigated thoroughly a.c. supply, and generally speaking he himself was in agreement as to the advantage to be gained from this type of installation. In the case of passenger ships and tankers there was nothing to hinder immediate adoption, and it was a matter of historical interest that the company with which he himself was associated equipped a number of small tankers with a.c. auxiliaries as long ago as 1926. Some of these ships were still running today. The company had also been associated in installing a.c. auxiliary supplies on distant water trawlers, which was as severe a service as one could have. All these installations had given complete satisfaction.

One of the chief things which had hindered the adoption of a.c. was that in the modern cargo liner the largest auxiliary load was the cargo winches. There was as yet no a.c. winch which would duplicate the performance of the d.c. equipment in providing facilities for breaking out cargo and also giving a high light hook speed, which many owners—erroneously, in his opinion—considered essential. It was, of course, possible to provide either converting plant and d.c. winches or to use winches operating with Ward Leonard control; but the capital cost (including the necessary standby plant) usually outweighed the savings on an a.c. installation.

One point that seemed to have been omitted in calculating the short-circuit current was the resistance of the fault. Mr. Savage had, he thought, been too conservative in his short-circuit ratings for d.c. generators. It had been found in recent tests that twelve to sixteen times was actually obtained on 600-kW d.c. generators; but it was difficult to get a fault resistance as low as 0·005 ohm. More often it was 0·01 ohm, and if this were the case on a 220-volt system, the fault was automatically limited to 44 kA; and it was a poor circuit breaker that could not deal with that.

An air-break circuit breaker which operated satisfactorily on d.c. would always have less trouble in dealing with an a.c. current, although, of course, allowance must be made for the peak value and d.c. component.

With regard to repairs, he was well aware that a number of electrical machine repairers had an exaggerated idea of the value of their services, and this particularly applied to marine work. He had at times asked for details and had found the cost unjustified. At the same time, even allowing for conditions abroad, Mr. Savage had been very unlucky in having to pay more for the cost of repairs to an armature than a new one would cost. The most vulnerable part of the d.c. machine was the commutator, and the fact that when it was running copper and carbon dust could be drawn into the machine. It was possible by using axial flow fans to reverse the ventilation, though such an arrangement usually incurred extra cost, and the machines became a "special", thus justifying the estimating department's "plus 30 per cent for marine".

Because of disorganization in the shops, apart from anything else, orders for spare gear were not a good advertisement for the manufacturer. As an example, one electrically propelled ship which had been in daily service for twenty-five years, had incurred less than £50 cost for spares. This was a justification for the extra first cost for marine gear. He was quite in agreement with Mr. Savage's suggestion that the best system for shipboard was a 440-volt unearthed 3-wire installation with separate transformers for lighting and heating, but here again he disagreed with his figures for short-circuit current. The most dangerous fault was an earth fault on any part of the system, followed by a second earth fault before the first had been rectified. The combined resistance of the two faults might be several ohms, in which case the resulting current might cause a fire before any protective apparatus operated. There was no simple method of protection against this, as to provide adequate safety entailed the use of relays which were usually neglected, and hence failed to operate when wanted. The best safeguard was adequate maintenance and inspection.

On a.c. motors the constant speed motor could very often be adopted, though it meant a little modification to the driven machines. In the case of ventilating fans and induced draught fans, where speed variation was wanted, there was no great objection to the use of a slip ring motor with speed reduction by rotor resistance, because the horsepower varied with the cube of the speed. Running the fan at 75 per cent speed required 42 per cent of power, and the losses were only about 11 per cent of the motor full-load rating. He thought that very shortly there would be new installations based on a.c. equipment.

In conclusion, he welcomed Mr. Savage's suggestion and forecast that the future trend would be towards the increasing use of a.c. auxiliaries for all classes of vessels.

MR. A. P. HARVEY, M.I.E.E., said that as a visitor he had greatly enjoyed the paper and the discussion.

He endorsed the comment made in the introduction to the paper that electrical distribution was a specialized subject and that shipowners and shipbuilders should have on their staffs competent persons to deal with such matters.

As the third speaker had pointed out, the amount of experience available as a result of land-based work was very extensive. He would urge marine engineers to draw on this to the full as it was waiting to be given to them.

There had been a lot of discussion on motors, but as switchgear also formed an important part of the electrical distribution on ships he must take exception to at least one particular aspect in relation to switchgear.

With regard to the author's remarks about operating efficiencies of circuit breakers and so on, there was not much that was not known about these. The specification referred to, B.S. 116, had been in existence more or less in its present form since 1937.

What the last speaker had said about d.c. breakers having an easier duty than a.c. breakers was quite wrong.

More careful attention should, he thought, be given to the presentation of the facts dealt with in the section on short-circuit protection. He said this quite kindly and sincerely and hoped it would be accepted as such. The reference to doubling factors, asymmetrical and symmetrical ratings were entirely out of their context, he would respectfully suggest. The "doubling factor" commonly known in electrical engineering circles was based on the assumption of zero power factor and time. The peak value of current in the first half-cycle after a short circuit with a power factor of 0·15 rose only to 1·8 times, and this was the basis upon which circuit breakers were tested at the present time. If one closed on to a short circuit, the current the breaker had to close on to was equal to 1·8 times $\sqrt{2}$ times the symmetrical breaking current of the circuit. If the power factor was 0·3, that was not 1·8 or 2 times but only $\sqrt{2}$ times. He would like, therefore, to make the plea that the statements made should not be taken entirely as factual, because so many factors associated with it modified the figures contained in the tables in the paper.

A propos of the discussion on asymmetrical *versus* symmetrical ratings, switchgear manufacturers were well aware of the matter. Switchgear manufacturers in this country probably had more experience than those of any other country in the world on the rating of circuit breakers. It might be of interest to know that a circuit breaker was rated not only in terms of symmetrical current but also in terms of asymmetrical current, which covered these short operating times. It was also rated in accordance with the peak making current on to which the circuit breaker must close.

Correspondence

MR. A. A. ADAMSON and LIEUT.-COL. A. G. BATES, D.S.O., M.C., considered that, in his intriguing and provocative paper, Mr. Savage made a good case for the wider use of a.c. and for greater attention to be paid to electricity afloat. He would not be surprised if the degree of "excitation" which characterized his paper produced appropriate reactions.

The charge that shipbuilders could not be bothered to investigate fresh techniques was untenable in face of the record of B.S.R.A. and Pametrada. Similarly, shipowners and their representatives were not necessarily dead from the neck up if they followed Kipling's very sound advice of "Stick to the devil you know" and so on.

Despite the "over excitation", there was plenty of fire behind the smoke. Why was it that with experience of a.c. going back to the 1920s, when one of their largest tanker companies adopted a.c. generation, British practice as a whole had preferred to stick to d.c.? It was quite true that a high proportion of foreign ships building today would use a.c., while in current British construction, apart from tankers, a.c. was exceptional. It was suggested below that the author himself might have supplied one answer to this puzzle without being aware of it.

Mr. Savage made a convincing claim for closer examination of short-circuit protection, particularly in large installations, and there was room for speculation as to whether the high degree of immunity from serious electrical trouble to which most British owners would testify, might be due, partly if not wholly, to a high standard of construction which very rarely tested the limit capacity of circuit breakers. It was traditional in British ships not to scamp things, copper included. Continental ships had not always enjoyed the same reputation. Fire records confirmed this. Thus the same root cause which might be responsible for the absence in British ships of the awful penalties which could follow inadequate breaker capacity might also be a main, and very sound, reason for British owners being in no hurry to change devils.

One of the inherent advantages of a.c., cheapness in transmission over long distances, not being realizable in ships and there not being much difference in machine efficiency, it was mainly under the headings of reliability, lower installation and maintenance costs and savings in space and weight that the claims of a.c. must be substantiated. Installation costs had not yet shown the savings which were so obviously possible. This situation was, however, on the move. The savings in weight and space were chiefly of moment to passenger ships and as electricity could, in some passenger ships, approach 20 per cent of the total cost when all was reckoned in, it might be in this field that change might first become marked. For cargo ships, reliability, first cost and maintenance cost were the main considerations and, being highly pertinent to this paper, some details of owners' experience with s.s *Maskeliya* (referred to in Mr. Brown's paper of 1956(5)) and of her sister ship s.s. *Maturata* might be of interest.

These ships came into service in 1954 and 1955 respectively and had since completed voyages to India and the United States of America totalling 170,000 miles of continuous duty. They were dry cargo liners of 9,000 tons d.w. with S.R. geared turbines of 5,000 s.h.p. giving a service speed of 15 knots. Engine room auxiliaries were mainly electric, deck machinery steam, except for a.c. winch development sites for two winches in each ship. Electricity was generated by three 170-kVA alternators driven by steam reciprocating engines.

Distribution was 440-volts 3-phase 3-wire 60-cycles and very similar to Fig. 2(a) of the present paper, except that only one low voltage of 110 volts was used. Transformers for this were 15 kVA with secondaries earthed. All motors were plain squirrel cage type. The power factor at sea was about 0·83.

Since going into service, which was non-stop in the trades concerned, each ship had experienced one interruption in supply. Both instances were due to the same cause, namely, the totally unexpected arrival of water on to the back of the dead front main switchboard. In one ship a tropical deluge off Aden proved the inadequacy of scuppers and other arrangements to prevent the entry of rain water into the engine room ventilating air supply. A duct designed to cool the back of the switchboard neatly deposited this water on to the busbars. In the other ship, water descended from the deck above, where an evaporator room was sited. In each case a flashover resulted, causing breakers to come out but no damage. It now seemed quite elementary that ducts should not deliver air directly towards switchboards and since all decks could leak, however unlikely it might seem, canopies were indicated.

Between the two ships there had been one instance of machine failure. An electro-feeder motor in a hot and rather cramped site had shown undue wear of a ball race which had been renewed. Unwittingly, while removing or returning the rotor for this purpose, stator windings were abraded and a fault between two phases ensued.

Except for the three foregoing incidents, none of which had an electrical origin, the performance of each installation had been virtually faultless. There had been no cable repairs. Fluorescent lighting on an experimental basis in the engine room of the first ship had been outstandingly successful, some of the original tubes having given two years' continuous service. It had therefore been extended in the second ship. There had been no difficulties in paralleling alternators. The electrical bills for these two ships to date covering all headings, i.e. repairs, renewals, spare gear, lamps and stores and not omitting those extra lights, bells, fans and whatnots every new ship seemed to require, no matter how meticulous the specification, had been totalled.

The electrical bills for two very similar ships using d.c. built by the same builders and employed in the same trades had also been totalled, using the same periods since commissioning.

At this early stage in their lives it was not surprising to find that there was virtually no difference in disbursements between the two pairs. It would be extremely interesting to see whether and, if so, when, the constructive simplicity of the a.c. ships and their freedom from electrolytic corrosion began to be reflected on maintenance.

There was no ascertainable difference in overall fuel efficiency but there was already one feature in which the a.c. ships showed a marked superiority. Unfortunately no way had yet been found by owners of making use of it. There was far less for the electrician to do! That might be the reason why one tanker company was reported to have found that no electrician was needed in their a.c. ships, but tankers normally lay up for survey, whereas these cargo liners never stopped except through accident. In an a.c. passenger ship, however, it should be possible to reduce the normal d.c. electrical staff.

After an interval for reflection and digestion, occupied by the building of three d.c. ships, two more a.c. ships were on order. Owing to main engine characteristics these would have electric deck machinery and might be the first British deep sea cargo liners to have cargo winches driven by squirrel cage motors. It was possible that one electrician might still suffice and still might have plenty of spare time.

Mr. G. B. Alvey thought that what the author said about the reluctance of manufacturers and shipbuilders to accept the change from direct current to alternating current installations was interesting. This happened thirty to forty years ago with industrial installations on land, in chemical works, paper mills and so on. The cause then was mental inertia although great mental effort must have been exerted to produce the many reasons to explain why the change was allegedly impracticable. A great point was made of the necessity for the fine speed control of motors driving centrifugal pumps and other machines but most plants of this nature now got along very well with drives consisting of constant speed induction motors. There were undoubtedly minor disadvantages in the use of alternating current for certain purposes on shipboard but these were entirely overshadowed by the manifest advantages.

He would like to ask the author about electrolytic corrosion on ships caused by leakage current from the electrical system. When direct current was used in factories where moist and chemically impregnated atmosphere prevailed, some difficulty occurred on this account but there was evidence that the use of alternating current considerably reduced its incidence.

Concerning circuit breakers or fuses on main and sectional distribution boards and on motor starters, when such equipment was used in conjunction with direct-on started squirrel cage motors, efficient time lags were necessary to cope with the starting current. It was then unnecessary to set the overload tripping current unduly high. It was also an advantage if the motor starter had overload release features that gave instantaneous action when the normal starting current was exceeded—for example, when a fault occurred on the motor or cabling. The setting of overload release values and time lags on section and distribution boards and at the main switchboard should be such that a motor would be tripped on overload or fault current by its own circuit breaker without interference with other circuits.

Fluorescent lighting was particularly sensitive to dips in voltage and care was needed to ensure that, during the normal working of the ship, voltage dips caused by the starting of large squirrel cage motors did not result in annoying flickering. In exceptional cases, where large motors were to be started frequently and there was no substantial steady load of running machinery, cooking and heating installations, for example, it might be desirable to operate one or more generators for an independent lighting service.

Mr. I. D. Austin mentioned that the author showed great concern regarding the capability of the modern circuit breaker to break cleanly excessive short-circuit current.

It was agreed that this dangerous situation was reduced somewhat when using a 440-volt a.c. supply instead of a 220-volt d.c. supply but, in the author's wide experience, how often had he met with a breaker that had failed to open under short-circuit condition?

It was, of course, possible that a breaker might fail to clear a short-circuit due to excessive current and it might also happen at the most inconvenient time with regard to the navigation of the vessel.

In view of this, would the author give his views on the following installation?

3,300-volt alternators feeding through breakers on to busbars, these busbars feeding through breakers to, say, 250 kVA 415-v. output transformers, each transformer (the number required depending on the size of installation) feeding through a breaker on to its own section of a sub-switchboard, each section of this sub-switchboard being interconnected by means of a non-automatic busbar isolating breaker, so that transformers need only be brought into use as, and when, necessary.

The maximum possible short-circuit current would then be brought down to a safe working level for all breakers.

Mr. G. W. Barlow wrote that the author had very wisely drawn attention to the danger of building up installations on board ship with very high short-circuit values. He showed in Table I that with a connected generator capacity of 2,400 kW at 220-volts d.c., a short-circuit current of 109,080 amperes was obtained and went on to say that the use of fuses in such a circuit was potentially dangerous. The author further stated that the highest category of duty for fuses for d.c. circuits was 33,000 amperes.

The implication was that this was the maximum duty for which fuses could be supplied. It was erroneous, however, to assume that fuses were not available for higher fault levels simply because the maximum category of duty for fuses for d.c. circuits was 33,000 amperes, both in B.S. 88:1952 and Lloyd's Extract from the Rules, No. 6. In actual fact H.R.C. fuses could be designed for any duty for which there was a demand. It so happened that the above two specifications were drawn up when the general demand for fuses could be satisfied by fuses with the above category of duty. If the market demanded or required a higher category of duty the fuse manufacturers could supply suitable fuses.

An interesting example of this point was the case of fuses for medium voltage a.c. circuits. In B.S. 88:1952, the highest category of duty was 440 volts A.C.5 which corresponded to an R.M.S. symmetrical current of 46,000 amperes. The Canadian Standards Association brought out a specification No. C.22.2, No. 106, which called for a rupturing capacity of 109,000 amperes R.M.S. asymmetrical at 600 or 250 volts. Fuses complying with this specification were now manufactured in this country and it was interesting to know that when tests were made during the development of these fuses it was found that the upper limit of duty was decided by the capacity of the test plant, not the fuses. Even with this limitation, a whole range of fuses was tested to a fault level in excess of 100,000 amperes R.M.S. symmetrical and as the fuses still did not fail they knew that they were capable, without further modification, of withstanding very much higher fault currrents.

He was quite sure, therefore, that H.R.C. fuses could meet any requirements likely to be met with on board ship. This was in contrast to the position with regard to circuit breakers, as there were at present no circuit breakers which could handle fault currents of the orders mentioned above. It would therefore appear that the correct solution to the problems arising from possible high fault currents was either to back-up existing circuit breakers with suitably designed H.R.C. fuses or to replace the circuit breakers by fuse switches where remote control was not required.

In view of the necessity of stringent fire precautions on board ship coupled with the desirability of maximum reliability and cutting unwanted outages to the minimum it was surprising that H.R.C. fuses had not been more widely adopted in marine work in this country.

At the present time rewireable fuses were widely used in British built ships but they suffered from the following disadvantages: —

1. Low-rupturing capacity, seldom reaching 5,000 kVA, with consequent danger to operators when used on circuits having a fault kVA in excess of this figure.
2. Subject to deterioration. A very serious disadvantage due to oxidization and sealing of the fuse wire. This resulted in a rapid increase of the resistance, in turn causing heating of fuse contacts and premature failure of the fuse.
3. Absence of accurate calibration.
4. External flame with consequent fire risk and danger of flash-over to adjacent earthed metal.
5. Slow speed of rupture causing other protective devices nearer the source of supply to operate, thus affecting healthy sections of the distribution network.
6. Grading of fuses impossible on account of deterioration.

On the other hand H.R.C. fuses had the following features desirable for marine work: —

1. High rupturing capacity, as mentioned above.
2. They did not deteriorate when carrying current. A full investigation with one make of H.R C. fuse had shown that after twenty-five years in service they had the same characteristic as when new.
3. They had accurate time current characteristics which gave reliable discrimination with overload devices.
4. Complete absence of smoke and flame when blowing.
5. It was not possible for ships' electricians to overwire fuses.
6. They could safely be inserted on to a fault. This was very important as an electrician might do this, not realizing a fault was still present.
7. The low cut-off currents limited the mechanical forces to which the equipment was subjected during short-circuit. Bearing in mind that these forces were proportional to the square of the current this was a very real advantage.

Mr. S. Booth agreed that there were no doubt advantages to be gained by adopting a.c. for certain marine installations. It was suggested, however, that the proposal to abolish a well tried and proved system of energy distribution on board every type of ship warranted very careful consideration, particularly when the alternative system offered was a retrograde step in so far as machinery drives and transmissions were concerned. The old workshop "Constant speed line shaft" was analogous to the power side of an all-a.c. installation in which, if squirrel cage motors were adopted exclusively, the auxiliary units for all duties were called upon to grab the imaginary "line shaft" to be spun up to a fixed speed of rotation which was always just short of the "shafting" speed, comparable to being driven through a continuously slipping clutch. The suitability of such a method of transmission of power to any kind of rotary machinery would hardly be considered acceptable in the mechanical sense.

On the other hand, whilst the simplicity of such a drive in the mechanical analogy quoted was exemplified electrically in the simple induction motor, it followed that in consequence of speed variation limitations, manufacturers of pumps, fans, refrigeration compressors, etc., would require to design their auxiliaries around the motors when a.c. was specified. Surely this exchange of design priority must, in varying degree, require readjustment of the auxiliary machinery with some increase in its price and upkeep which would partially offset the saving in first and operating costs electrically. For instance, refrigeration compressors would require special unloading valves or facilities for regulation either side of the fixed speed steps of a two- or three-speed induction motor. The range of operation of automatic boiler control gear would need extending, owing to the speed control limitations of the forced and induced draught fan motors. Dual duty pumps, normally requiring variable speed motors, would have to withstand turbulence effects if discharge valve regulation had to be resorted to, bearing in mind that the choice of speeds available for 60-cycle motors were 1,800, 1,200, 900, 720 r.p.m., etc., less the percentage slip, and these values would not exactly match all combinations of dual duty requirements for a single impeller. Of course, one could fit more pumps for individual duties but not without increased first cost, upkeep and space requirements.

However, in spite of the effect the foregoing and other considerations might have on overall costs, an all-a.c. installation should be economically advantageous on certain classes of ship in the long run. Tankers, for instance, would fall in this category and it was well known that many British tankers, as well as those of other maritime nations, were so equipped.

This led to the controversial question in which lay the principal difference between tankers and general or refrigerated cargo vessels—namely, cargo handling equipment.

With regard to costs illustrated by the author for electric cables, his comparison between those for 220-volt d.c. and those for 440-volt 3-phase a.c. show a saving of 59 per cent in favour of a.c. when using Butyl cable. If, however, he substituted 660-volt, lead covered, varnish cambric cables for the d.c. examples, the total cost became £4,264 instead of £9,098 quoted for P.C.P.-V.I.R., and which reduced his percentage saving for a.c. to 12 per cent when using "Butyl" cable, which he apparently favoured for an a.c. installation.

The fact that a saving could be made at all was attributable to the higher voltage which would be employed, rather than to a.c. as such. No explanation was needed for the statement that 440 volts, 3-phase, meant 620-volts peak potential to "earth" if, as the author rightly advocated, a 3-phase, 3-wire system were installed, which pressure was very close to the grading value of the 660-volt cables. Raising the working pressure practically to the grading point of cables must mean a shorter average life. So must it shorten the life of insulation in general unless surface creepage and "tracking" distances were made at least three times longer than at present for 220-volts d.c.

Regulations, even for ships, permitted up to 500-volts d.c. for power purposes. For the above-mentioned reasons, however, no one advocated d.c. at this pressure for marine equipment, mostly due to the probability of commutator failures. On the other hand, there must be many 660-volt d.c. traction motors in service, which suggested that manufacturers could, if they got down to it, produce reliable motors, etc., for 500 volt working on board ship, which would effect considerable economy in weight and cost of cables and switchgear, while retaining the advantages of variable speed machinery.

Mr. A. Sidney Brown, M.B.E., endorsed the author's remarks on "Deck Machinery" where he stated that closer attention should be given to fitting winches suitable to the duty cycle.

Over the last few years, particularly when considering vessels with a.c. supply, it had been noted and welcomed that owners had been putting their varied problems before the manufacturer. This was the time to get together when considering a.c. winches as it was doubtful whether British manufacturers had produced a standard range. The main points appeared to be: —

1. Speed of cargo handling in British and foreign ports.
2. Breaking out of cargo.
3. Light hook speed.

With regard to point (1) all forms of Ward Leonard control could give speeds identical to that produced by d.c. winches. However, in the case of the single-speed squirrel cage motor spur geared winch with gear change, it was suggested that in the case of the 3-ton size a speed of 130ft. per min. should be given consideration, with a change gear to give 2 tons at 200ft. per min.

If 5-ton winches were required on the same vessel, in order to standardize in electrical equipment and reduce spares, the duty should be 5 tons at 80ft. per min. with a change gear to give 2 tons at 200ft. per min.

One of the speakers during the discussion (Mr. Towle) doubted the ability of the a.c. squirrel cage motor winch to break out cargo satisfactorily. The latest spur geared winch fitted with a single-speed squirrel cage motor had been designed to give two steps on the hoist and lowering sides; the first step would connect the stator winding in star and the second step in delta. The torque in the delta winding could be designed to vary between 175 per cent and 200 per cent full load torque. The star winding would therefore give one-third of these figures, namely 60 per cent full load torque. Comparing this with the d.c. contactor winch, the first step was usually arranged to give 55 per cent full load torque and the second step 170 per cent full load torque. It was agreed that the torque speed curves were quite different but, by suitable application of the foot brake in both cases, breaking out oı cargo should be accomplished satisfactorily.

The same speaker mentioned light hook speed. It is a well known fact that a very large percentage of cargo handling was under 2 tons and therefore, considering the two sizes of winches mentioned above, it would be noted that for loads of 2 tons and under a speed of 200ft. per min. was obtained. This speed was obtained by changing the gear of the spur geared winch to suit the load as compared with the automatic load discrimination on the d.c. worm geared winch. This discrimination did however take a short time to operate whereas in the a.c. winch the acceleration was good and also the rotor only had to accelerate up to its normal full load speed and not higher speeds as in the d.c. winch. The d.c. worm geared winch was usually arranged with a light hook speed of 450ft. per min., but it was contended that on an average ship the height of lift was such that it was doubtful whether speeds higher than 300ft. per min. were ever attained.

With regard to the use of Class B insulation, it might be remarked that when commencing to design machines for a.c. deck auxiliaries, it was decided to include this, which had been done with advantage. It was known that there were new types of insulation either being offered or soon to be offered, and, assuming that the classification societies would recognize these, a considerable saving in frame sizes should be experienced.

Mr. A. F. Cross, as the chief electrical engineer of the shipbuilding company which was responsible for the development of the electrical installation for the first of the modern a.c. tankers built in this country and which had since built a number of a.c. tankers, two of which had in their time had the distinction of being the largest in the world, felt that the author had been unfortunate in his association with shipbuilders. Shipbuilders would provide owners with what they wanted, and asked for, even if the owner ignored the advice tendered by the builder, but owners were no more infallible than builders when it came to new developments.

It was a pity that the author had not compared like with like throughout the paper and so given a better comparison between a.c. and d.c. and between past practice and new. Figs. 11-22 gave comparisons between d.c. at Lloyd's ratings with Class A insulation and a.c. at maximum continuous ratings with Class B insulation. Had similar ratings and the same insulation been compared, the trend of the comparison would have been the same, but the comparison would have been fairer since Class B insulation was used for d.c. marine work, and whether or not one dispensed with overload ratings was a matter not dependent on the type of supply.

The two-speed a.c. motor was compared against the variable speed d.c. motor, and this was not a true comparison. If two-speed motors were used for forced and induced draught fans, some form of combustion control was necessary, and the cost and space requirements of this must be allowed for. Similarly, in the case of the main circulating pumps, unless the ship were steaming at fairly constant power as in the case of a tanker, then the two speeds would be insufficient and the fuel consumption of the vessel would be jeopardized.

Again, Tables III and IV were misleading due to:—

(1) Tube watts for fluorescent lamps having been used as a basis of comparison, whereas, due to losses in the control circuits, they should be increased by from 22·5 per cent to 46·7 per cent to arrive at true consumption figures.

(2) When installing fluorescent lighting advantage was usually taken of the higher lumen output to raise the intensity of illumination for amenity purposes.

The saving on the fuel consumption by the air conditioning plant would be nil due to a.c. main supply *versus* d.c., but would depend on the extent to which fluorescent lights replaced metal filament lamps. Against this saving must be offset the charges on the increased cost of the fluorescent lighting installation and the increased weight. With a.c. the losses in the motor alternators required for fluorescent lighting on a d.c. ship were, of course, avoided.

In determining whether a ship was to be provided with a.c. or d.c., or a combination of both, the performance of every auxiliary must be investigated and not only the losses in the electrical system. Also, the overall effect on the performance of the main machinery must be taken into account. The effect of design tolerances and errors had little effect with d.c. since they could usually be neutralized by shunt regulation, but with a.c. there was little chance of remedy, apart from recourse to throttling, or some such artifice, with the possibility of erosion and loss of power. The power factor of the motor, and consequently also that of the ship, was also impaired. The owner had to balance the cost of maintenance, prime cost and the effect of weight against the loss of operating efficiency of the propulsion machinery taken over the ship's normal itinerary, and increased losses due to transformers, etc. The matter was therefore an economic one.

The question of maintenance costs was in itself controversial, and would vary between shipping lines. The instances given by the author were to his mind not the cost of having a d.c. installation but rather the cost of bad maintenance which could have been avoided. It had been found that where the electricians on board gave reasonable attention to the electrical equipment maintenance costs were low, but, at the other extreme, where no electrician was carried the equipment was often neglected and the maintenance costs were high. With a.c., the potentialities for failure were of course, less than with d.c., but there was no guarantee that failures would actually be less, particularly if the gear were neglected. The a.c. two-speed starter required every bit as much maintenance as its d.c. counterpart and the open ventilated type of squirrel cage motor could get into trouble.

He was intrigued by the author's comments on a shipbuilder's suggestion for arriving at the size of the alternators for an a.c. scheme, but he could not agree with the author's suggestion that the calculation should be done on similar lines as for d.c., and that the power factor should be taken as a standard 0·8. Whilst it was reasonable to expect a power factor of approximately 0·8, it should nevertheless be calculated to make certain. As previously stated, each auxiliary should be considered on its own, and having determined its load under sea and harbour conditions it was a straightforward matter to assess the power factor of each auxiliary under these conditions. Determining the load on the generators and its power factor was then a simple matter for any electrical engineer.

The question of short circuit protection and rupturing capacity of switchgear was an all-important one, whether on a.c. or d.c., and was a matter to which great thought must be given. Busbar sectionalizing as mentioned in the paper was not altogether the answer since the switching of the standby generator raised serious complications in the switchgear if it were adopted. With d.c., there was room for considerable development in the industry, the facilities for testing breakers under d.c. fault loading being inadequate at the testing stations at present, apart from those at the Admiralty laboratory. This was a matter that industry must face up to.

There was no question of the 220-volt d.c. system being out-of-date. Both a.c. and d.c. systems had advantages to offer and before deciding on one or the other a thorough investigation must be made into all the factors and the final choice should be determined by the overall economics. On this basis he was certain that some ships would have all a.c. systems, others d.c., whilst some would be a compromise between a.c. and d.c.

LIEUT.-CDR. M. B. F. RANKEN, R.N. (Member), wrote to say that the author had made a very convincing case for the adoption of a.c. electrical installations in all new ships, and he felt sure that most marine engineers would learn much from this extremely clearly presented paper. There were, however, a number of provocative and controversial statements and no doubt the people more intimately concerned would rise to the bait but he would like to take up a number of points.

The author stated several times that shipowners should resist the attempts of manufacturers to elaborate designs to produce excessively expensive "marine" equipment, and he suggested that heavy industrial type electrical machinery was directly suitable for ships. While the writer was not intimate with the latest a.c. equipment, he was of opinion that, in common with nearly everything else that was fitted in ships, it was most important that all electrical equipment should be carefully appraised to ensure its suitability for marine purposes as it must withstand high humidities and temperatures, considerable vibration and the working of the ship, quite apart from any need there might be to cater for the extraordinary human idiosyncrasies which so often became apparent on board ship.

The increase in electrical load over the past thirty years was staggering. It included electric galleys, winches and capstans, steering gear, many pumps, cranes, boat-hoisting machinery, fans, radio equipment, numerous navigational aids, and even sirens; another big load in wartime had been the degaussing equipment. In passenger ships, refrigeration had increased enormously, and air conditioning was now outstripping refrigeration to such an extent that over 2,000 h.p. would be required for this alone in at least two new ships. Electric lifts had become commonplace, and there would even be escalators in four new ships.

There was now the tendency to drive practically everything electrically, and the writer only hoped that this would not lead to a serious catastrophe due to putting all one's eggs in one basket. He was not in favour of placing full reliance on electric drives alone for such vital auxiliaries as forced lubrication pumps, boiler room fans, feed pumps and fuel pumps, though there was every advantage to be gained from having electrically driven alternative or standby machines.

The dangers from earths and short circuits in the very large electrical installations now found in ships should certainly not be minimized and the currents involved gave plenty of food for thought but it was only fair to add that the number of serious fires due to these particular causes had not been large, at least in recent years.

The advantages to be gained from using a.c. were many, and the author had shown the spectacular saving which was possible in weight, space, maintenance and cost. In the writer's opinion, transformers were infinitely preferable to motor/alternators or motor/generators for ancillary services, more particularly in warships, and they should be far more reliable as well as virtually eliminating the maintenance commitment. The complete isolation of all circuits connected to their secondaries was a most decided advantage.

The main disadvantages of a.c. from the designers' point of view, were:—

(*a*) The difficulty of providing variable motor speeds, and the consequent need to use only synchronous speeds. There were a number of applications where these speeds were not ideal, and others where considerably more than two speeds were desirable or essential, e.g. forced draught fans, winches, boat hoisting machinery, capstans, and some large refrigerating and air conditioning plants. There might also be a need in some cases to introduce additional sizes of machines capable of certain outputs previously obtained from others, simply by selection of an intermediate speed.

(*b*) The high starting currents involved in direct-on starting could certainly be a problem with the largest motors now being fitted, e.g. as high as 500-600 h.p. for some applications such as air conditioning, and it might be preferable to use other prime movers—steam or Diesel—in such cases in a.c. ships.

It was important from a power factor point of view not to design motors with a large reserve of power over that actually required at full load and this placed an onus on designers to calculate their power requirements more accurately before approaching the motor manufacturer. The present practice of allowing 5-10 per cent to meet possible contingencies would have to go, both on the mechanical and electrical ends of the design.

The author castigated the manufacturers and shipbuilders for their conservatism, and there was no doubt considerable justification for this view, but such changes as he envisaged were initially expensive, irrespective of the ultimate savings to be achieved, and the recent war, followed by full order books, and the current lack of drawing office labour, as well as of personnel educated to design, install, and above all, to operate and maintain a.c. installations all over the world were not conducive to such fundamental changes of approach with the inevitable upheavals which they were bound to cause throughout industry, and eventually in the shipping world. The onus was on the shipowners to initiate the changes, and it was gratifying to see that they were now beginning to meet the challenge.

The author did not make any mention of why 440 volts was selected, nor did he explain the choice of 60 cycles per second as the frequency to be used in ships, as opposed to 50 cycles per second ashore in the United Kingdom and Europe generally. For completeness, he might also have included the full range of synchronous motor speeds available.

The writer made one last plea irrespective of whether a.c. or d.c. were used, and that was, that non-watertight electrical control gear and switchboards should never be fitted in any machinery space where steam was used. This would exclude main switchboards and the like from any boiler room or engine room containing steam driven machinery.

MR J. M. L. SLATER had read Mr. Savage's paper with great interest, and thought he was to be commended for the strong case he had made for the use of alternating current on board ship.

He had no personal bias against a.c.; on the contrary he welcomed its introduction as his firm turned out four to five hundred times as many a.c. control equipments as d.c.

A major point not dealt with, so far as he knew, in any of the papers read on this subject, was the effect of constant speed auxiliaries on the running efficiency of a ship. Presumably variable speed equipments were employed with direct current systems in order to reduce the quantity of oil used per shaft h.p. Was the same efficiency obtained with constant speed a.c. equipment.

Motor control gear makers would welcome Mr. Savage's desire for simple control schemes, which reduced the first cost by reducing the drawing office and engineering expenses.

The difficulty at present was that contrary to what Mr. Savage said, the control gear engineer was faced with a complicated problem put forward by the marine engineer, and his job was to produce as simple a scheme as possible, built up of standard components to meet these requirements. The matter was, therefore, in the hands of the marine engineer, and he could be asssured that the electrical engineer would willingly co-operate. It must, however, be borne in mind that whereas with direct current only two major methods of control were generally considered, normal constant speed, or variable speed by field variation, with alternating current equipment there was available at least five main methods of control. They were now faced with a variety of requirements which were determined in the main by the relation between the largest motor to be switched directly on to the line, and the capacity of the generators.

Regarding the use of standard industrial gear for marine service, here again the control gear engineer had been given to understand that special constructional features were necessary and had designed accordingly. The modifications, although simple, relating as they did in the main to enclosures, necessitated special work, and had to be taken out of the stream of standard control gear going through the factory, thereby slightly increasing the cost. The average enclosures for industrial starters, whilst perfectly satisfactory for a factory, were not robust enough for the conditions obtaining on a ship during building or refit. Too often the cover fastenings were too light and liable to rust up, and he considered all watertight enclosures should be tested under water, and sheet steel cases treated by zinc spraying or a similar process to prevent deterioration which would occur where the cases could not be repainted, as for example the back of a case mounted against a bulkhead. Gear so designed would last the life of the ship, and as regards spares supplied after the ship was put into service, his firm's experience had been that even on a ship such as the *Queen Elizabeth,* for which they had supplied 90 per cent of the control gear, they had supplied under £100 worth of spares since she first sailed, and apart from a few isolated services, for example sanitary pumps and the like, lifts and winches, the service was such as to render spares above those initially supplied only necessary due to an electrical fault.

This paper was a valuable contribution to the question of applying a.c. on ships and if it could be shown that it was economically an advantage both on first cost, which he did not doubt, if the simpler form of equipment were employed, and on the more important question of running costs, he thought the case for alternating current was well established.

MR. C. SMITH (Member) remarked that the auxiliary power systems in the larger ships, taking into consideration the generating voltage, were large power stations and the distribution system, though small in physical size, was a distribution system with a heavy load density.

It followed that it was not sufficient to buy a collection of generators, motors, cookers, heaters, etc., and to connect them together in a haphazard way. The author rightly pointed out that the system as a whole must be designed. He did not, however, emphasize the many benefits which were obtained as a result of installing a carefully designed system. Some of these features were listed below:—

(1) Minimum system disturbance under fault conditions. In other words, increased availability of supply. This was largely obtained by a carefully co-ordinated protective system applied over the whole network.
(2) Easy location of faults.
(3) Increased safety.
(4) Reduction in maintenance costs.

With reference to short circuit protection, the author very rightly devoted a large portion of his paper to this most important subject. Referring first to a.c. systems, relatively simple methods—outlined by the author—could be applied to obtain reliable and reasonably accurate assessment of the worst possible faults which might occur. The result was that one could readily and accurately assess the fault level of a system and obtain circuit breakers carrying an approved certificate, which were known to be up to the required duty.

When they came to d.c. systems, however, not nearly such a happy state of affairs existed. In the first place, the assessment of the fault level of the system was much more difficult. The figures given in Table I were probably very pessimistic; they largely ignored the impedance of the machines and of the part of the system included in the fault loop which would, in most cases, considerably reduce the prospective fault current expected from simple calculation methods. Unfortunately, the necessary impedance figures were very difficult to obtain so that more complicated calculations were of doubtful value.

It was suggested that electrical manufacturers were in the habit of designing their auxiliary motors with a very large margin of overload rating. It was the auxiliary makers themselves who specified the horse power they required and the electrical manufacturers quoted to that specified power without adding any margin of safety overload.

Starters for marine use were usually of the automatic push button operated type and although it was agreed that they in themselves were more complicated than the old hand operated type, they were not subject to abuse by unskilled operators, making the overall result far more reliable.

Protection for the operator was necessary and this usually called for an enclosed form of cubicle switchgear with accompanying protection interlocks, etc. With the switchgear enclosed and often working in warm oily atmosphere, ventilation was of great importance.

Some manufacturers preferred to operate their push button control system on 110 volts a.c. and this called for step-down transformers incorporated in the switchboard itself.

It was doubtful that, in total, an a.c. installation would show a saving in cost over a similar d.c. installation and some of the advantages of d.c. had been lost, particularly speed control.

Would it not be more reasonable to say that the reason why this country had not, in the past adopted a.c. throughout all classes of vessels was more due to their usual caution before going blindly into a system which had not yet been fully explored.

It was quite safe to say that at no time was the customer influenced by the manufacturer to install d.c. in preference to a.c. purely for reasons of a better turnover for the supplying company. In point of fact, most marine electrical manufacturers were better laid out to produce a.c. machinery in greater quantities than d.c.

Shipbuilders might be a little cautious where their knowledge of a.c. installations was limited but the goodwill of electrical manufacturers was rapidly instilling confidence in the minds of the builders' electrical departments.

From the point of view of the most satisfactory operation it was right to say that the a.c. installation gave the perfect answer to fluorescent lighting with its many advantages of low current consumption, low heat loss and greater lumen output per watt.

Cable comparisons given in Tables VI and VII were made with P.C.P./V.I.R. cables of sizes seldom used on board ship. The comparison in weight and also cost would be better shown between varnished cambric cable and "Butyl", as it was agreed that for the conductors the current rating of "Butyl" cable should be the same as varnished cambric above size 7/029 and with this comparison it might be that "Butyl" would show little saving over varnished cambric.

MR. A. H. WHITE (Associate) congratulated the author on a most interesting and controversial paper.

He was primarily interested in the cross-channel type of vessel. His shipboard a.c. supply experience to date had been with public room fluorescent lighting installations. Together with colleagues, careful consideration had been given to the subject of a complete installation and a scheme had been developed for one of their post-war motor car ferries of 3,500 gross tons, engined with steam turbines. It was on this basis he would add to the discussion.

Undoubtedly, one of the principal arguments in favour of the a.c. shipboard installation was that use could be made of the induction motor. The majority of the auxiliaries' drives could be adequately served by a constant speed machine; the remainder, excepting deck machinery, presented no problem. Discussions with interested parties concerning the maintenance of d.c. motors made him realize that quite a number of statements as to cost were not supported by a shred of evidence; consequently, with the co-operation of workshop staff at their principal repair depot, a check was made on time spent on overhauling and cleaning the d.c. armature, commutator, also bush assembly, over a period of twelve months. The results were given under two headings, (*a*) as a percentage of the total days worked by the whole of the electrical staff, which amounted to 3 per cent, and (*b*) a percentage of the days worked by the whole of the electrical staff on shipboard equipment only, this figure being 6 per cent. Making due allowance for the fact that certain of the vessels were surveyed by a ship repairer, item (*b*) was certainly no greater than 7½ per cent. He suspected that cleaning lamp fittings and lamping-up exceeded this figure.

Concerning the type of a.c. distribution, for the sake of *availability* he was in favour of 3-phase, 3-wire, but agreed with the author that it was essential that the ship's staff ensured that the vessel was kept clear of "earths" as soon as they were observed. He felt the use of lead sheathed cable could be an advantage in this respect.

With regard to the comments on manufacturers of electrical equipment, his experience had shown that they had always been most helpful and willing to supply his exact requirements. The initiative had always been with himself as the owners' representative. The same could be said of the shipbuilders for that matter.

Concerning generating plant, he was unhappy about the voltage characteristics being dependent on an auxiliary unit instead of the inherent characteristic of the iron circuit of the machine. He would like to see the compensated type of alternator with an inherent regulation of 2½ per cent developed for a higher output; the Germans had developed a machine rated at 300 kVA at 0·8 power factor, which had been fitted in their cargo vessel *Cap Blanco,* the operating experience of which appeared to have been quite satisfactory.

He agreed with the previous speakers that the synchronization of alternators should be kept as simple as possible and he was quite sure that the shipboard staff would have no difficulty in effecting satisfactory operation.

He confirmed the author's figure concerning the comparative cable weights. In the case of the vessel he analysed, the a.c. installation was 0·671 of the d.c. installation.

A summation of weight and cost based on the main electrical elements was compiled, assuming that shipboard labour cost, fuse panel and lighting network costs were similar for both types of installation, and the results were: —

Weight, taking d.c. as 1, a.c. represented 1·03.

The actual increase in weight was 7,540lb.

Cost, taking d.c. as 1, a.c. was 1·1, amounting to some £5,000.

Much could be claimed for both systems of shipboard electrical installation; assuming that the basic requirements could be satisfactorily met, the problem became one of cost, having three components—(*a*) capital (*b*) weight (*c*) maintenance. As far as the owner of a cross-channel vessel was concerned, he had nothing to gain by swinging over to a.c. installation at this stage of development. He felt his policy should be to take the best from both systems, namely install d.c. for the auxiliaries, deck machinery, etc., and a.c. supply for the lighting of public rooms, supply to certain electronic equipment, the smaller refrigerators, etc.

Mr. T. S. Wood observed that the paper was very comprehensive and the author in his enthusiasm for a.c. as well as in his wholesale condemnation of d.c. made a very brave show.

After considerable trouble and investigation he had come to the conclusion that 3-phase 440-volts with insulated neutral was the ideal system, but surely he knew that this was the system which owners and builders had been installing for a number of years on large tankers and in many vessels for the Admiralty. With regard to d.c. "marine" motors and control gear, the British makers, whatever their faults, had done their job so well that they had probably postponed for a number of years the general adoption of a.c. in ships with its undoubted economies.

The cases of breakdown of d.c. equipment quoted would appear to indicate exceptional neglect, and he could not believe that they were typical.

He agreed that "further research must be carried out in order to solve the question of short-circuit current values for various installations" as the size of generating plant now being installed in most large vessels was such that the existing range of fuses was inadequate to deal with the suggested values and even if breakers were used for all feeder circuits, fuses were still necessary for some control circuits adjacent to busbars.

Although the squirrel cage motor was robust and reliable, it was possible to have a burn out in the stator winding and as it was not a practical job to insert replace coils in large motors at sea, any such motor would be out of service until the ship returned to port.

The author mentioned two alternatives for a.c. lighting voltage, viz. 440/150 insulated neutral and 440/230 mid point earthed, but surely there was a third alternative, viz. 440/115 insulated secondary, for although sub mains and switches, etc., would be slightly larger the small wiring would remain the same size as for 230 volts and there would be the advantage of the more robust filament of the 115 volt lamp as well as whatever further degree of safety would accrue from the lower voltage. This would be in line with ship practice on the Continent and in America.

The chief points which had retarded the adoption of a.c. supply on ships were: —

(a) High cost of deck machinery with d.c. characteristics.
(b) High cost of enclosed 440-volt switchboards.
(c) Absence of adequate speed control for auxiliary machinery.
(d) Space for and heat given out by transformers in accommodation.
(a) and (b) The additional costs were more than balanced by savings elsewhere.
(c) Marine engineers were gradually adapting themselves to the new conditions.
(d) Naval architects would find that the small amount of space required was a small price to pay for the overall advantages described by the author.

The picture of the dishonest manufacturer and the lazy shipbuilder impeding the progressive owners' representative provided a little comic relief to a paper which was otherwise a very useful contribution to the subject.

Mr. C. F. Young (Associate) congratulated the author on a paper in which, on a very wide subject, he had covered so much ground and done a great deal to simplify the approach to the use of alternating current installations on ships. In particular, the reference to short-circuit protection was both pointed and timely, although the exact value of the short-circuit currents quoted might be open to question.

On the adoption of alternating current installations, however, one had the impression the author felt he was conducting a crusade against somnolent shipowners, bigoted builders and mercenary manufacturers. His company's experience showed that the approach of shipbuilders and shipowners to the use of a.c. was not as conservative as the paper suggested and it seemed the author might be mistaking caution for prejudice. It was surely over-simplifying the problem to state that "alternating current systems do not represent any fundamental difficulties, just a different line of thought". In these days of shortage of competent engineers it was understandable that owners should give careful and serious thought to what must be a major change in technical design and application.

On the manufacturing side, the cost of marine equipment had been ventilated time and time again. It was agreed that the cost of machinery and equipment for marine use was, in many cases, higher than its industrial equivalent, but it seemed the author gave an excellent reason for this when he stated that marine electrical engineering was a specialized subject and that "a ship is a live, moving and working body. . . . .and earths can result. . . . .and fires have developed". Few would dispute there were problems to be faced in marine electrical engineering which were not found in industrial application ashore, and in fact the author himself underlined this point in his reference to the vulnerability of the different types of systems to earth and short-circuit faults and the serious consequences which might follow. Appreciation of these problems by classification societies, shipowners and manufacturers had in many cases produced more stringent specifications, with consequent increase in cost of marine equipment.

On the subject of costs, the comparative figures given for various items of equipment were extremely interesting but they were necessarily of limited value only. One appreciated the difficulty of producing overall costs of comparable a.c. and d.c. installations, but it seemed clear that a.c. was at present more costly in the case of smaller ships' installations and it would be most interesting to know at about what point, in terms of generating capacity, the two curves crossed. This might be based on a cargo ship with the statutory twelve passengers having all-electric auxiliaries, rather than the cargo liner type of vessel with large hotel and similar loads.

On the question of electric galleys, the comparison with accepted conditions in a domestic kitchen was a good point but it was doubtful if one would be so happy if the kitchen floor started to roll and pitch.

Author's Reply

The author had to thank all who contributed to the discussion on his paper, for he firmly believed the most valuable part of any paper was the discussion it provoked. The discussion was so lengthy, and so many had dealt with the same points, that the author proposed to group his replies rather than answer each contributor individually.

In assessing the prospective short circuit current for d.c. installations the value of ten times full load current had been taken as the short circuit contribution by the generators. Mr. Atkinson agreed with this and quoted the A.I.E.E. Publication No. 45, which was the equivalent of the I.E.E. Regulations for Ships. Mr. Towle stated that in recent tests twelve to sixteen times full load was actually obtained, and this the author was inclined to accept. Mr. Holdsworth appeared critical of the author's suggestion that more research should be carried out for the assessing of short circuit current values, and Mr. Auterson stated that the resistance of the connexions between the machines and the switchgear played its part to bring about a *substantial* reduction in the prospective short circuit current.

These various comments had been brought together to demonstrate the different opinions of those best qualified to speak. The only satisfactory answer was to apply short circuits on an installation and so find out what was the true value of prospective current, and this was what was implied by stating that further research should be carried out.

The author had in his possession a copy of a report which dealt with short circuit tests applied to an existing 220-volt d.c. installation. The installation consisted of four 300-kW generators, of which not more than three were on the board together. Tests were made at points of low and high prospective current and final tests were made at the main switchboard to determine whether the actual short circuit current confirmed the calculated value. The short circuit was applied through a contactor, the contactor being connected to the main busbars by test cables as it was undesirable to pass the heavy short circuit currents through existing cables.

The resistance of the circuit was as follows:—

		Ohms
(a)	Test cables and apparatus	0·0054
(b)	Resistance (modified for armature reaction) of three generators in parallel	0·0020
(c)	Cables, generators to main board ...	0·0003
	Total	0·0077

The calculated value gave a short circuit current of 28,500 amperes and the tests proved that the prospective current was in excess of 20,000 amperes. Of the total resistance of the circuit in the above example, 70 per cent was represented by the test cables and apparatus, which had a limiting effect on the prospective short circuit current. It could be assumed therefore that the prospective current at the switchboard would be ten times full load current and possibly nearer to Mr. Towle's figures of twelve to sixteen. Rules and Regulations allowed the user to fit 250-volt D.C.3 fuses in conjunction with a generating capacity up to 2,000 kW, but it would appear that a D.C.4 fuse should be fitted for systems having a generating capacity of 1,000 kW and over. Again, the author must point out that it was impossible to obtain an A.S.T.A. tested and certified D.C.4 fuse. As far as d.c. circuit breakers were concerned the carrying capacity, making capacity and breaking capacity were all as assigned by the manufacturer. The author could not help but agree with Mr. Atkinson that the limit for 220-volt d.c. installations lay in the region of 2,000 kW.

Turning to the question of the 440-volt a.c. system, thanks were due to Mr. Auterson and Mr. Harvey for raising the question of doubling factors, and the author stood corrected. While agreeing with so much that Mr. Atkinson had had to say, one could not agree with his statement regarding 440-volt a.c. plant of 5,000 kW and the capabilities of 100,000 amperes rating of circuit breakers. The breaking capacities of standard circuit breakers were in the region of 15 M.V.A., 26 M.V.A. and 31 M.V.A. related to carrying capacity and with symmetrical breaking currents of 22,000, 36,000 and 43,000 amperes respectively.

The majority of feeder circuit breakers for the average merchant ship would be of the lower rating, and while circuit breakers of 31-M.V.A. breaking capacity with suitable overload settings could be utilized, it would mean increased cost and space occupied. A better proposition might be to fit the appropriate circuit breaker in relation to the feeder circuit and adopt back-up protection by means of H.R.C. fuses.

At this point the author would like to thank Mr. G. W. Barlow for his written contribution to the discussion, with which he was in general agreement. At the present moment the A.C.5 fuse was not included in the Rules by which they, the users, had to abide, but there was no doubt it would be when the Rules were revised and there would be no objection to using it now. A 440-volt A.C.5 fuse had a certified breaking capacity of 35 M.V.A. which lined up with a generator capacity of some 3,000 to 3,500 kW, a figure which fell far short of Mr. Atkinson's 5,000 to 6,000 kW.

A number of speakers had mentioned the use of reactors and the sectionalizing of busbars as a means of limiting short circuit values, and it was interesting to note that in the Swedish

American Line's new vessel *Gripsholm,* with a main generating capacity of 4,375 K.V.A., sectionalizing of the busbars had been adopted. In the case of the *Flandre* of the Cie. Generale Transatlantique, the author understood that one modification carried out had been the fitting of reactors to limit short circuit values, the *Flandre* having a generating capacity of 6,875 K.V.A. It was also interesting to note from Mr. Groom's contribution that the Admiralty had succeeded in keeping the fault power down to 25 M.V.A. for their largest ships by careful design and the use of interconnecting breakers. Mr. Groom observed that the author had touched on the vexed question as to whether for large powers 440 volts was the appropriate voltage. This was only touched upon because it was felt that 440-volts a.c. should be digested before offering 3·3 kV. However, it was most gratifying to learn that Messrs. Atkinson, Tuke and Austin had definite ideas on this subject, and there was no doubt the question of generation at 3·3 kV would be thoroughly analysed in the near future.

With reference to Mr. Ogle's and Mr. Clarke's observations when starting relatively large squirrel cage induction motors, they had read something into the author's remarks that was never intended. It was never intended that the transient dip would be dependent upon the automatic voltage regulator; the example given was a dip of 10 per cent and where the voltage was restored in 0·5 sec.

The voltage regulation and general stability when dealing with a fluctuating load was broadly indicated by the ratio of

$$\frac{\text{Full load field ampere turns}}{\text{Full load stator ampere turns}}$$

The transient voltage dip had a definite value for certain definite conditions only and would vary with varying conditions.

For tankers, where it was the general practice to run one generator which was of sufficient capacity to carry the sea load, there was an obvious limit to the size of motor which could be direct-on started.

He would like to make it clear that in merchant ships, whether passenger or cargo ships, the starting of large motors relative to individual generator capacity was nothing new. The very first 220-volt d.c. vessel the author sailed on was fitted with 100-kW generators and also a 185-h.p. compressor motor. It was obvious therefore that two generators had to be available to start and run such a machine. Similar conditions applied today; one could not start up large refrigeration and air conditioning compressor motors, or switch on large cooking loads first thing in the morning, without making sure sufficient generator capacity was available.

As far as starting relatively large S.C. motors was concerned, there was a relation between generator capacity and the largest motor, and as examples he quoted the following:—

Ship	*Generator kVA*	*Largest motor h.p.*
M.V. *Bergensfjord*	5,200	335
M.V. *Gripsholm*	4,375	365
New Royal Mail Line Ships	3,750	200

The transient voltage dip would therefore depend initially on the ratio of field ampere turns to stator ampere turns, and after that would vary according to the following conditions:—

(a) Generator capacity on the bars.
(b) Amount and power factor of base load.

The largest motors installed would be those for boiler draught fans and refrigeration and/or air conditioning compressors. Lieut.-Cdr. Ranken gave a figure of 500-600 h.p. for the latter service, but such ratings would, as he thought, be Diesel or steam driven.

By the very nature of their service, boiler draught fans and refrigerating compressors would be driven by two-speed motors which in turn greatly reduced the starting current peaks. Such motors would be started on the low speed and then when necessary switched to the high speed—all of which was good practice. The 200-h.p. motor quoted above would be a two-speed motor rated at 200/143 h.p.

In order to demonstrate what could be achieved, the author quoted the following starting currents for a 200-h.p. rated motor:—

H.P.	*Type*	*Full load, amperes*	*Direct-on starting current, amperes*
200	Standard S.C.	300	1,800
200	Double S.C.	315	1,260
200/143	„ „	315	825 (maximum peak amperes)

With the two-speed motor there would be a second current peak of 800 amperes when switching to high speed. Mr. Clarke also agreed that direct-on starting was the simplest, lightest and cheapest, provided the prime mover driving the a.c. generator could accept the largest starting load without transient speed drop. The point was, if the generator could accept the starting kVA, then the prime mover would accept the kW; after all, the power factor of such starting currents would be in the region of 0·4. If they took the case of the 200/143-h.p. motor quoted, with a starting peak of 825 amperes, the starting kVA would be 628, but the power thrown on to the prime mover would be only 250 kW.

Mr. Alvey had raised the question of the effect of voltage dips on fluorescent lighting. For instant-start circuits the point of failure was around 67-71 per cent volts at 20 deg. C. ambient. Fluorescent lamps should therefore stay alight at drops in voltage which would cause other electrical gear to fail. The loss of illumination with the same value of voltage dip was considerably less with fluorescent lighting than with metal filament.

Mr. Holdsworth and Mr. Ogle discussed the question of double-cage motors. In the case of a tanker, and to a great extent in the case of a dry cargo ship installation, the vast majority of motors were under the control of the engineer-in-charge. For the passenger ship, fully air conditioned and possibly carrying refrigerated cargo, they were up against a different proposition. Outside the engine room they had the refrigeration plant under the control of the refrigerating engineer, and there a particular installation of eighty-four motors could be quoted, with a total h.p. of 1,540.

Further, there were scores of ventilating and air conditioning units under the control of the electrical engineer and numerous service motors under the control of the catering department. They could not have everyone running around to find out if the other fellow was going to start a motor, and so the problem was to decide where one was going to start and finish in taking advantage of the low starting current—it had been said that the last straw broke the camel's back.

Several speakers had referred to the question of variable speed motors. After close collaboration with his engineering colleagues it had been decided that the only two-speed motors required for new tonnage (Diesel) that the author's company had ordered were the main lubricating oil pumps, refrigerating compressors, air cooling fans for refrigeration and mechanical ventilation fans where fitted. Mr. Booth, in discussing this question, painted a dismal picture of the efforts and ingenuity required of the designer of auxiliaries to accommodate a single-speed or two-speed drive. When talking about refrigerating compressors requiring special unloading valves, such compressors were already in service with 220-volt d.c. drives. Might he quote a very recent incident when a manufacturer of auxiliaries notified his company that a two-speed motor was unsuitable for his equipment, and yet, after friendly discussion and a little co-operation, the problem was resolved and four units were obtained for the price of three.

To Mr. Cross's statement that the effect of design tolerances and *errors* of the auxiliary manufacturer had little effect with d.c. since they could usually be neutralized by shunt regulation, he could not improve on the observations made by Mr. Tuke in his contribution to the discussion, which in effect meant—why should the user who, incidentally, was the customer—be persuaded to adhere to variable speed d.c. motors in order to compensate for the loose designs of the supplier of auxiliary equipment? That variable speed was often used for this purpose, rather than from the operational angle, was undeniable.

Mr. Cross and Mr. Ogle had discussed the question of power factor correction, and the assessing of power factor by taking into account the power factor of each auxiliary. These suggestions were technically correct but if carried out for the larger passenger ship it was feared the building contract would never be signed, let alone the ship built, for it was long after the signing of such a contract that the various sub-contractors submitted their final proposals.

Mr. Clarke suggested that they should consider the truly variable speed a.c. motor; Mr. Clarke was fully aware that he was acquainted with these motors and would not discredit them in any way, but at the present moment he could not foresee any demand for them for marine purposes.

With reference to Mr. Clarke's observations on deck machinery, the author's remarks on this subject were very limited, bearing in mind that Mr. A. S. Brown gave a paper(5) on this subject as recently as 1956. Having just spent a week on the Continent in the company of marine electrical engineers, he could not find any evidence to support Mr. Clarke's statement that Continental owners were reverting to d.c. winches.

He did consider that it was the wrong approach to try and emulate the performance of the d.c. winch. It was first necessary to find out exactly what duty the winch had to perform and to fit a winch accordingly. Mr. Towle was quite right in considering it erroneous to consider a high light hook speed essential, and this contention was borne out by the following figures obtained during cargo working, loading from lighter to lower hold with ship in light condition, that is, maximum lift and lower:—

	Average, secs.
Hook, lighter to hold	37
Hook, hold to lighter	30
Hook, wait in hold	74
Hook, wait at lighter	95

It would be noted that the light hook was returned to the lighter in 7 seconds less time, but as it was then necessary to wait 95 seconds for the next sling load, no advantage was gained from the high light hook speed.

On a shorter lift (approximately half) the light hook speed had no effect, there being insufficient time for the motor to accelerate up to top speed, as shown by the following figures:—

	Average, secs.
Hook, gantry to hold	20
Hook, hold to gantry	20
Hook, wait in hold	15
Hook, wait in gantry	15

It was obvious, too, that to fit faster winches would result in increasing the waiting time.

Mr. Groom mentioned in his contribution to the discussion the exceptionally good control achieved with a winch using a single-speed squirrel cage motor with star/delta control. Mr. Brown had gone into more detail with regard to this particular type of winch. Mr. Adamson and Lieut.-Col. Bates anticipated having the first British deep sea cargo liners to have such winches fitted, and the author had such confidence in these winches that orders for sixty had already been placed. There was no question that the Ward Leonard control was the most suitable for windlass and capstans.

Mr. Booth had raised the question of lead-covered varnished cambric cable. The reason this type of cable was not mentioned in the paper was simply because such cable was not considered suitable for marine installations. A lead sheath was totally incapable of withstanding the unavoidable abuse cables received during the fitting-out period of any ship. Any tearing or cracking of the lead sheath during the installation was particularly undesirable due to the hygroscopic nature of varnished cambric insulation. It was because of this, and troubles experienced, that the author as long ago as 1942 suggested to the cable makers that they should develop a varnished cambric insulated cable with a polychloroprene sheath but it was not until many years later that this suggestion was adopted. Again, with varnished cambric insulated cables all terminations must be effectively sealed, a point one could not guarantee either during the installation or during the life of the ship. "Butyl" insulated cable had all the advantages of rubber and varnished cambric insulation without their attendant disadvantages, and how right Mr. Harrop was when he stated that he could see a great future for this type of cable.

The Admiralty for many years fitted lead covered cables, and long after the Merchant Service adopted polychloroprene sheathed, but now had eliminated lead covered altogether. Fire risk was also greater with lead sheathed, whether the insulation was rubber or varnished cambric.

He could not understand Mr. Smith's statement that the cable sizes given in Tables VI and VII were seldom used on board ship because they were being fitted every day of the week, and no one should know that better than Mr. Smith. Also, Mr. Smith raised the same point as Mr. Booth, that a better comparison would be shown between varnished cambric cable and V.I.R. than "Butyl" and V.I.R.; or was it a question that certain cable manufacturers had not yet succeeded in satisfactorily extruding "Butyl"?

A number of contributors to the discussion had touched upon the question of why Britain, as a country, was lagging behind others in the adoption of a.c. for marine installations. It must be remembered that there was a vast amount of experience available with regard to 440-volt a.c. and there was absolutely no question of going blindly into a system which had not yet been fully explored.

When Mr. Adamson and Lieut.-Col. Bates referred to fire hazards in Continental ships as compared with British, it had nothing whatsoever to do with whether d.c. or a.c. was in use or with the capacity of circuit breakers. If they had had the opportunity, as he had had, of removing deck head and bulkhead linings and noting not only the class of wiring, but also the method of making joints, which incidentally British rules did not allow, then the risk of fire would have been obvious. It was no use talking about circuit breakers on d.c. rarely being tested to the limit of their capacity, because no one knew the capacity of such breakers, whereas with a.c. they did. There was a far greater store of knowledge with regard to a.c. than d.c.; furthermore, the limitations of a.c. but not d.c. were known. It was simply a question of installing an a.c. system in a knowledgeable and intelligent manner.

The Guild House Charity Ball

The first Charity Ball held to raise funds for the Guild House took place, under the patronage of Lady Anderson, on Wednesday, 8th May 1957, at the Dorchester Hotel, Park Lane, London, W.1. The guests were received by Sir Donald and Lady Anderson and Mr. W. Lynn Nelson, O.B.E., and Mrs. Lynn Nelson.

Two hundred and eighty-two people were present and all reports indicate that the Ball was a great success. Financially the result was most encouraging indeed in that the sum of £1,138 was raised. Music during the reception and for dancing was provided by Sydney Jerome and his orchestra and the cabaret included Robert Harbin, Shirley Abicair and Arthur Askey.

Lady Anderson, Sir Donald F. Anderson, Mrs. Lynn Nelson and Mr. W. Lynn Nelson, O B.E.

This brief report would not be complete without grateful acknowledgment being made to all those companies and individuals who provided gifts for the Tombola, which was directly responsible for raising £120; also to those companies which took advertising space in the brochure programme, thereby contributing greatly to the financial success of the evening.

Arrangements are now in hand for the next Ball to take place on Friday, 9th May 1958, in the Ballroom Suite at Grosvenor House, Park Lane, W.1.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Institute on Tuesday, 26th March 1957

An Ordinary Meeting was held at the Institute on Tuesday, 26th March 1957, at 5.30 p.m., when a paper entitled "Developments in Marine Electrical Installations with Particular Reference to A.C. Supply", by A. N. Savage, M.I.E.E., M.N.E.C.Inst. (Member), was presented and discussed. Mr. T. W. Longmuir (Chairman of Council) was in the Chair and 124 members and visitors were present. Twelve speakers took part in the discussion that followed.

A vote of thanks to the author, proposed by the Chairman, was accorded by acclamation. The meeting ended at 8 p.m.

Summer Golf Meeting

The summer meeting of the Institute Golfing Society took place at Sunningdale Golf Club, Berkshire, on Thursday, 16th May 1957. Thirty-five members played in the morning and afternoon competitions. A strong, gusty wind made conditions difficult but nevertheless the morning Medal Competition for the J. Weir Cup was won by Mr. H. P. Jones, with a net score of seventy. Lieut. Cdr. R. D. French, R.N.(ret.), was second, with a net score of seventy-two.

In the afternoon, the result of the bogey greensome competition was a tie between Messrs. P. R. Masson and H. E. Upton, O.B.E., and Messrs. J. L. G. Black and H. Armstrong; both pairs had a score of two down. In accordance with the rules of the competition, Messrs. Masson and Upton won with the better score over the last twelve holes, having also tied over the last nine holes. The prizes consisted of a silver soda syphon container and an electric clock respectively for the winner and runner-up of the morning competition, and hors d'œuvres dishes and golf balls for the winners and runners-up of the afternoon competition.

Mr. Stewart Hogg, the Chairman of the Social Events Committee, presented the prizes and thanked the committee and secretary of the Sunningdale Golf Club for the hospitality extended to the Society and to the catering staff for the enjoyable lunch and tea. Mr. Hogg also thanked the following contributors to the Prize Fund: J. L. G. Black, E. F. J. Baugh, H. C. Counis, Lieut. Cdr. R. D. French, R.N.(ret.), J. A. Goddard, L. E. Hardy, R. Hunter, H. P. Jones, S. J. Jones, W. Kemp, N. C. Marr, B.Sc., P. R. Masson, J. M. Mees, W. Ridley, A. A. Scaife, J. C. Shanks, Lieut. Cdr. C. A. Sims, R.N., C. Smith, H. E. Upton, O.B.E., R. M. Wallace, J. A. Watt, Cdr. J. White, D.S.C., R.N.(ret.), and C. F. Young.

It was announced that the autumn meeting would be held at the Berkshire Golf Club on Thursday, 3rd October 1957.

The meeting terminated with a vote of thanks by H. R. Humphreys, O.B.E., to the Chairman, Secretary and Social Events Committee.

Election of Members

Elected 19th June 1957

MEMBERS

Thomas Westcott Davenport Abell
Robert Carr, M.A.(Cantab.)
William Clemence Casebourne
Hugh MacInnes Currie
Reginald Lyle Dewar
Jack Dibsdall, Lieut.-Cdr., R.N.
Hugh Wilson Findlay, Cdr., O.B.E., D.S.O., R.N.
Alexander Walter Heley
George Charles Holland, Lieut.-Cdr., R.N.
Claude Simpson Jessop
Stanley Marwood Johnson
John Keating, Eng. Lieut.-Cdr., R.N.
Douglas Frederick Marrian
George Henry Randolph Martin
Eric Valentine Burton Patzl
James Price
Rupert Terence Robson
Graham Melbourne Wells

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Pyare Lal Chohan, Lieut., I.N.
William Colville
Lewis James Conway
Donald Wilfrid Crancher, M.Sc.(Durham)
Anthony Philip de Mello
Anthony Francis D'Penha
Peter Henry Dunk
Philip Haydn Ferri
Robert Cecil Hugh Hawton
James Burns Hopper
John Ronald Hounslea
Philip Edward Ireland
William Henry Jones
Peter Thomson McAllister
Douglas Frederick Macmarquis
Stuart Marshall
David Love Murray Matheson
Charles Lewis Maunder
William Rowan Pettigrew
Alfred James Reid
Robert Scott
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Michel L. Soultanakis
John Wilfred Sturrock, Lieut.-Cdr., R.N.(ret.)
Allen Louis Tregarthen
William Urquhart
William Brian Weston
Sidney Hamilton Williams

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Kevin Francis Curry
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John Andrew
Gordon Broome

John Roxburgh Brown
Dennis Brunton
Gordon Collins
William Colquhoun
Cyril John Flynn
John Bell Harrison
Charles Barry Holmes, B.Eng.(Liverpool)
Alexander Mathieson Moore
Peter Munro
Aubrey James Nathanielsz
John Payne
John Wauchope Petrie
John Anthony Rundstrom
William Smith
Ronald Peter Williams

STUDENT
Alan Harrison Higgins

PROBATIONER STUDENTS
Paul Anthony Burns
John Derek Carter
Terence Ian Chivers
David Edward De Garis
David Arthur Eastham
John Christopher Gee
Roger Keith Gibbs
Ronald James Groombridge
David Michael Herd
James Alfred Kelly
Roger Lee
Patrick David McMahon
Edward Lionel Mallett
David Llewelyn Maynard
John Edward Miller
John Charles Moys
Frederick Joseph Parle
Alan Melbourne Pearse
Allen Edward Pengelly
Graham Robert Pinner
Alan Robinson
Michael John Schilling
Laurence John Small
Terrence Leslie Stephens
Roger Nicholas Lawrence Sydes
Peter Taylor
George Frederick Jones Thomas
James Gordon Tucker
John Michael Tucker
Michael Rowland Edwin West
Reginald John White
Billie Wilkinson

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER
Albert Anthony Hepworth
Derek John Lochhead

TRANSFER FROM ASSOCIATE TO MEMBER
Albert Henry Brake
Carol Craig Richardson

TRANSFER FROM GRADUATE TO MEMBER
Harry Chilton

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Thomas Curphey Corteen
Eric John Couzens
Alfred Chin Hin Heng
John Norman Hesketh

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
Albert Edward Pitchford
Satya Parkash Uppal, Lieut., I.N.

TRANSFER FROM STUDENT TO ASSOCIATE MEMBER
William Alan Mason, M.Eng.(Sheffield)

TRANSFER FROM STUDENT TO GRADUATE
John Dilnot Watson, B.Sc.(Marine Eng.)

TRANSFER FROM PROBATIONER STUDENT TO STUDENT
William Harold Fenton
Roy Robert Grenham
Roger Hardy-Birt
Stanley Arnold Hill
Alexander Duncan Tosh

OBITUARY

Lawrence Quinn Beck (Member 13985) was born in 1914 and served an apprenticeship with Samuel Lee Bapty, Ltd., Watford, from 1931/35. For the next two years he was a fitter with the Gloster Aircraft Co., Ltd., at Hucclecote, and then joined the Royal Mail Lines, Ltd., as a seagoing engineer, serving in various ranks up to second engineer between 1939 and 1947. He obtained a First Class Ministry of War Transport Motor Certificate in 1945 and a Steam Endorsement a year later. From 1947/50 he was an engineer surveyor with the British Engine, Boiler and Electrical Insurance Co., Ltd., but then returned to sea as chief engineer of the salvage motor vessel *Hercules* owned by the Bland Line, and was later chief engineer of the passenger and car ferry *Mons Calpe* for the same company; he remained in this employment until May 1956 and then returned home to study for an Extra First Class Certificate. He was found to be suffering from a serious illness in October 1956 and died on 9th May 1957.

Mr. Beck had been a Member of the Institute since 1952.

Robert Birnie (Member 8665) was born in 1885. His apprenticeship was served with the Nile Foundry, Workington, and then the Workington Iron and Steel Co., Ltd., from 1899/1904. He first went to sea in 1907 with the Booth Line but came ashore in 1915 to work for Harland and Wolff, Ltd.; after spending two years in their employment and shorter periods with the Cunard Steam Ship Company and H. and C. Grayson, Ltd., as an engine fitter, he returned to sea in vessels of the Moss Hutchison Line, Ltd., remaining with the company from 1919 until 1946 and serving latterly as chief engineer. He joined the Currie Line in 1949 and stayed with them until 1952. Mr. Birnie was seagoing until the end of his life, his last two ships being the *Argodon,* owned by A. Lusi, Ltd., and the Rex Shipping Company's *Brookhurst,* in which he was serving when he was taken ill in Rouen on 20th December 1956 and died within a few hours.

Mr. Birnie had been a Member of the Institute since 1938.

Hugh Woodhams Brady (Member 8454) was born in Northern Ireland in 1879. He was educated at Uppingham and then served a premium apprenticeship at the Great Eastern Railway Company's works at Stratford. Five years at sea followed, from 1899/1904, and he obtained a First Class Board of Trade Certificate. On coming ashore he was works manager of an electrical firm in the Midlands and then in independent practice until 1914 as an inspecting and consulting engineer in Manchester; at this time he was also for some years engineering editor of "The Manchester Guardian". When war broke out he joined the Royal Indian Marine, serving as chief engineer of several inland and seagoing vessels for a time and then being appointed, first, staff engineer at R.I.M. headquarters, Basrah, and then Deputy Assistant Director (Major Special List) of Inland Water Transport, R.E. In 1918/19 he was deputy controller for the Indian Munitions Board, first at Bombay, then at Calcutta; and for the next two years he was organizing secretary of the Institution of Engineers (India). In 1921 he returned to Government service as chief inspector of factories and finally chief mechanical adviser to the Government of Bihar and Orissa, remaining in this appointment until 1935 when he reached retiring age.

On returning to England at this time he was invited by "Syren and Shipping" to contribute to the journal each week a page on marine engineering topics and as a result he wrote the "Engineer's Log" under the pen name of Marineer for twenty-one years. In April 1957 he had to give up this work owing to the failure of his eyesight and a recurrence of the heart trouble against which he had been fighting ever since his return from India caused his death on 1st May 1957.

Mr. Brady was a Member of the Institution of Mechanical Engineers and of the Institution of Engineers (India) and an Associate of the Institution of Naval Architects. After being a Member of the Institute for some years from 1907 onwards he resigned but rejoined in 1937 when he was once again settled in this country.

Andrew Reid Graham (Member 4308) was educated at Leith Academy and served an engineering apprenticeship with Ramage and Ferguson, Ltd., Leith, from 1907/13. During his apprenticeship he attended the Heriot Watt College, Edinburgh, and obtained the College diploma in mechanical engineering. He remained with the same company as a draughtsman until February 1914 when he took a seagoing appointment with Messrs. Alfred Holt and Company, Liverpool, with whom he served until 1921, obtaining a First Class Board of Trade Certificate of Competency during this period. He then joined Messrs. John White, Boyd and Company of Glasgow as a marine surveyor, being made a partner in 1927 and becoming sole partner in 1940. In 1934 he was appointed non-exclusive surveyor in Scotland for Det Norske Veritas. He died after a short illness on 2nd April 1957.

Mr. Graham was a Member of the Institution of Naval Architects and a Fellow of the Society of Consulting Marine Engineers and Ship Surveyors. He was elected to membership of the Institute in 1921.

George Noel Hallett (Member 7598) was born in 1882. He served apprenticeships with the Taff Vale Railway Company, Cardiff, from 1898/1901, and the Sunderland Forge and Engineering Co., Ltd., from 1901/03 before spending nine years at sea and obtaining a First Class Board of Trade Certificate of Competency. The rest of his professional career was spent in the Far East: from 1913/18 he was installation engineer with the Rising Sun Petroleum Company, Japan, and for the next five years he was manager of the Royal Brush Company at Osaka. Mr. Hallett joined the Vacuum Oil Company in Japan in 1923 as chief engineer and remained in that capacity throughout his service with that company, and with the Socony Vacuum Oil Company and the Standard-Vacuum Oil Company, until his retirement in 1937.

Mr. Hallett died at Sidmouth on 15th February 1957. He had been a Member of the Institute since 1934.

G. Lloyd Jones (Member 2554) died in March 1956. He served an apprenticeship with the Great Western Railway Company, Swindon, and after a short period at sea in the G.W.R. Irish service was engaged as a consulting engineer at the time of his election to membership of the Institute in 1911.

WILLIAM MALTBY LORDING (Member 15393) was apprenticed to O'Connell and Kerr Pty., Ltd., Melbourne, from 1922/27, and was then seagoing for seven years. He came ashore in 1934 as assistant engineer for twelve months and then as chief engineer for fifteen years with Peters Ice Cream (Victoria), Ltd. After a further year in his old ship, s.s. *Taiping,* as refrigerating engineer, he was employed in the same capacity by the Toppa Ice Cream Company for a short period. In 1952/53 he served as sixth to fourth engineer in the m.s. *Braeside* owned by Burns, Philp and Co., Ltd., and then obtained a First Class Australian Steam and Motor Certificate. From 1953 until his death on 17th August 1956 Mr. Lording was chief engineer in the Victorian Public Works Department (Ports and Harbours), Melbourne. He was a Member of the Australian Institute of Refrigerating Engineers and of the Australian Institute of Marine and Power Engineers; he joined the Institute of Marine Engineers in 1955.

CHARLES HENRY STANBRIDGE (Member 5797), who died suddenly on 12th December 1955, was elected to Associate Membership of the Institute in 1927 and transferred to full Membership in 1935. He served an apprenticeship in the Electric Power Station, Port Elizabeth, of which he became chief engineer in 1908, then took an appointment in Queenstown as engineer in charge of erection of plant, returning to Port Elizabeth in 1913 as engineer to Stanton and Co., Ltd. He served in the Forces throughout the first world war. After the war he had appointments, each lasting for several years, as electrical engineer in the Municipality of Cradock, with the Grahamstown Corporation, and in charge of electrical construction in Capetown. During the second world war he was a captain in the Union Defence Force, South Africa, but this service ended in June 1945 owing to a foot disability. He then became a consulting engineer in Port Elizabeth in the firm of Messrs. C. H. Stanbridge and Partner. Mr. Stanbridge was an Associate Member of the Institution of Mechanical Engineers. He was elected to Associate Membership of the Institute in 1927 and was transferred to full Membership in 1935.

WILLIAM BERNARD THOMPSON (Member 3865), formerly director and general manager of Durastic, Ltd., died on 19th April 1957, aged sixty-nine. After serving an apprenticeship at the works of Humphreys and Tennant of Greenwich, he was at sea for twelve years, obtaining a First Class Board of Trade Certificate at the early age of twenty-two. During the first world war he served in minesweepers, holding the rank of engineer lieutenant in the Royal Naval Reserve. On coming ashore he was a member of the outside staff of R. and H. Green and Silley Weir, Ltd., at Millwall for some years and in 1926 he joined the Durastic Company. At that time wood was the only material used to any extent for the covering of ships' decks but the employment of bituminous compositions was favoured in certain cargo ships; with the introduction of the combination floorings that Mr. Thompson designed shortly after joining the company the use of bituminous compositions increased and is now common practice. During the second world war he introduced the manufacture of plastic armour for ships, which was to prove a valuable asset in remedying the shortage of steel available for this purpose. Due to a diabetic condition which he had contended against for ten years Mr. Thompson ceased his active association with Durastic, Ltd., at the end of 1948 and went into retirement at Bickley, Kent. He had been a Member of the Institute since 1920.

CYRIL ERNEST TONG (Associate Member 13092) died on 16th April 1957. He was a boy artificer at H.M.S. *Fisgard* from 1913/17 and was passed out first on the completion of his course; he was then at sea for two years in H.M.S. *Dreadnought.* The next five years were occupied with special courses on turbines, oil fuel and internal combustion engines (in 1923 he obtained a Higher Educational Certificate, R.N., first class) interspersed with periods at sea. In 1927 he was promoted warrant engineer and served in H.M. Ships *Iron Duke, Caradoc* and *Centaur.* In 1932, by now a commissioned engineer, he was retired from the Royal Navy as medically unfit for active service and spent some years trying to recover his health. On the outbreak of war, however, when the need for skilled men was great, he felt he must make what contribution he could and was employed by Messrs. J. Evans and Son, Portsmouth, as foreman on production work and later as manager of all fitting and assembly departments. Unfortunately his health broke down again in 1944 and he was told that he must not undertake heavy work. He took a position at Poplar Technical College as senior laboratory technician; on obtaining a Higher National Certificate in Mechanical Engineering he was appointed to the teaching staff of the college as a workshop instructor, the position he held at the time of his death.

Mr. Tong was elected an Associate of the Institute in 1950 and transferred to Associate Membership in 1951.

WILFRED THOMAS TOWNEND (Member 3695) was educated at Gresham's School, Holt, Norfolk, and then at an engineering college in London. He was an engineering pupil with Messrs. Vickers, Sons and Maxim, and later at the Tyne Engineering Works, Newport, Monmouthshire, before becoming a seagoing engineer with the Anglo American Oil Company and the Peninsular and Oriental Steam Navigation Company. He obtained a First Class Board of Trade Certificate of Competency and joined the Royal Naval Reserve. During the first world war he transferred to the Royal Navy and spent five years in active service afloat as engineer lieutenant and six years on the special reserve. In 1920 Mr. Townend joined Handcock and Dykes and became a partner the following year; he was responsible for the design and erection during the next twenty years of a number of power stations, and for the engineering equipment and lighting of factories, public buildings and hospitals. In January 1940 his services were required by the Ministry of Works and he was appointed resident engineer to R.O.F. Bishopston in charge of all mechanical and electrical services; two years later he was transferred to the London headquarters as senior engineer in charge of all propellent and explosive factories, sites and construction. In 1942 he took an appointment as chief engineer and local director of Newton Chambers and Co., Ltd., being responsible for engineering supplies connected with all their projects. He joined Gresham and William Press, Ltd., in 1946 as technical sales manager in charge of their export business to the Middle East and his final position was as partner with Young and Partners in London, with whom he was associated from 1953 until his sudden death on 11th May 1957.

Mr. Townend was a Member of the Institutions of Electrical Engineers and Mechanical Engineers and a Fellow of the Institute of Fuel; he had been a Member of the Institute since 1919.

EDMUND GEORGE WARNE (Member 5444) died on 19th August 1956, aged sixty-seven. He was assistant editor of "The Motor Ship" from its establishment in 1920 until his retirement in April 1956. Mr. Warne served in submarines during the first world war and was well known in the British shipbuilding and marine engineering industries. He attended regularly the technical meetings held at the Institute, of which he had been a Member since 1925.