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# THE ELECTRICAL POWER SYSTEM IN THE QUEEN ELIZABETH 2—DESIGN AND OPERATIONAL EXPERIENCE

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This paper covers the principal problems encountered in arranging for the generation and distribution of electrical power in the most complex and sophisticated passenger liner afloat. It goes on to describe the unconventional solutions which resulted, some after considerable research and development. During testing and commissioning, a number of unsual failures occurred and one of these highlighted the need for specially designed system protection devices. The paper concludes by reviewing the electrical power systems, in the light of operational experience.

Mr. Bolton

## PART I—SYSTEM DESIGN

### GENERATION VOLTAGE

During the early design stages, it was decided for economic and operational reasons, to restrict the number of main generators to three. Two of them had to be capable of carrying the peak electrical load, and the machine size for this duty worked out at 5·5 MW. At this power, generation had automatically to be at high voltage, because, at medium voltage, circuit-breakers of the required current rating and short-circuit performance did not exist. The available standard voltage of 3·3 kV was the obvious choice.

Several problems arose:

1) safety of personnel;
2) treatment of the neutral point;
3) installation and protection of high voltage cables and transformers in accommodation spaces;
4) adaptation of high voltage switchgear to marine use.

The advantages were:

a) the electrical power network could, through transformers, comprise a number of electrically separate systems, instead of one system connected to common busbars: this meant that the voltage and the treatment of the neutral point could be appropriate to the requirements of each system;
b) generators, switchgear, large motors and cables could all be smaller, lighter and less costly to purchase and install;
c) switchgear performance under system fault conditions would be within recognized duty categories: in all previous large passenger liners, switchgear designed and built specially to suit marine requirements had to be used;
d) under short-circuit fault conditions, the prospective currents would be relatively small compared with those obtained in medium voltage systems, and the potential damage at the seat of the fault appreciably less.

### FREQUENCY

Most ships' electrical systems use a frequency of 60 Hz, for well known reasons. In this ship, it was not an automatic choice because the voltage selected for the medium voltage networks was 415 V, usually associated with 50 Hz. For reasons of electrical standardization, the lower frequency was seriously considered, but it was overruled on the grounds of standardization of the speed of marine auxiliaries, the higher power to weight ratio and overall cost.

### THE HIGH VOLTAGE SYSTEM

Much information already existed upon the various ways of treating the neutral point. It seemed simpler to follow conventional marine practice of insulating it, eliminating the need for earth fault protection and its complications, and allowing an essential service with an earth fault upon one phase, to continue to function until it could be isolated. The drawback then was that arcing earth faults could produce induced over-voltages which could over-stress the insulation to earth, and so require it to have a considerably higher dielectric strength than would otherwise be needed.

Industrial users were consulted and it was found that such over-voltages had occasionally caused the failure of groups of large electrical machines. It was finally decided to adopt a resistance earthed neutral system provided that it could be made simple and easy to operate.

Conventional neutral earthing practice at the time was to connect the alternator neutrals to earthing resistors, through neutral earthing circuit-breakers, but in a ship carrying only a relatively small number of electrical officers, this was thought to be unacceptably complex.

The manufacturers were therefore asked to produce machines with chorded windings, to allow all three alternator neutrals and their earthing resistors to be permanently commoned before earthing. The resulting third harmonic circulating currents were thus restricted to a few amperes, which was considered to be acceptable. No earthing circuit-breakers were needed and the ship's staff could, from an operational viewpoint, ignore the neutral earthing requirement.

Because the emergency alternators could also be used to supply power to the high voltage system, through two of the machinery space supply transformers, resistance neutral earthing, using smaller resistors, was also applied to the two transformers. Fig. 1 shows the arrangement. To eliminate maintenance of the earthing resistors, they were totally enclosed

* Y-ARD Ltd.

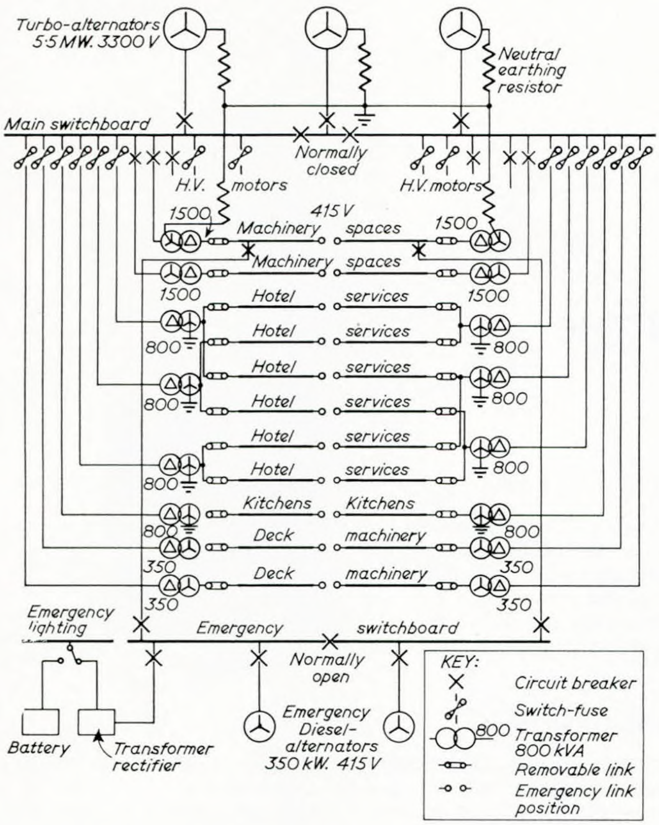


FIG. 1—*Power system arrangement*

in unventilated steel cases. The heat produced under paralleling and fault conditions was calculated to be well within the natural cooling cycle of the units.

## THE MEDIUM VOLTAGE SYSTEMS

The conventional solution for the medium voltage side would have been to install insulated neutral networks for both machinery and hotel services. This would have been acceptable for power apparatus, but for lighting and similar low voltage equipment many more transformers would have been needed. There was no real reason why, for each sub-network, the system should not be appropriate to its use, particularly as there would be several other advantages in so doing. The solutions finally adopted and the reasoning behind them will now be discussed.

### *Selected Voltage 415 V*

440 V is conventional for ships, but the phase to neutral voltage for this, is 254 V, which is too high for standardized and generally available fluorescent lighting apparatus, domestic equipment etc. A line voltage of 415 V results in a phase voltage of 240 V, a recognized standard. For marine rotating plant 440 V is usual, but 415 V can be accommodated without difficulty even at 60 Hz.

Because of the exceptionally heavy lighting and domestic load, therefore, 415 V was selected as the medium voltage.

### *Machinery Space Systems*

For the machinery spaces and for deck machinery, there was no advantage in earthing the neutral point, and conventional three-phase, three-wire networks, with earth leakage indicating equipment were used. Machinery space lighting was powered by four three-phase 415/415 V transformers, the secondary sides having their neutrals earthed to provide 240 V.

### *Hotel Networks*

Here, there were several reasons for using the three-phase, four-wire, solidly earthed neutral system so common ashore in the United Kingdom:

i) every zone would be supplied through triple pole and neutral distribution fuseboards, so that the triple pole, triple pole and neutral, or single pole and neutral loads, would receive appropriate electrical power without any need for low voltage transformers: copper used in cables, switches etc. would be at a minimum: there would be no restriction on the use of standard triple pole and neutral or single pole and neutral hotel and laundry equipment;

ii) single phase circuits would all be single pole and neutral, thus allowing single pole fusing and switching throughout: standard BS 1363, 13 A sockets and fused plugs would be used to full advantage;

iii) earth fault finding would be greatly simplified: an earth fault would cause a fuse to blow or a circuit breaker to trip, so that most faults would be self-locating: this is in contrast to insulated systems in which each earth fault would have to be traced painstakingly by isolating circuits in turn: elimination of this chore was later found to be the greatest of all labour-saving advantages to the electrical staff;

iv) "ghosting" of switched-off fluorescent lighting would be eliminated.

Concerning earth leakage currents in particular, it is true that a general lowering of the insulation of the network could occur, due for example to dampness in a particular area, and this could cause an earth leakage current, of perhaps several amperes. To cover this possibility, a current transformer-operated, earth-leakage ammeter was connected in the earthing connexion of each transformer neutral. When the leakage current in a network rose to more than a nominal value, alarm contacts on the instrument would close and an identifying alarm print-out would be given on the data logger. For general checking purposes the earth leakage instruments were installed in the main console.

The fire risk aspect of earth leakage currents did not escape attention and, in passenger areas, which harbour the greatest risk, every sub-circuit was protected by a fuse of a rating not exceeding 15 A.

## THE LOW VOLTAGE SUPPLY SYSTEMS

Because a large proportion of the passengers to be carried are American it was decided to provide, in addition to standard BS 1363 sockets, 115 V, three-pin U.S. type socket outlets in all passenger cabins, to supply personal tape players, hair dryers, dictaphones etc. The advantages of these sockets to the passengers were obvious; they also eliminated the need for converter units to be carried on board, and for the ship's staff to distribute and maintain them.

110 V (55 V to earth) supplies were provided in all machinery spaces where portable electric tools might be needed.

Extra low voltage power for talk-back systems, loud-speaking telephones, sprinkler and manual fire alarms etc., was supplied at 50 V d.c. from two groups of transformer rectifiers, each of which, under loss of main power conditions, would be automatically replaced by a battery supply.

Supplies for emergency lighting were from a 240 V transformer rectifier under normal conditions and from the emergency battery under a mains failure condition.

A.C. operation was considered both for normal and emergency use, but inverters were found to be too costly. And because an appreciable number of emergency lights were required to be fluorescent, d.c. supplies were necessary for both operation modes.

## POWER NETWORK LAYOUT AND OPERATION

The essence of any electrical power network on board ship is simplicity, both for ease of operation and maintenance.

All principal electrical power centres are divided into port and starboard switchboards, each supplied through a transformer from the appropriate side of the main switchboard. Although the port and starboard sections of the 415 V switchboards will normally be electrically separate, provision was made for connecting them in parallel by means of special copper links in the busbars (see Fig. 1). These links are only obtainable from the ends of the busbars where they form the connexions to the transformers, or to the transformer cables. They will only be used if it is necessary to take out of service for an extended period, a main transformer or its cable or the circuit-breaker feeding it. The links for any pair of switchboards are non-interchangeable with those for any other pair of switchboards. This ensures that the main generators can only be paralleled at the main switchboard and at no other point in the network.

The same general philosophy was applied to the emergency switchboard, which was also divided into port and starboard sections; and here the place of links was taken by a suitably interlocked circuit-breaker.

For power supplies to hotel services, each transformer feeds two switchboards. The feeders were staggered in the manner shown (Fig. 1), because the electrical load in the centre of the ship would obviously be greater than that at the ends; the standardized transformer size was kept to a minimum by arranging that each transformer fed one heavily loaded switchboard and one lightly loaded switchboard.

For the purpose of raising steam from the "dead-ship" condition, all necessary electrical supplies can be obtained from one 415 V emergency alternator. The high voltage supply for the low speed winding of a boiler fan can be obtained by back-feeding to the main switchboard through either of two of the four machinery space transformer groups.

In the unlikely event of a main power failure, both emergency alternators automatically start up and are connected to their respective halves of the emergency switchboard. In addition to making power available for the statutory emergency services, supplies are immediately connected to the passenger lifts (to enable them to be homed automatically) and to the engine room lift.

## MAIN TURBO-ALTERNATORS

The three main high voltage turbo-alternators are each continuous maximum rated at 5·5 MW, 6·6 MVA (Fig. 2). Thus the rated power factor is 0·833 instead of the conventional 0·8. The higher figure more nearly matched the expected average system power factor and thus saved over 800 kVA of generator capacity.

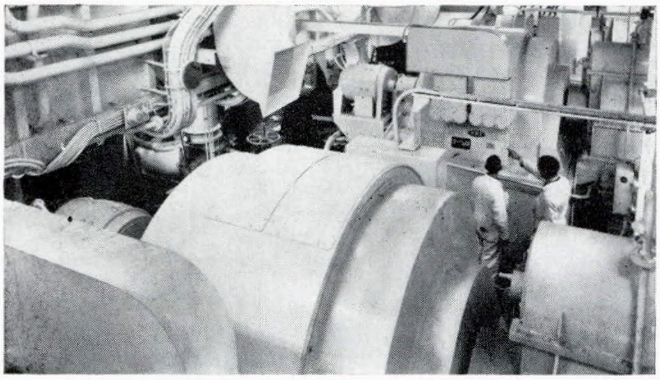

FIG. 2—*One of the 5·5 MW 3300 V brushless main alternators*

### *Voltage Dip*

For highest reliability, and lowest maintenance requirements, totally-enclosed, closed air-circuit, water-cooled, brushless machines were chosen, the relatively large kVA rating making it unnecessary to resort to the high response characteristics of static excitation for starting large motors. The largest motors were 1000 hp for the bow thrusters, and direct on-line starting of these from two alternators in parallel was estimated to result in a transient voltage dip of 11 per cent, recovering in half a second. Technically such a dip was quite acceptable, but it was possible that lighting flicker could prove annoying to passengers. Anticipating this problem, exhaustive practical tests, with both fluorescent and tungsten lighting had been carried out at the AEI lighting laboratory. Groups of laymen were asked to rate the severity of flicker as various random values of dip were selected. Using these results, suitably de-rated because the test groups were actually looking for flicker, it was estimated that no real annoyance to passengers would be caused by the occasional start of a bow thruster (11 per cent dip) or the relatively frequent change of a two-speed boiler fan from low to high speed (6 per cent dip). The voltage drop estimates were dependent upon a specified sub-transient reactance of 16·5 per cent which was subject to a manufacturing tolerance of $\pm 20$ per cent.

### *Automatic Voltage Regulation*

The decision to use brushless alternators was partly influenced by the requirements of automatic voltage regulator equipment. Static excitation would have involved very large excitation units and also sliprings and brushes. Brushless excitation avoided sliprings and drastically reduced the size (but not the complexity) of the excitation equipment. It was relatively easy to provide a spare AVR, wired permanently to terminals, and change-over links associated with each service AVR to enable an emergency change-over to be performed quickly. In addition, each alternator was provided with a change-over switch and an emergency manual voltage control, to enable voltage regulation to be switched from "auto" to "hand" under running conditions.

### *Alternator Cooling*

Closed air-circuit water cooling was specified, primarily to keep the windings free from external contamination, but also to prevent dissipation of the considerable heat loss into the machinery space. Bottom mounted coolers were chosen to allow free access to the alternators when required and so that, in the event of cooler leakage, salt water would not run into the machine.

With closed air-circuit cooling, there was the risk that cooler failure could severely restrict the machine output and emergency doors were specified, to allow full output to be obtained with the machine running open ventilated.

### *Terminal Boxes*

At the time when the specification was being prepared, the C.E.G.B. and several manufacturing firms were concluding investigations into a series of explosions which had occurred in high voltage terminal boxes. Most had not involved personnel, as the machines were situated in areas to which people did not normally have access (although there were a few cases of injury, one of them fatal). The risk from such explosions was quite unacceptable aboard ship and it was decided to adopt a phase segregated design of terminal box which had been fully tested and approved under simulated fault conditions.

## EMERGENCY ALTERNATORS

By basic specification, the emergency alternators were similar to the main generators for broadly the same reasons, but because their running hours are short and because they were relatively small in size and had, for their purpose, to be as simple as possible, they were enclosed-ventilated, drip-proof and cooled by air ducted to the compartment.

They differed in voltage dip requirements for two reasons. They did not supply the passenger lighting system and so lighting flicker did not matter, and they were relatively small compared with some of the motors which were to be started from them. Any such motor could be started from one alternator direct-on-line, with one exception, the 150 hp fire and washdeck pump, for which it was necessary to adopt auto-transformer starting to keep the voltage drop within limits which would not affect the performance of loads already connected to the busbars. The biggest theoretical voltage dip was of the order of 25 per cent and, for this reason, special contactor coils were selected for those starters which could be in operation at the time.

To cater for lighting-up and test conditions, the alternators were designed to run in parallel with the main alternators for short periods. Both machines were arranged for automatic start-up on loss of main power.

SWITCHGEAR

The main 3·3 kV switchboard comprised air-break switchgear and switchfuses.

*High Voltage Circuit-Breakers*

Based on a main alternator subtransient reactance of 16·5 per cent, the prospective fault level was calculated at over 150 MVA and so 250 MVA circuit-breakers were specified. The largest feeders, i.e. those for the bow thrusters and the machinery space power transformers, were controlled by circuit-breakers backed-up by HBC fuses (Fig. 3). The incorporation of fuses was a special requirement to take advantage of "cut-off" under short-circuit conditions. It was considered important, for several reasons, to restrict potential fault damage to an absolute minimum.

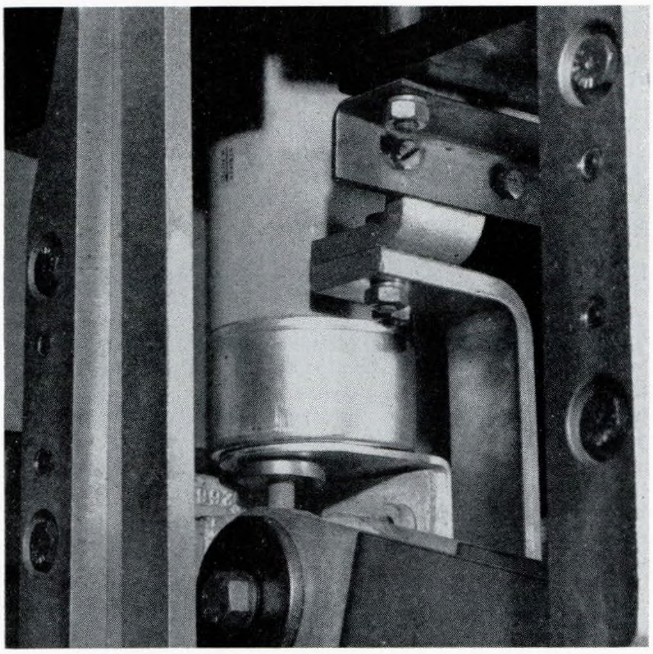

FIG. 3—*3300 V back-up fuses fitted to type AH circuit-breaker*

*High Voltage Switch-Fuses*

Partly as a result of the electrical specification for the ship, the Whipp and Bourne type AF high voltage switch-fuse was developed. Devices of this type were not available at the time the specification was written, but the advantages of simplicity, small size and weight, economy and reduced maintenance, were worth pursuing and the equipment was developed and made available in time. Had the switchboard been composed solely of circuit-breakers, it would have been almost twice its present size.

*Segregation of Circuits*

In the early design stages, it was proposed to divide the main switchboard into sections installed in separate compartments, so that a main busbar short-circuit fault could not put all of the main switchgear out of service. The space required was considerable and investigations were put in hand to establish whether this precaution was really essential. Switchgear test and service data were checked and it was concluded that a busbar fault in a switchgear cubicle would be unlikely to affect more than one cubicle on each side. The compromise finally adopted was that of dividing the switchboard into three sections connected by bus-section circuit-breakers, the alternator circuit-breakers being separated by several cubicles.

*Switching Control*

All of the high-voltage circuit-breakers and switch fuses were arranged for electrical closing and tripping, the supply being 240 V d.c. from a special battery fitted in a compartment adjoining the control room. 240 V d.c. was selected to coincide with the ship's emergency lighting supply system, so that the latter could provide an emergency supply in the event of failure of the closing/tripping battery or its charger.

Arrangements were made for all normal switching to be carried out at the main electrical control console, where the control switches and instruments were laid out in mimic form; but local control was also provided at each circuit in the switchboard. Means of closing all circuits by hand was provided, for emergency or off-load maintenance use only.

*Safety and Maintenance Procedures*

To ensure that all high voltage switching and maintenance would be carried out in good environmental conditions and under the supervision of a senior officer, all high voltage switchgear was confined to the main control room. Access to a high voltage transformer could only be obtained by isolating and earthing down the circuit, an action which released a Castell key to enable the transformer room door to be opened. The door having been opened, the key was then trapped in the lock. Similar safety measures were applied to high-voltage motors, the only difference being that the officer responsible for supervision of the work on the motor would retain the Castell key until the work was complete.

High voltage switch-fuses were of the draw-out type and could be locked in the withdrawn position for maintenance. When necessary they could be removed from the cubicles by means of a special truck. For the withdrawal of a high voltage circuit-breaker, a special maintenance rack could be bolted to the deck, and the circuit-breaker was racked out on to it. Circuit-breakers and switches of similar ratings were all interchangeable.

For maintenance of high-voltage equipment, a "permit-to-work" system, similar to that in force in industry, was considered, but because it was possible to concentrate all high voltage switchgear in one position and because the number of electrical officers on board numbered only eight, this was found to be unnecessary. Standing instructions which listed personnel having authority to carry out switching were drawn up stating that maintenance upon any item of high voltage apparatus must be under the direct supervision of the first electrical engineer, under authority from the chief engineer. This was less arduous than it appeared since all high-voltage motors were to be totally enclosed and the transformers in their air-conditioned rooms would require cleaning only once a year.

*Medium Voltage Circuit-Breakers and Fuse-Switches*

The fault current limiting effect of transformers enabled standard 31 MVA, 415 V switchgear and fusegear to be used throughout the medium voltage system, except for circuits which could be paralleled with the emergency alternators. Here, based on estimated reactances at the design stage, it was found necessary to use 37 MVA equipment, special short-circuit tests being necessary for starter switchboards connected to these circuits.

*Electrical Protection*

From the main turbo-alternator circuit-breakers downwards, over-current and earth fault protective devices were selected to discriminate, so that only a faulty circuit would be isolated. With one exception, which was specially developed following sea trials, all protective gear was entirely standard, and simplified as far as possible (almost all relays etc. had been proved in service in earlier vessels). Fig. 4 shows typical circuits and the protection which was used.

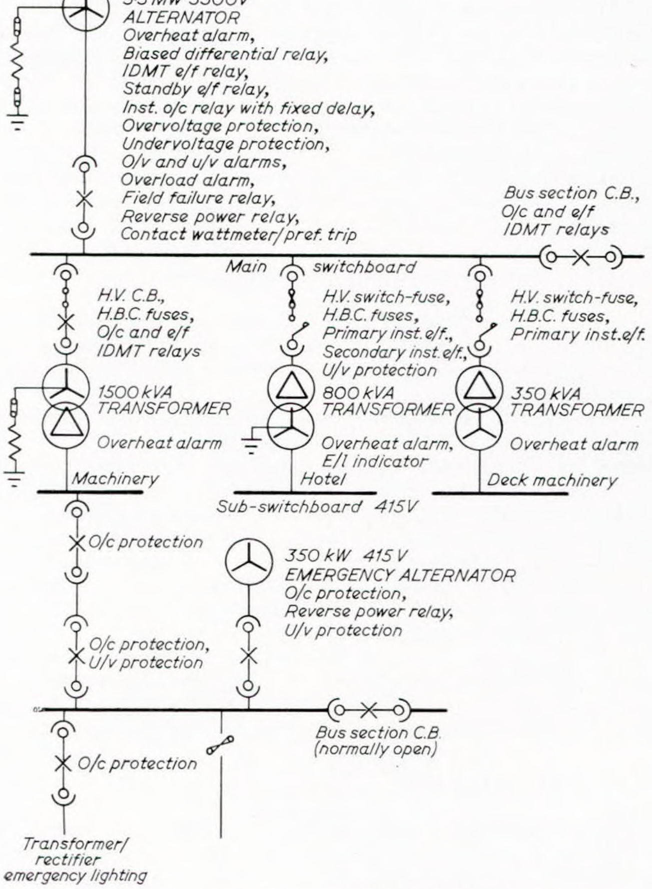


FIG. 4—*System protection—typical circuits*

TRANSFORMERS

Estimates of electrical load indicated that three-phase 3·3 kV/415 V transformers of up to 1500 kVA in rating would be required. They would be by far the largest transformers ever installed on board ship for auxiliary purposes and several new problems were posed. (See Fig. 5.)

The installed transformer capacity is large indeed (Fig. 1), especially when compared with the installed load. There were several reasons for this:

1) because of their size, the transformers needed to be installed relatively low down in the ship, and so had to be ordered at a very early stage in order to obtain delivery to suit the building programme: at this time only the preliminary loading estimates were available, and the estimated rating needed to be conservatively high;
2) a transformer once installed, would form a "block" in the network such that the load in its area could not be increased above the unit rating: it was therefore necessary to allow a margin for development of load during building, and for the addition of unforeseen loads later in the ship's life;
3) transformers would be cheaper and delivery would be shortened if they were bought in quantity: three sizes of transformer were therefore selected—one for machinery spaces, one for accommodation and galley, and one for deck machinery. Thus, in each group, only one transformer approached optimum size and the others were all larger than their loads required;
4) with one exception, it was decided to carry no spare transformers on board because of their need to be accommodated and kept dry and warm. It was considered preferable to incorporate spare capacity into the transformers installed, and, in the event of a failure, to feed the affected area from adjacent sections: under certain conditions, this could mean overloading a transformer up to 120 per cent of its rated output: this was considered acceptable for a short period, because almost certainly the ambient temperature would be below the maximum allowable, besides which a class "C" transformer could stand a degree of over-loading for a short period without any appreciable loss of effective life.

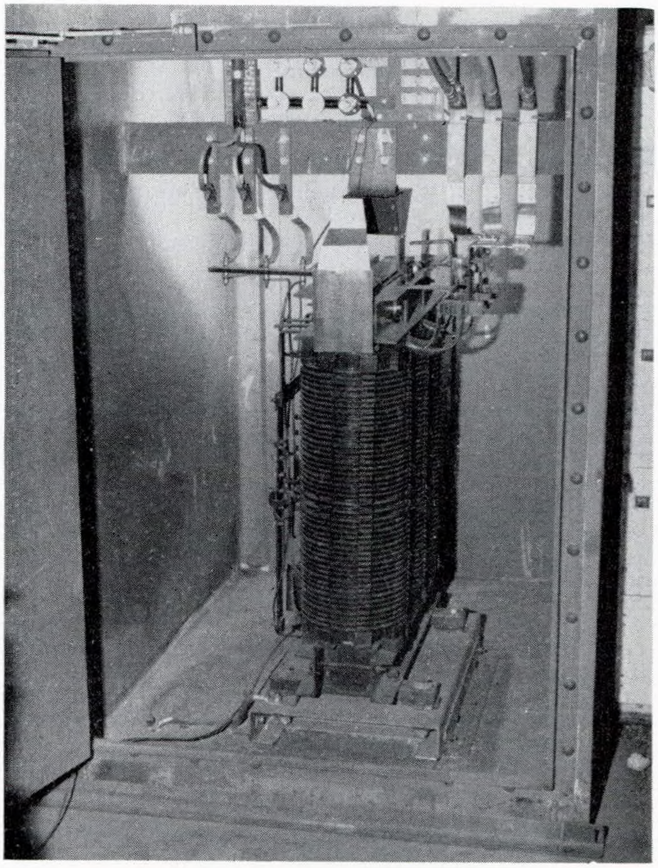

FIG. 5—*A 3300 V/415 power transformer in its cell*

Following conventional marine practice, all transformers were air insulated, but the high voltage units were unconventional in that they were not enclosed in ventilated sheet steel housings. Because of their large size, it was decided to install core and coils in special cells, which, in most cases, formed part of the ship's structure. This gave several advantages:

a) the transformers were as small as possible, thus saving on initial cost and weight:
b) easy access was obtained all round each unit in its cell, for inspection and maintenance: general inspection could be carried out at any time through glass ports in the cell bulkheads;
c) no cable boxes were required and cable cores were made off directly to terminals;
d) enclosure vibration noise was eliminated.

Class "C" insulation was chosen, rather than the usual class "B", because of its higher temperature rise (which made for minimum dimensions) and its non-flammability.

1500 kVA was the rating required for each of the four machinery space transformers. Three-phase units would have been unacceptably large, especially with built-in spare capacity, so each unit comprised a group of three single-phase transformers connected star/delta three-phase. One single-phase transformer was then supplied as spare and installed in one of the cells.

Almost all the high-voltage transformers were installed adjacent to, or below, accommodation areas and close attention was paid to the reduction of noise by resilient mountings, special core materials, etc.

The highest noise level emitted from any transformer was 56 dbA, further reduced where necessary by acoustic cladding.

To allow for regulation according to the average load in each area, the high voltage transformer primary windings were provided with tappings at $\pm 2\frac{1}{2}$ per cent.

Machinery space transformers had further tappings of $-7\frac{1}{2}$ per cent and $-10$ per cent so that if, at some future time, a 440 V shore supply were required, compensation could be made to produce the correct voltages in the ship's systems.

MOTORS

Generally, electric motors were continuous-maximum-rated, insulated to class "B" and for maximum protection against single-phasing, all windings were star-connected. Except for a few large, well-situated auxiliaries, all medium-voltage motors were totally-enclosed fan-cooled; for most of the high-voltage machines, water cooling was employed.

Special phase-segregated or vented terminal boxes were not considered necessary for the high-voltage motors, as the prospective fault energy of each circuit was limited below explosion risk level by HBC fuses.

Following now established practice in ships built earlier, bearing grease nipples were replaced by plugs, to avoid indiscriminate over-greasing. All horizontal motors were fitted with pre-loaded bearings to avoid brinelling trouble.

CABLES

Power cables were butyl insulated, p.c.p. sheathing being used in accommodation areas and c.s.p. sheathing in the higher ambient temperatures of the machinery spaces. It had been intended to use c.s.p. sheathing throughout; this proved uneconomic with the cable prices obtaining at that time.

Regarding high voltage cables in particular, the classification rules required that if the cables were to be carried on open tray plating, then metallic sheathing or armouring had to be provided. Alternatively, the metallic sheath or armour could be omitted, provided that the cables were installed in continuous earthed metal ducting. Neither of these precautions was regarded with favour, because of anticipated performance under fault conditions and also because of the additional space, cost, weight and labour entailed. But these precautionary considerations were particularly important in passenger accommodation.

It was therefore decided, if it could be shown that there were no hazard to personnel from capacitative currents between a man's hand on a cable sheath and the conductor, then the matter could perhaps be reconsidered. Accordingly, the three major cable companies were asked to produce supporting evidence.

As a safety criterion, one milliamp was decided upon as the maximum current which could be allowed to flow through the body of a person standing on earthed metal and grasping the cable sheath.

By calculation and by test, it was proved that provided the longitudinal cable sheath resistance was not less than 20 megohms/ft, this fault current figure would not be exceeded.

Upon receipt of this information, the classification authorities agreed that unscreened, unarmoured butyl rubber insulated, p.c.p. or c.s.p. sheathed 3·3 kV cable, could be used on open tray plate inside ceiling spaces in accommodation and machinery spaces, provided that single-core cables were run in trefoil and the cable was secured by earthed metallic clips at a prescribed spacing.

It should be recorded that whilst the dispensation was given, the 3·3 kV cable runs in passenger accommodation ceilings were, in fact, additionally protected by light tray plate, bolted to the sides of the tray bearing the cable.

## PART II—OPERATIONAL EXPERIENCE

TURBO-ALTERNATOR FEATURES

It is worth commenting upon the performance of the following features on trials and in service.

*Design Power Factor*

The saving in kVA by specifying a power factor of 0·833 has been more than justified. The average system power factor has been in excess of 0·85, and at the same time there have been no motor starting or voltage dip difficulties to justify a lower figure. In future tonnage of a similar type, a factor of 0·85 would appear appropriate.

*Emergency Voltage Regulation Arrangements*

It is becoming more usual to find emergency change-over arrangements and standby manual voltage regulators in modern ships, and there was nothing exceptional in their being fitted for these particular machines. What is worth noting is that they were used on several occasions when faults arose and that they kept the alternators in service. At the times when a faulty automatic voltage regulator was suspected, the change to the spare regulator, using the special change-over links was achieved smoothly and quickly and with no disturbance to wiring.

*Reactance and Voltage Dip*

Permissible maximum voltage dips depended upon the transient reactance which was related to the design sub-transient reactance of 16·5 per cent $\pm 20$ per cent. It was a matter for concern, therefore, when the works tests revealed an increase of 33 per cent on the design figure. The voltage dips produced when starting large motors were in excess of those estimated as a maximum during the tests at the AEI Lighting Laboratory, but practical experience on board has shown that, except for persons with an engineering background, the lighting flicker goes unnoticed and has never been cause for complaint or adverse comment.

One bonus is that circuit-breaker breaking capacities are well within their ratings. For the high voltage switchgear the prospective fault level was reduced below 150 MVA, so that the extra expense in providing 250 MVA equipment was wasted, although this could not possibly have been foreseen at the time of ordering.

*Preference Tripping*

The turbines used for driving the alternators were continuous maximum rated and thus were more susceptible to sudden overloading than were the alternators, i.e., they would tend to stall under the application of heavy kilowatt overloading, whereas the alternators had a certain thermal capacity which would enable them to absorb short-time overloads without damage.

The standard operating procedure on board, at times of maximum load, was to be that two of the three turbo-alternators would be running, the theoretical peak load being 80 per cent of the nominal rating for both machines. There was, then, the possibility that one alternator might trip, leaving the other to carry the load until preference tripping could operate. The tripping stages were set as low as was reasonable at three, five and seven seconds.

It was decided that the sudden application of an extra 80 per cent load on a turbo-alternator already carrying 80 per cent rated load, was sufficiently unusual to justify a full trial on board—in particular to prove the preference trip time settings. The results are given here.

*Alternator and Overload Trial*

The port alternator was selected for the test. The load was built up to 8·4 MW on the port and centre machines, as follows:

| | |
|---|---|
| Electric motors | 5·3 MW |
| Lighting and galley ranges | 1·2 MW |
| Test tanks | 1·9 MW |
| | 8·4 MW |

(8·4 MW represented 152·5 per cent of one alternator full load and although this was not the theoretical maximum peak load, it was the maximum available at the time and sufficient to give an indication of performance.)

The centre machine was tripped and the entire load was thrown onto the port machine. The following readings were observed and after approximately 22 seconds the load was reduced below normal machine full load by manual tripping:

| *Instrument* | *Observation* |
|---|---|
| kW | Hard on the preference trip contact at 5·5 MW throughout test. |
| Amperes | Hard over, dropping finally to 1100 A. |
| Volts | Initially 3300 V, dropping to 3050 V, recovering to 3225 V. |
| Frequency | Initially at 59·8 Hz, dropping to 57 Hz, recovering to 60 Hz, and settling at 59 Hz. |
| Preference relay | The relay tripped 0·6 MW of galley load after three seconds but it did not operate the stages at five and seven seconds (the defect was later found to be due to dirty contacts). |

The results show that the inertia of the rotating load throughout the ship helped to maintain the frequency within acceptable limits until the excess load was tripped. They are on the pessimistic side, as nearly a quarter of the load was from test tanks and, therefore, non-rotating.

## TURBO-ALTERNATOR TROUBLES

At the design stage, close attention was paid to the main h.v. alternators, to make them as simple and as trouble-free as possible. It was, then, particularly vexing to find that they were a constant source of trouble during the first year of service.

*Main Exciter Failure*

During the commissioning period it was noticed that for one machine the exciter field current and voltage were not in accordance with the works test figures. The exciter rotor was returned to the maker's works where it was found that foreign metallic matter had entered the windings during manufacture and had finally caused a short-circuit between turns.

*Closed Air-circuit Contamination*

After commissioning, dust deposits were noticed at several joints and cover edges on all three alternator casings, and it was evident that a considerable volume of dirty ambient air was being drawn into the closed air-circuits. The joints were re-sealed and the covers re-jointed.

After trials, the cooling air-circuits were opened up for inspection and in two alternators the end windings were found to be covered with a heavy oil and dirt deposit. It was found in each case that oil had migrated from the alternator/exciter pedestal bearing, run up a taper in the shaft and been drawn into the machine by the interior cooling fan.

Preventing the oil migrating up the shaft taper was difficult because of space restriction and it was difficult to fit a thrower ring to divert any future leakages. A compromise was effected by fitting felts to the labyrinth and by making the shaft guard of expanded metal instead of steel plate, to reduce the tunnel effect. Air had obviously been drawn in at the base plate water drains, and so the drains were re-located to enable water manometers to be fitted. These incidentally showed a difference in pressure between inner casing and the machinery space of 2 in. w.g.

*Cooler Failures*

Shorty after commissioning, examination of the aluminium brass cooler tubes revealed severe pitting, and it was necessary for the tubes in all three machines to be replaced. It was thought that the pitting was due to contaminated cooling water taken from the Clyde during the commissioning period.

Subsequent to this, the connexions to the coolers inside the baseplates of two of the machines failed, due to the use of a short length of mild steel piping adjacent to a cupro-nickel fitting. Leakage water had escaped through the drains, but since these were one inch above the baseplate, there was water to this depth inside each machine. It was fortunate that bottom-mounted coolers had been specified, anticipating the possibility of such leakage and no electrical damage was caused. Following replacement of the faulty pipe sections, inspection windows were fitted to the base to enable any further leakage to be seen, and the drains were re-located to ensure proper drainage.

*AVR Failure to Over-Voltage*

During sea trials, at a time when the vessel was stopped, the system voltage suddenly rose from the nominal 3300 V to more than 5000 V. The actual voltage could not be observed, as the control room voltmeters were hard against their stops. Two main alternators were running and their ammeters were seen to be reading off-scale. After approximately ten seconds, the starboard bus-section breaker tripped, followed by the starboard alternator breaker and field switch. Supplies to the port busbars were maintained by the port alternator and the bus-section circuit-breaker was re-closed to restore power to the whole installation.

The starboard alternator (still running) was re-excited and found to generate over 5000 V at all regulator settings. The automatic voltage regulator was then replaced by the spare, by changing over the emergency links and upon re-excitation the alternator was found to operate normally.

A check of equipment throughout the ship revealed extensive damage to radio communication apparatus and slight damage to the sound reproduction system. Fortunately most navigation aids etc., were switched off at the time.

Examination of the faulty AVR showed up an open-circuited diode, which had caused the field build-up relay to drop out, thus simulating a low field condition. The regulator responded by giving full field-forcing, which caused the over-voltage.

In later discussions it was established that failure of several other components could reproduce a similar fault but re-design of the regulator to take this into account was out of the question. The fitting of over-voltage protection was the only solution.

Over-voltage protection is rarely fitted in ships, principally because over-voltage faults are rare, and when they do occur, do not normally cause damage. When first reviewing protective requirements for the ship, over-voltage protection was seriously considered, but the complexity of sufficiently reliable "fail safe" equipment was thought at the time to be more hazardous than protective, and thus only over-voltage alarm was incorporated. However, faced with practical evidence that over-voltages could not be tolerated, there was no alternative and effective protection had to be fitted before the ship could continue her trials.

An over-voltage relay which could simply trip the alternator circuit-breakers would have been easy to fit, but to do this would court blackouts, which could occur at any time. The only real solution was to isolate the circuit causing the trouble and replace it by something similar.

Ashore the problem is sometimes solved by fitting each alternator with two AVRs and automatic change-over arrangements, but this was quite impracticable, because of the lengthy delivery time, quite apart from the high cost entailed and the complexity resulting.

It was decided to proceed with protection in two forms:

(i) relays to detect the fault and isolate the faulty equipment in sufficient time to prevent damaging over-voltages occurring;
(ii) means to trip radio communication and navigation aids power supplies upon initiation of the fault and isolate them before the voltage could rise to a damaging value, the alternator time constant being about 400 ms.

For detection of an over-voltage condition, over-voltage relays were provided for each alternator. Alone, these were not sufficient, since normally, with two or three alternators in parallel, all relays would detect the same voltage and would operate. Selection of the faulty circuit was to be made by combining with each over-voltage relay, another relay to detect heavy field forcing, since only the faulty circuit would exhibit this symptom in addition to over-voltage.

A field over-voltage relay was tried, but proved too sensitive to the pulsing wave form of the AVR output. Since a field over-current relay would be too slow, it was finally decided to monitor field current by measuring the voltage drop across a series resistor.

Having obtained sufficiently fast and reliable means of detection and selection, the problem was then to trip the voltage control from "auto" to "hand", sufficiently quickly to arrest the voltage rise. To do this the manual hand/auto switch was replaced by another switch with hand—close/ electrical-trip feature and the operating speed of this, added to the relay speed was estimated at 100 ms.

The hand voltage regulator associated with manual control was then fitted with a stop, such that the voltage under minimum ship load conditions could not greatly exceed 3300 V. This was essential because there would be little point in tripping an AVR, causing over-voltage, only to substitute it by a hand regulator repeating the condition. The stop could then be over-ridden if the excitation were found to be low.

The whole set-up was installed and tested under average load conditions by withdrawing the AVR sensing voltage transformer fuses to cause field-forcing. The voltage rose to 3800 V (115 per cent of nominal) before the voltage change-over switch tripped to manual. This was most satisfactory and was considered adequate to protect the electrical installation. However, to give additional back-up protection to the radio communication equipment and navigation aids, the high speed circuit-breaker mentioned earlier was fitted. The operating-time of this was shown to be 15 ms faster than that of the automatic voltage change-over switch.

*Automatic Turbo-alternator Run-up Scheme*

Each turbo-alternator was fitted with an automatic scheme of the relay type, to take the turbine through all preparation stages automatically, and finally to synchronize the alternator with the running machines and to share load. Commissioning of the equipment did not take place until many months after the ship had entered service, and after a considerable number of modifications had been made. During the first winter cruise programme away from the United Kingdom, the automatic synchronizer failed and remained out of service until the ship returned months later.

## SWITCHGEAR AND CONTROL GEAR

*Main Switchboard Short Circuit Fault*

During the final commissioning period between the technical and acceptance trials, an incident occurred in the main high-voltage switchboard and caused a busbar short-circuit fault.

It was discovered during tests of the automatic combustion control scheme that the HV switch-fuse for a boiler fan was occasionally tripping for no apparent reason.

Tests were being carried out using the remote controls to establish the trouble zone, when several sharp reports were heard, each being accompanied by a dip in the intensity of the ship's lighting, and the circuit-breaker associated with the alternator feeding the starboard busbars, tripped. From the condition of the switch-fuse panel, a busbar short-circuit had obviously occurred and so supplies to the starboard half of the ship were temporarily lost. The emergency links in the switchboard pairs throughout the vessel, were then removed from the starboard ends of the busbars and used to connect all switchboards to the port feeders; all port use supplies were then restored.

The damaged circuit was investigated and the damage was found to be confined to the cubicle, although some soot had been forced into the compartment on either side and into the control room generally. The switch was stuck in the closed position and, on freeing it, it could be seen that all three busbar isolating plugs and two of the phase-fixed and moving contacts had been burned away by a three-phase short-circuit.

With so much of the evidence destroyed, it was difficult to be certain about the cause of failure, but it is the author's opinion that the arcing originated at the fixed and moving contacts and spread to the isolation plugs. The cause of arcing could have been connected with manual operation of the switch during commissioning, an operation which is not recommended by the manufacturers for a switch which is designed to be electrically closed. All remaining switches were inspected, then and at regular intervals for a year, but no undue contact erosion appeared.

It was reassuring to find that a full three-phase short-circuit was effectively confined to one cubicle.

*Group Starter Switchboard Short-circuit Fault*

Also during the commissioning period, smoke was seen to be coming from one of the turbine control room 415 V group starter switchboards and the feeding circuit-breaker tripped. Investigation showed that a three-phase short-circuit had occurred in the busbar chamber. The cause of the fault was an unused length of metal angle which had been taped to the inside of the chamber, had finally become loosened and had fallen on to the busbars. In view of the rapid clearance time of the circuit-breaker, the fault damage was not severe and the damaged sections of busbar were soon replaced.

This was a further lesson in the care which is necessary in commissioning electrical equipment.

This and the previous incident did serve to reassure the ship's staff that the ship was provided with effective discriminative protective equipment.

*Switchgear Battery-charger Failure*

Following commissioning, a transformer winding failed in the tripping and closing battery-charger, causing the battery voltage to drop to a level at which the low voltage alarm operated. The closing and tripping supply source was changed over to the emergency supply from the ship's main emergency battery, and all ship's services continued without break. It was fortunate that the emergency supply arrangements had been fitted, because several days elapsed before a replacement transformer was available.

*Transformers*

Service at sea has not shown up any practical arguments against the specification of the transformers or the way in which they were installed. There have been no complaints from passengers or crew in compartments adjacent to the units, about noise or excess heat.

The free standing arrangement in cells has made cleaning during the annual overhaul periods particularly simple and rapid.

The practice of solidly earthing the neutral of all power transformers, excepting those for machinery supplies, has proved to be well worthwhile. Almost all of the earth faults which have arisen in the circuits have been self-identifying through the blowing of a fuse, and this has reduced time spent on fault-finding to a fraction of what it would otherwise have been.

The reliability of the transformers themselves was, however, at first open to question. This was anticipated at the design stage in 1966 when, because industry had experienced a number of failures in high-voltage air insulated transformers, the Electrical Research Association was consulted. The Association was able to advise, from its records of failures, that the majority were due to insulation failure following motor-starting or switching surges. These problems were discussed in detail with prospective manufacturers, who confidently expected that with the experience of the failures behind them, no further trouble should occur.

It was, then, disturbing, when during routine shop tests of two of the transformers, they were found to have developed short-circuits between turns on the secondary side on one phase. Following repair, all the transformers were oven heated to 220°C and induced voltage tests at twice normal volts at 200 Hz for 30s were carried out to test the inter-turn insulation. High voltage tests were then made at 8000 V between H.T. and L.T. windings to earth, and at 2500 V between L.T. and H.T. windings to earth. It was hoped that the failures had been eliminated but, after installation prior to sea trials, a further similar fault made its appearance on a third unit. The transformer was returned to the works for repair and was reinstalled.

With a record of three similar failures within a short time from manufacture, it was no longer considered wise to adhere to the policy of not providing spares for the units outside the machinery space and accordingly a complete set of three-phase coils was manufactured and placed in store at the maker's works to minimize repair time should any further failure occur.

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# Discussion

Mr. D. Gray, B.Sc., M.I.Mar.E., said that it was interesting to note that high voltage generation was necessary because of a decision made for economic and operational reasons, i.e. that the number of generating sets was to be restricted to three. It was because the generating plant had to be restricted to three units that high voltage generation became necessary. This was an interesting difference between this ship and other passenger ships built in the last twenty years.

Mr. Gray thought it curious that whenever high voltage generation had been used in previous years, it was nearly always an economic or operational reason which dictated the choice. For instance, there were some comparatively small tankers building at the present time in which electrically driven cargo pumps were to be fitted. It was also a requirement that the time of loading/unloading had to be within the period of one tide, i.e. 12 hours. The requirement of the fast turn round time, coupled with the preference for electric cargo pumps, required large motors. Motors of this size rendered 3 kV appropriate for the system voltage, because medium voltage motors of this rating would be uneconomic.

Another facet of the question occurred when large generating sets were proposed for a ship. The physical difficulty of installing 440 V generator cables frequently swayed the balance in favour of high voltage generation.

Mr. Gray thought it was open to question whether 60 Hz would have been chosen in 1971. Electrical manufacturers throughout the world were merging into larger units. This had produced and would produce, problems with the placing of orders for non-standard equipment; in Europe 60 Hz had to be regarded as non-standard and if this were not true today, then it certainly would be in 1975. The author had mentioned the reasons for this choice of 60 Hz as: the speed of auxiliaries, the higher power to weight ratio and the overall cost. These were the deciding factors in 1964/5. He thought this had now to be equated with the cost of spares (if they were obtainable) needed during the life of the ship. Perhaps the author would care to give some present-day comments on this question.

Regarding the number of generating sets, it would appear that it was because the number of these was restricted to three, all located in one generator room, that high voltage generation was necessary. Fig. 6 showed the electrical systems for some of the passenger ships built between 1954 and 1963.

Mr. Gray said that *QE2* had one generating room containing three generating sets. He was not criticizing the wisdom of this choice but the systems shown in Fig. 6 illustrated the views of other marine electrical engineers. Of the ships illustrated; one had three generator rooms, others two generator rooms and some only one generator room. The advantage of more than one generator room did not require amplification.

As regards the number of generating sets, *QE2* needed two to supply power for the normal ship's load so that there was one set standby. With one unit defective the ship could still be fully operational; two units defective and all services could no longer be supplied.

A one fault philosophy such as this was perfectly normal and acceptable for a commercial ship; it was doubtful for a warship because a warship had to remain operational even after damage had occurred. *QE2* was not a warship, but it was debatable whether it should be considered an ordinary commercial ship. She had 2000 passengers on board, and was a 'prestige' ship.

Considerably more redundancy had been built into the systems shown in Fig. 6 than existed in *QE2*, and this extra redundancy expressed the philosophy of the marine engineers responsible for the design of these passenger ships.

Mr. Gray would make the same comments viz-a-viz automatic voltage regulators. Three large generating sets had one spare AVR for all three sets. That spare AVR had, in fact, already been called into service as described in the paper. There could well be a case for having two AVRs per machine in a ship of this type.

He thought that they were stuck with the problem of over voltages as a result of AVR failure. There was no easy answer. Field forcing was always necessary to a greater or lesser extent. If one had too much field forcing in the design one would get overvoltage problems and damage such as that described by the author; too little field forcing and the generator voltage would not recover fast enough after a sudden load change, with the risk of motors overheating.

The author had mentioned the failure of fuses in a voltage sensing circuit. If one attempted to protect such a circuit accurately then this meant a low rating fuse with the problem of possible inadvertent operation with the attendant dangers of overvoltage on the system. There were many marine engineers who held the view, which was shared personally by Mr. Gray, that if fuse protection was to be fitted in such a circuit the protective element should be of such rating that inadvertent operation was unlikely.

This meant that close protection of the circuit might not be afforded; protection against full short circuits only and the hazard of fire would be provided.

This ship had a very large electrical installation. It had also many signal and control circuits, and Mr. Gray asked Mr. Bolton whether there were any problems connected with noise pick-up from the power system into the control, signal and communication circuits, and what steps were taken at the design stage to try to minimize this interference.

Transient over-voltage had been mentioned with particular reference to the all-insulated system. It had been measured in ships of the US Navy and more recently a number of commercial

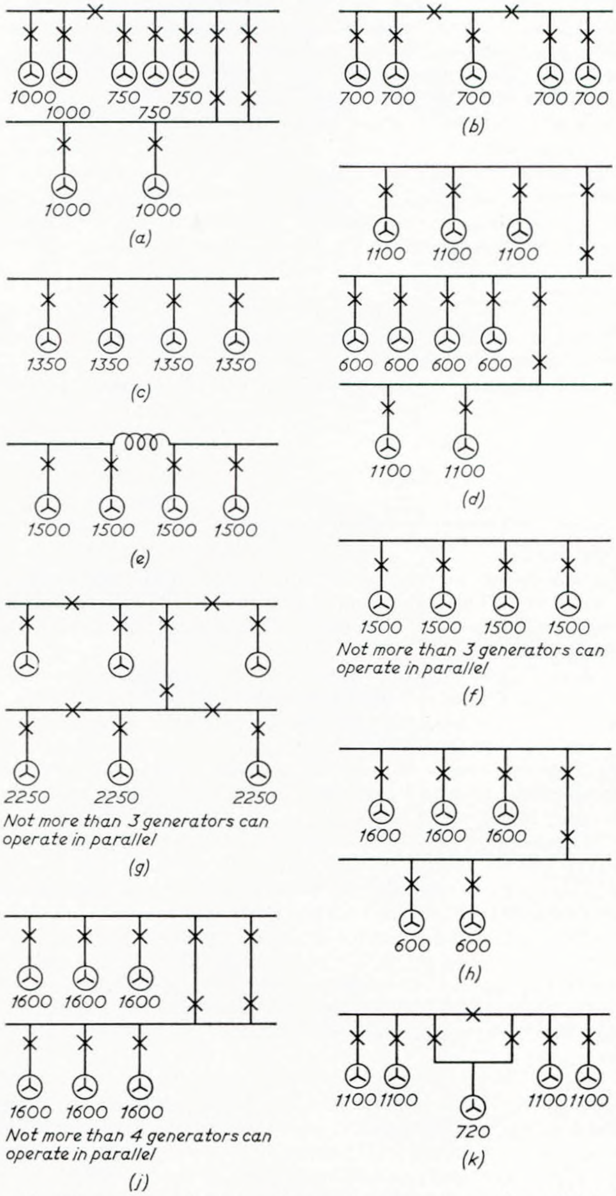



FIG. 6—*Examples of system layout in passenger ships* 1954–63.

| Fig. | Date of build | Country of build | Country of ownership |
|---|---|---|---|
| *a* | 1954 | Italy | Italy |
| *b* | 1957 | Italy | Sweden |
| *c* | 1959 | Holland | Holland |
| *d* | 1960 | Italy | Italy |
| *e* | 1961 | Britain | Britain |
| *f* | 1961 | Britain | Britain |
| *g* | 1961 | France | France |
| *h* | 1963 | Italy | Italy |
| *j* | 1963 | Italy | Italy |
| *k* | 1963 | France | Israel |

All ratings shown are given in kilowatts. Emergency generators are not shown. In all cases the system is 440V, 60c/s.

ships had reported it, yet to the best of his knowledge Mr. Gray had never heard of any failure of power equipment which could be directly attributed to transient over-voltage, by which he meant an over-voltage with a duration of milli-seconds. The author had referred to failures attributed by industrial users to this. He would like to know more about this if the author had any details because the only plant he knew ashore which had used an insulated system on this sort of voltage was The Steel Company of Wales, and this had been several years ago. If there was any evidence of failure of power equipment he would be very grateful to hear of it.

Finally Mr. Gray asked whether the ship staff dealt with maintenance of the high voltage switchgear or whether a maintenance contract had been arranged with the switchgear manufacturers. This, he thought, would be of considerable interest to all marine engineers who might have to adopt HV systems.

MR. CRICK asked the author to comment on whether, in the early stages of design, any consideration had been given to using a split busbar system, which might have permitted a medium voltage installation. If so, what were the over-riding disadvantages of implementing this system at that time (or the advantages of the high voltage system) and had this reasoning been substantiated in practice?

The choice in passenger liners, between using 60 Hz and 50 Hz was not an obvious one. For a vessel primarily intended to operate from American ports carrying American passengers, the case for 60 Hz, however, was substantial. But for vessels intended for UK, Australian, European and South African trades, etc., the arguments might not be so valid. Standard hotel equipment and appliances and lighting chokes, etc., would be 50 Hz; thus on 50 Hz frequency new and replacement equipment, as well as spares, would be cheaper and easier to procure, and few difficulties would be encountered with shore connexions.

With regard to the adoption of three-phase, four-wire systems to take full advantage of 13 amp standard fused outlets (among others), could the author indicate any parameters which decided the number of outlets per circuit and whether any restrictions were imposed—cable sizes, spurs, or area covered by each circuit for example?

The author, said Mr. Crick, had made a good argument for a three-phase, four-wire system for the hotel network but where more essential circuits such as navigation and communications were involved, the disabilities associated with such systems were introduced and it would seem prudent to consider providing a separate insulated system in such cases.

The adoption of 110 V supplies for portable tools and handlamps to be used in areas of high shock risk should be more widespread in ships than at present is the case. Portable tools for machinery spaces and even for deck use might even more preferably be compressed air operated, and handlamps supplied from a 24 V circuit.

The concept of totally enclosed motors and generators was fully endorsed by the speaker on the grounds of increased reliability and reduced maintenance. Regarding water-cooled machines, the speaker felt the tendency should be towards using double tube coolers and effective leakage alarms, thus allowing appropriate action to be taken before water entered the windings.

The provision of over-voltage protection was becoming increasingly important, but manufacturers seemed reluctant to endorse this view because of the difficulties involved. Protection to susceptible equipment should be coupled with security of supply, and consideration should be given to parallel and single operation of generators. On smaller installations care had to be taken not to impair the performance of the voltage regulations with the introduction of over-voltage protection. Consideration might also be given to incorporating no-voltage protection in equipments likely to be damaged by over-voltage. Finally it was vitally important to ensure that the provision of any protective device did not introduce otherwise non-existent hazards to the system security.

The author's remarks on system power factors confirmed the speaker's own experience. The best power factor was usually obtained at peak-load conditions as a result of high non-inductive galley loads, but in deciding the power factor rating of generators some thought had to be given as to whether the selection of say 0·85 instead of 0·8 would, under low-load conditions, result in running one more generator than would otherwise be necessary.

Finally, as made apparent by the paper, increased amounts of electrical equipment resulted in increasingly complex problems.

A successful ship, economically and operationally, had to depend on full co-ordination and understanding between the mechanical engineer, the electrical engineer and the naval architect; and in any design the problems to be met by the operating, maintenance and repair personnel had to be very much taken into consideration.

MR. G. VICTORY, Member of Council I.Mar.E., said that the author had set out very clearly the particular problems involved in designing very high electrical powers required to cope with propulsion, auxiliaries and hotel services in a modern passenger liner.

The solutions the author reached had resulted from the problem being tackled by a somewhat new method in marine practice using the analogy of land practice, whereby the main machinery rooms and generator rooms were treated in effect as a self-contained power station; and the hotel and ancillary services were treated as distribution areas, with what were in effect transformer sub-stations each with their own area of distribution based on the neutral earthed principle, complete even to the familiar 13 amp plug points. That it had been so successful was a pointer to the probable continued use of this philosophy in the future where very high electrical power was needed.

Naturally, with *QE2* registered in the United Kingdom it was necessary for the electrical arrangements, as for all other particulars of hull and machinery, to be examined, approved and surveyed during construction by the Marine Department of the Board of Trade (now the Department of Trade and Industry) and the somewhat unconventional approach, brought, he could vouch, problems and headaches to the Department. He complimented the author on his choice of the blanket phrase, "classification authorities", and wondered if perhaps by this he had meant statutory authority and classification society. They were in fact two different things.

One divergence from land practice was that the sub-station did not incorporate high voltage switchgear which of course required that any necessary isolation had to be carried out from the main switchboard. The author had said that the short distances involved obviated the need to operate a "permit-to-work" system in that such work would carry on under the direct authority of the chief electrical officer. However, this did not appear to cover the work on 415 V circuits where one could be killed just as nicely and cleanly and it would appear that in this area the "permit-to-work" system could be used to advantage. Perhaps the author could say whether in practice the system he had adopted had really guaranteed protection to personnel working on these systems.

Although *QE2* was not in fact the first passenger vessel using unscreened cables at 3·3 kV to be surveyed by the Board, he thought it was the first ship in which the 3·3 kV circuits had been extended outside the machinery spaces; and it was probably the first ship in which it was not intended to screen the cables and in fact not enclose them in really strong ducting. As the author had said, the solution in respect of personnel safety on these exposed cables was to obtain a surface resistance of 20 megohms per foot on the cable insulation, and to nullify the possibility that current accumulated over a reasonable length could be concentrated into one point, by having fairly closely spaced metallic clips. Mr. Victory thought this solution was quite effective, but to maintain the surface resistance it was necessary to keep the surface undamaged, clean and free from oil, dust or paint, deposits of which were always likely to accumulate on cables. He wondered if the author could report on any tests having been carried out to ensure that the adequacy of the cable surface resistance had been maintained in operation, and whether there were any precautions taken to avoid, for example, spray painting in these areas.

Another problem concerning neutral earthing between transformers and alternators arose when the system was fed back from the emergency generator. This could have been dealt with by introducing a switch into the neutrals, but originally it was proposed that the transformer neutrals should be tied to the alternator neutrals at the "hot" end of the earthing resistors. He believed it was the suggestion of the Board of Trade which made it obvious that there would be a circulating current of some 105 amps in the common neutral and that one solution would be the earthing down of the feeder to the transformer by a neutral earthing resistor.

The operational experience quoted by Mr. Bolton was very interesting. The speaker thought it showed that no matter how much care and consideration went into a large, sophisticated installation such as *QE2*, the fact that a marine system was essentially a "one off" job almost certainly introduced problems of manufacturing defects and possibly some degree of mismatching. The use of emergency changeover arrangements to keep the alternators in service showed that the human touch could still be the best "fall back" facility, whilst a need to fit over-voltage protection, despite the fact that theoretically such protection should have been unnecessary, reminded one that it was a good precept to say: "If it can happen, it will happen."

The contamination of the alternator end windings indicated that care needed to be taken even in the design of cooling air circuits. A differential air pressure of 2 in. w.g. appeared to indicate that air passages were probably too restricted, whilst the fact that dirt and oil migrated into the casing, at least indicated that this section of the circuit was below the ambient pressure. Perhaps the answer, apart from ensuring leak-free joints, would be to arrange for a controlled inlet of dry filtered air at the point of lowest pressure, and this would ensure positive pressure at all other points after the fan. His opinion was that many of the incidents related were typical of those expected in the shake-down period of such a sophisticated installation, and one could hopefully assume that the bugs were now out of the system.

MR. R. F. NICHOLAS said that his job involved designing electrical supply systems for the Royal Navy. About the time *QE2* was being designed his department were in the process of designing a new aircraft carrier. And it so happened that they came to much the same solution (a 3·3 kV system) for much the same reasons—the amount of power would have been far too great for a 440 V system in terms of current and breaking capacity.

The aircraft carrier which was axed in a defence review would have had about the same maximum load as *QE2* or possibly somewhat more, but they were proposing to fit six 3 MW generators. *QE2* had in fact fitted the absolute minimum of three sets. The Royal Navy's problems were considerably different from the merchant service—they had to cater for action damage and the usage of the ship was very much different; therefore it was difficult to draw a true comparison. Nevertheless, Mr. Nicholas shared Mr. Gray's doubts whether economy in the initial installation had been carried to the extent of possibly reducing reliability. In his experience if generators had to be run in parallel, the very worst arrangement was to run two. There were several reasons for this. The most obvious of course was really brought out in the paper by the simulated failure which in effect threw the whole load from one generating set onto the remaining one. A failure in prime mover or generator with only two sets was the worst condition. Had there been four 4 MW sets instead of three 5·5 MW sets (which was not much different in total capacity, in fact slightly less) running three in parallel, on the maximum load postulated in the paper the loss of one set would have left an overload of 0·8 MW on the remaining two, which was almost insignificant, and probably no load shedding would have been required.

There were always protection problems with generators running in parallel, some of which were accentuated because the two sets were in fact mirror images. If something went wrong with one, the same happened in the other. There could be governor or prime mover difficulties, and in this context if one set partially lost driving power further load would be thrown on the other one. This could result if all went well in load shedding (the quite considerable 3·3 MW load shedding in this case) or if the load shedding did not work as planned, blackout might occur.

A second difficult problem was excitation failure or potential failure in one machine. This was more difficult to cope with because the net result was a large circulating current to keep up the voltage of the defective machine, and if the only protection was overcurrent protection the generator breakers would not know what to make of it. The probability was that they would both trip out.

Finally there was the problem of internal faults in the generator or in the cables connecting the generator to the switchboard. Mr. Nicholas was not clear whether or not unit protection was fitted, but he thought not. Here again one could have a problem in ensuring discrimination between the supply breakers of the healthy machine and the faulty one.

In conclusion, had the author any information on the number of blackouts or heavy load sheddings that had occurred and secondly, if he were starting again, would he go to four smaller generating sets or possibly fit some more sophisticated protection arrangements?

MR. E. M. ADAMS said that he found it difficult to accept that generators, switchgear and large motors could be smaller, lighter and less costly to purchase and install for a 3·3 kV system compared with a medium voltage system. His own experience of power up to 1500 hp indicated that 3·3 kV machines and control gear were both heavier and larger than their equivalent on a medium voltage system. Furthermore, the 3·3 kV equipment had also been between 10 per cent and 25 per cent more expensive than medium voltage equipment. Of course, one had to accept that the major saving in a 3·3 kV installation was in the cost of copper, particularly in the cabling and busbars. He accepted the author's statement that there was a very strong technical reason for going for 3·3 kV on *QE2*.

The paper also stated that under short-circuit fault conditions the prospective currents on a 3·3 kV system would be relatively small compared with those obtained in the medium voltage system and the potential damage at the fault would be appreciably less. Mr. Adams agreed that the prospective currents would be appreciably smaller, but if the electrical energy were the same for the two systems, he would expect the potential damage to be the same.

He agreed with other speakers that a frequency of 60 Hz was as equally acceptable these days as 50, and that the higher power outputs expected for the higher frequencies did not always materialize due to the division of motor outputs to fixed frame sizes.

The likelihood of induced over-voltages being experienced due to arcing earth faults on an insulated system was very much dictated by the design and extent of the installation, with particular reference to the capacitance of the system. Mr. Adams believed that each individual ship's installation should be examined to establish the extent of danger from induced over-voltages before an insulated system, with its obvious advantages, was rejected. It should be also borne in mind that a false sense of security could be developed with any other form of earthing system, since over-voltages could also be experienced on these systems.

On the selection of medium voltage of 415 V there was an agreed standard in the UK and it was referred to as one reason for choosing it for *QE2*, but not 240 V at a frequency of 60 Hz. Presumably this would affect fluorescent lighting control gear; certainly UK gear would not be standard for such an installation.

The merits of an earthed 240 V system were amply covered in the paper. One problem however was to ensure that switches were in the correct line and that all fittings were adequately earthed. The ghosting of switched-off fluorescent fittings could be overcome by double pole switching on an insulated system, possibly at some slightly extra cost.

The paper clearly indicated the facility, illustrated also in Fig. 1, for feed-back supply from the 415 V emergency alternators onto the 3·3 kV switchboard in the case of "lighting up" conditions. He also noted that the emergency alternators were designed to run in parallel with the main alternators. Was this parallel running condition stable over the loading of the machines?

High voltage switch-fuses were referred to in the paper. Mr. Adams presumed this meant "fused contractors" in his terminology.

In *QE2*, transformers were air insulated, following conventional marine practice. Two advantages should not be overlooked when comparing them with oil insulation—namely the reduction in weight and dimensions—though of course they were more costly than their oil insulated counterparts. The method of installation into individual special cells seemed very attractive but it was likely that shipyard costs would offset any savings obtained from transformer manufacturers.

Mr. Adams noted with some alarm that the sub-transient reactance of the alternators was of the order of 33 per cent greater than the original design figure, and he was equally alarmed to discover recently that 2·5 MW alternators for some ships at present building had an actual sub-transient reactance of some forty per cent lower than the design figure. He realized this might well cause difficulties depending on the safety factors used, but these instances did indicate the necessity for extreme care, so far as the design of the installation was concerned, with regard to prospective fault levels. They also highlighted the need for manufacturers to tighten up their manufacturing tolerances—to cover the twenty per cent tolerance they were allowed.

The paper stated that cooler tubes were manufactured from aluminium-brass—from experience of cooler failure perhaps they should consider the use of cupro-nickel tubes. Mr. Crick had also mentioned double welded tubes which Mr. Adams thought a good idea.

Over-voltage protection was rarely fitted in ships because over-voltage faults were rare but had probably become more apparent with the use of brushless alternators and field-forcing AVRs.

In conclusion, the author's experience with the run-up system confirmed Mr. Adams's own view that the auto-synchronizer was not justified in view of the greater degree of complexity involved which, in itself, did not give any direct saving in manpower.

MR. H. DU V. ASHCROFT said that the paper showed that a project of such complexity as the *QE2*'s electrical systems was not just a collection of details which could be designed in isolation. The whole concept had had to be built up in logical steps, and any major change would have meant starting again from scratch.

When confronted with 3·3 kV generation the Board of Trade did not think there was really any choice—the high voltage system would therefore have to be earthed. The choice involved was how to earth; and the designers had decided to earth through a comparatively high earthing resistor.

A resistor to pass the full load current of one generator would be normal, but in this case the resistor passed only 23 per cent of full load. This was quite acceptable as long as the earth fault relays were sufficiently sensitive, but it did mean that the same grade of cable would have to be used as for an insulated system. Having put one earthing resistor in each alternator in a position where it would reduce the circulating current, it was not clearly seen why special precautions were necessary to cut down the third harmonics.

In choosing the medium voltage it was shown that had 440 V been adopted the line-to-neutral voltage would have been 254 which is 4 V higher than the desired maximum of 250. Mr. Ashcroft wondered why 440 V was accepted as the marine standard and why so few ships were built for 415.

He also thought that sometimes marine engineers called for alternators with unnaturally low sub-transient reactances and something like ten per cent seemed to be expected. In this case a reactance of 16·5 per cent was called for and this was approaching the values expected from similar machines on land. The British Standard tolerance on reactance was plus or minus 30 per cent; the builders specified plus or minus 20 per cent and the actual machine finished up with plus 33 per cent giving a sub-transient of 22 per cent. It would appear that Mr. Bolton had been sold short weight because the size of an alternator was inversely proportional to its sub-transient reactance.

There was a move in some standardizing circles to calculate the system fault capacity to the last milli-amp, the formulae being collected from textbooks on advanced design. The wide range of alternator reactances shown indicated that, at best, the fault calculations could only be approximate.

Mr. Bolton did not need to spend sleepless nights thinking about using 250 MVA switchgear when 150 MVA would have done. The speaker had spent some time in the design department of a large steelworks where they had two rules on the selection of switchgear. Out in the works they might install circuit-breakers which were marginally higher in rated fault capacity than the system because there was always a back-up breaker in the power station. In the power station they always kept a very good margin in hand. If the design capacity came out at 200 MVA they would not think of using 250 MVA gear but would go straight to 350. The second rule was that they would de-rate the fault capacity of switchgear with age. Nobody would expect a breaker, after ten years' service, to meet the same short-circuit test conditions as when it was new.

Mr. Ashcroft was in the main control room of *QE2* when the over-voltage occurred, and he had wondered whether that fault and the earlier fault on the exciter might have been diagnosed earlier if power factor meters had been fitted. Voltage build-up relays seemed to be essential to self-excitation schemes using rectifiers, but they were dangerous devices if they did not operate properly. Where a station battery was available it could be used to initiate build-up, and this basic excitation would not increase with rising voltage; if the relay stuck, the control circuit would be able to cope. This incident did prove the wisdom of providing alternative manual control which was not always included in static excitation control systems. He said he was interested in the AVR protection scheme which was simple and worked, as well as the fact that a reasonable average setting for the hand field regulator could be pre-determined. He had installed more sophisticated proprietary AVR protection equipment which was not reliable and had had to be taken out of service.

There did appear to have been a disconcerting number of winding failures. It was now thirty years since he had left the design of electrical machines and in the intervening years countless articles on new and improved insulating materials, impregnating varnishes and impregnating procedures had been written but the number of insulation failures on test or on commissioning seemed to be as high as ever.

Mr. P. Murray-Robertson, B.Sc., S.I.Mar.E., said that his company believed that one of the main items for detailed consideration when using a high voltage system instead of one of medium voltage was the treatment of the neutral point.

Mr. Ashcroft had referred to 23 per cent line current passing through the neutral resistor. Mr. Murray-Robertson was under the impression that it was greater on the *QE2*, but nowadays in any case he would only propose say, ten amps, both because there were protection devices available and because it was desirable to make the current as small as possible to reduce fire hazards. The reason for using a high resistance earth on the system (or using an earth at all) was to reduce the over-voltages that could otherwise occur. Some investigations had been carried out by an American firm with a three-wire system; they had discovered voltages in excess of four and a half times, some even in excess of seven and a half times line voltage, and the result was the failure of a large number of machines, a situation which was clearly quite intolerable on a ship.

The answer was to earth the system, through a resistor of a value sufficient to just eliminate over-voltage without making fault currents excessive. It had been calculated that to achieve this the resistance value should equal the capacitive reactance, but this resistance value would give fault currents of less than one amp, resulting in problems with the selection of adequately sensitive earth leakage protection devices. A value of 7½ amps was being used for a high voltage system at present being built. Mr. Murray-Robertson said he would be interested to hear the author's comments on these matters and Mr. Bolton's experience with the resistance earthing as it stood on the system.

His final point on the resistor was that more than one path to earth through this resistor was desirable, because in the event of a failure in this connexion the earth circuit became open circuited and the system unearthed.

The simplicity of the system which had been described in the paper was quite apparent. However, it was unusual for a sea-going electrical engineer to be confronted with high voltage, and Mr. Murray-Robertson was interested to know if the author knew of any problems with manning, and what criteria were applied when selecting personnel. The reduction in cable sizes and equipment was also of great interest and bore out his own company's experience. The advantage of electrical drives in place of steam turbines for instance was also apparent in the light of reduced maintenance and the flexibility of the system.

Mr. A. H. Stobbs, Member of Council I.Mar.E., said that due to the methods of earthing used on *QE2* he suspected that stray currents would be present in the hull to a greater extent than in a conventional ship.

The paper recorded that oil had covered the alternator and windings. Would the author agree that the design of alternator/pedestal bearings needed some research? One point, for example, which did need some investigation was that the alternator drive from a turbine created completely different vibrations to the electric motor drive used during shop testings; and therefore much trouble was inevitable due to oil migration from pedestal bearings.

Finally, could the author say whether corrosion had occurred elsewhere in the ship than in the coolers?

Mr. J. S. Morton said that Fig. 7 showed the discrimination curves for the 3·3 kV system on *QE2*. The three outputs for the three machines could be seen and also superimposed on these curves were the settings for the alternator and bus-section circuit-breakers and also the curves for the various switch fuses that were used. The largest size of fuse was 350 amps, which was the top curve; its chances of blowing were fairly remote—only possible when three machines were connected. The fault level was less than originally planned and in fact overload relay protection had to be introduced as well as the fuse characteristic to give discrimination when in the normal running condition of two machines.

Fig. 8 showed the earth fault characteristic curves. The dotted lines were the settings for the various switch fuse circuits. The inverse time curves were for the alternator, bus-section and also the back-up protection. It had not been possible to make the alternator protection settings very low—it was in the order of about 40 or 50 amps. The reason for this was that the earth fault protection hadn't to operate on the highest circulating current from the three machines, so the minimum earth fault current setting had to be set above this value. This meant that there couldn't be very sensitive earth fault protection on the alternators themselves, but that obviously this did not apply to the feeder circuits. Had the author had any experience of the earth fault protection operating on any of the 3·3 kV circuits for which occurrence there was no explanation?

In the ship, circuit breakers could be pulled out into the fully withdrawn position on racks and rails, thus avoiding damage to the linotiled floor in front of the switchgear or the switchboard. A portable lifting carriage, manoeuvred on steel floor plates, enabled circuit breakers to be carried from one cubicle to another.

Mr. R. L. Ames said that he would like to know if any tests had been done on *QE2* to determine the effects of inrush currents when switching on the transformers. He appreciated that each transformer was a fairly small item for the high tension generator, but from the low tension side it appeared as if it might be a large item for one of the small emergency generators.

The author had mentioned that he had asked for chorded windings to reduce the third harmonic with parallel generators. As the main generators were identical machines, Mr. Ames thought that the third harmonic currents circulating would be very small anyway, and he was a little bit surprised that anyone would make generators this size without a chorded winding. He himself would not care to do so.

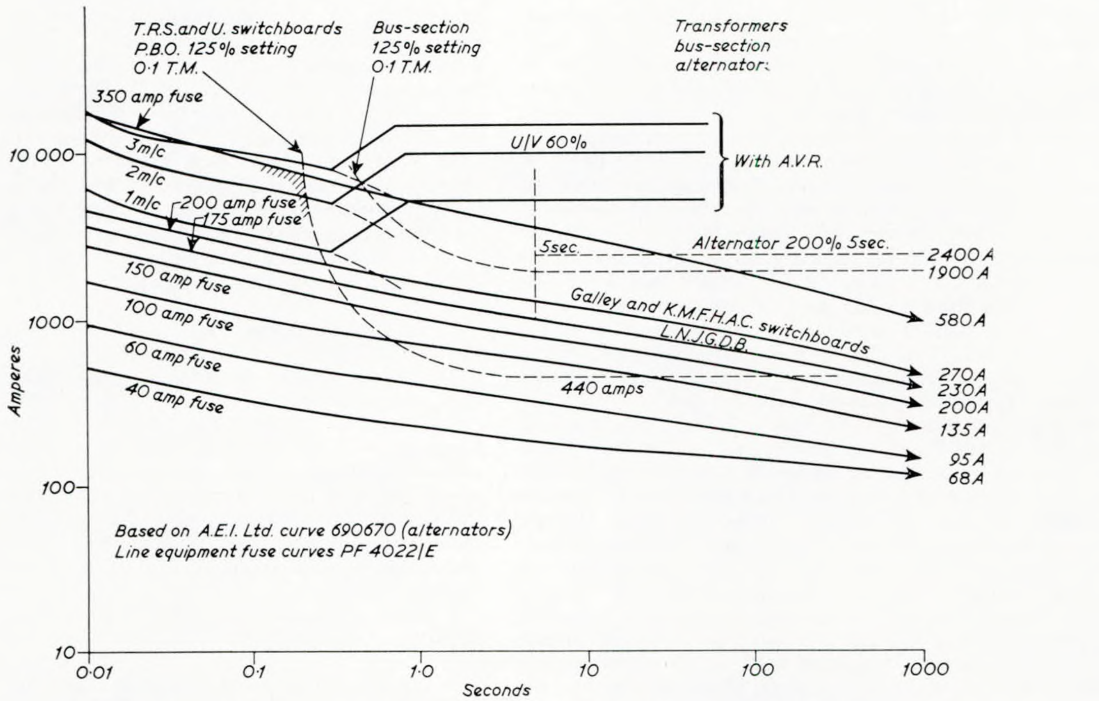



FIG. 7—*Discrimination curves for the 3·3 kV system on QE2*

In view of tests having been undertaken, what insulation levels to earth and interturn were decided on? He appreciated that Lloyds had a different approach to industrial land-based voltage requirements inasmuch as they differentiate between an earthed and unearthed neutrals, but Mr. Ames would like to know what sort of interturn and earth voltage had been agreed, particularly as some tests had been done. These appeared to be at a very low value, because if he were searching for a possible weakness in interturn insulation he would be very surprised if it failed at twice voltage; he would expect something more like ten times nominal volts. But it might not have been possible to test the interturn voltage as many as ten times; was this so, and why had a test at twice voltage been thought satisfactory? Were any tests done on the ship to determine the order of surge voltage obtained? It was too much to ask whether any monitoring was done during the short circuit faults; that would have been ideal.

Mr. Ames could not find, in the paper, any mention of whether the generator terminal boxes were vented or not. Also,

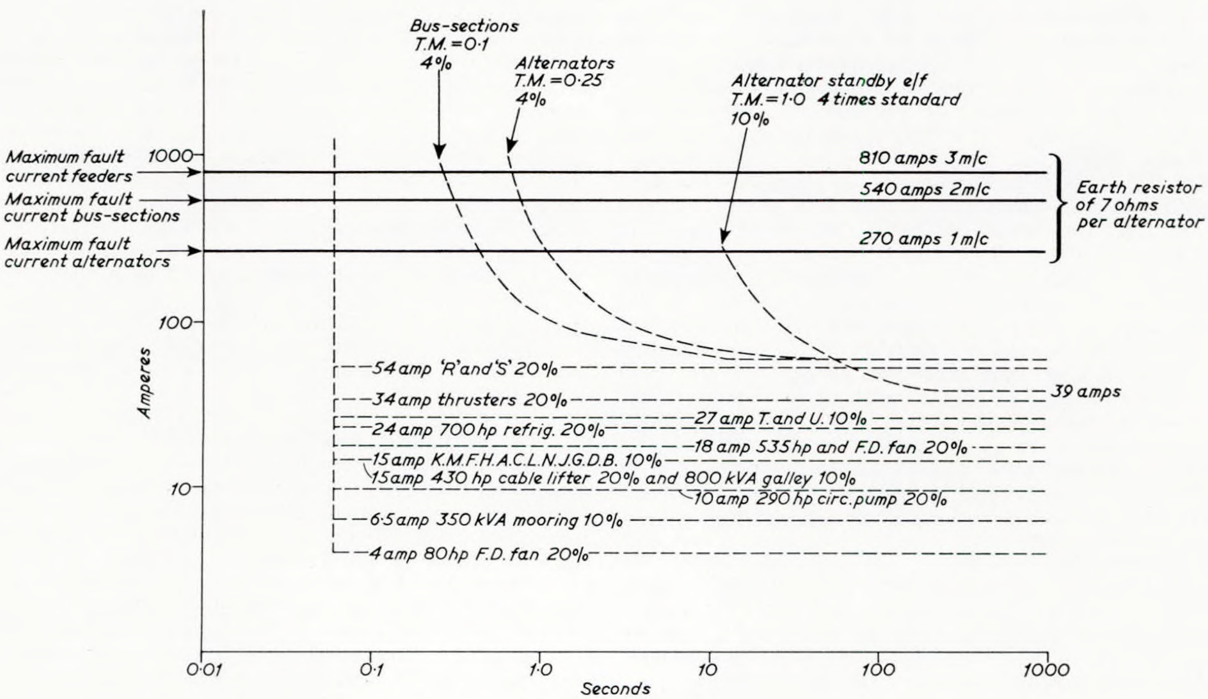



FIG. 8—*The earth fault characteristic curves*

was any earth current noticed or expected when any of the large machines or transformers were switched?

MR. R. E. PRAGER felt that as a machine designer he had come under a certain amount of criticism, particularly in relation to the reactances of the machine. When designing a machine, particularly for marine applications, he was frequently faced with conflicting requirements for the machine reactance. In order to minimize the voltage dip the transient reactances had to be kept as low as possible. On the other hand the sub-transient reactance had to be kept as high as possible in order to limit the fault level. It was important, therefore, that very early in the design stage, acceptable values of reactance were agreed between the customer, his intermediaries and the manufacturers. This unfortunately did not always happen. In this particular case the sub-transient reactance was specified to the designer as being not less than 16½ per cent. The guaranteed tolerance on the reactance was agreed would be plus or minus 15 per cent and not plus or minus 20 per cent, and this of course was considerably closer than the tolerance of plus or minus 30 per cent which is stated in BS 2949. The machine, therefore, was designed to have a reactance of 19½ per cent, plus or minus 15 per cent which gave a minimum of 16½ per cent and a maximum of 22·4 per cent. The test reactance was 22 per cent, within the tolerance of plus or minus 15 per cent. He thought that the suggestion that Mr. Bolton or his company were sold short by the manufacturers was perhaps a little unfair. The transient reactance was quoted as being 30 per cent, again with a tolerance of plus or minus 15 per cent, and that on test was found to be 33 per cent, which again was well within the tolerance guaranteed.

As the author had pointed out in his paper, the voltage dips obtained were acceptable and in fact within limits. The matter of winding chording had been raised by a few of the speakers. The machine was not chorded for 66⅔ which would in fact have given a minimum third harmonic. They were designed perfectly normally with a combination of chording and pole shaping to minimize the third harmonic. The problem of circulating harmonics was not particularly great but it was felt desirable to keep it to a minimum. The third harmonic was in fact about 2¾ per cent.

Looking at Fig. 2 Mr. Prager recognised the terminal box as a phase separated fault containing box, and not as stated, a phase segregated box.

Air leakage was a particularly difficult problem for manufacturers. This machine was a totally enclosed CACW machine and as such to BS specifications, was not an air-tight machine. If an air-tight machine was necessary, this had to be specified. An air-tight machine would necessarily be very much more expensive. In fact there were probably other ways of gaining the small additional advantage that could be obtained by having an air-tight machine. A CACW machine could be pressurized. Alternatively, air could be ducted into the machine, allowing leakage through the minor openings which had to exist, so that the flow of air was from the machine to the ambient and not in the other direction.

MR. J. A. WILSON said that he knew of a large 3·3 kV tanker which had been in service for five years in which the neutral was earthed through resistors capable of carrying the full load generator current because it was thought at that time that this was the only way to guarantee the earth fault protection; but he would suggest that Mr. Murray-Robertson's method of earthing a neutral through a relatively small resistance was the right one today. He certainly would not be happy with the unearthed neutral which other speakers had suggested.

At the time the tanker was designed, a survey of British and American opinion was undertaken on the question of over-voltages generated in unearthed neutral systems, and there was enough evidence and experience to cause concern.

On the subject of the main supply system, Mr. Wilson said that many users would still have a preference for a split system, and it was of interest to note that had *QE2* had two separate systems of generation, more generators would have been required, which would have roughly halved the prospective short-circuit current, possibly bringing it down to the point where 440 V systems could be considered.

He would expect a high power factor for *QE2* because of the nature of the load, but he wondered if any special attention was paid to the motors in this respect. He was of the opinion that the level of voltage dip mentioned was tolerable, and even higher dips had occurred in some liners without anyone apparently noticing them.

So far as he knew there had been very little trouble with the tankers he had mentioned earlier after five years' service—certainly no failure which could be attributed to the system voltage had occurred. Although most equipment installed was almost standard, protection relays, etc., were selected from equipment which was likely to give good service in marine conditions, and he understood they had done so over the period of service, despite a relatively high level of vibration on certain parts of the ship.

It was becoming more popular these days for design organizations to do a separate analysis of possible faults to avoid the sometimes dramatic train of events following a failure. At the same time there had been an upsurge in attention to quality control which could also help to eliminate the possibility of failures.

MR. J. RATTENBURY said it was worth remembering that at the time when there was an over-voltage fault on one machine two generators were operating in parallel. The fact that there were two generators operating in parallel resulted in a large circulating current, which meant that the high generator voltage was not quite as high as it would otherwise have been. According to Mr. Bolton's paper, the first circuit-breaker to open was the starboard bus coupler breaker. This meant that the circulating current load was lost before the generator circuit-breaker tripped. This would have produced a higher over-voltage than necessary on the starboard side of the ship.

Concerning the mean time between failure figures, these tables always tended to be very pessimistic. One reason for this was that manufacturers of components were constantly improving their devices and obtaining better figures. As MTBF tables took a long time to compile they were always out of date, and up-to-date figures were always better.

In addition some of the failures which were recorded and counted in the MTBF figures were due to the components going outside of the various tolerances the manufacturers placed on their devices. These sort of failures did not necessarily produce any harmful effect on the operation of the equipment and so far as the equipment was concerned they could be ignored.

MR. R. W. T. COLEMAN spoke about the difficulties of satisfying a purchaser in supplying air coolers. The problems invariably arose over the choice of materials, and the better the cooler the more expensive it tended to be.

There were generally three ways in which a decision about materials to be used was arrived at: first, the materials were specified by the customer; secondly, the water to be used was stated and the analysis given; and finally, the decision was left to the manufacturer. Which in the author's opinion was the most desirable of these three courses?

Mr. Coleman pointed out what he thought was a slight inaccuracy in the paper. Aluminium-brass tubes were in fact specified for the particular coolers mentioned in the paper. And the alternator did not itself suffer leakage—there was a leakage on the condenser, and an examination of the alternator revealed erosion of the tube ferrules which were changed to aluminium-bronze. It had been stated that it was thought pitting was due to contamination, because considerable amounts of estuary water had been used in these coolers.

Mr. Coleman felt that double coolers resulted in an expensive and bulky cooler and that the money would be better put to use, by using higher grade materials such as the Ministry of Defence specify, i.e. cupro-nickel, aluminium-bronze, etc. This would give a better resultant unit.

## Author's Reply

Mr. Bolton thanked the members present for supporting the reading of the paper, and the speakers for their most useful contributions. In his reply, he would deal with the questions by subject working from the generators outwards.

The small number of main generators had obviously worried several people but the decision to fit only three had not been taken lightly. It had been made against a background of many years' experience of turbo-generator operation in large passenger ships and in accordance with the basic principle that the ship had been built to carry passengers at a profit.

This had meant making maximum space available for accommodation and reducing hardware to a minimum consistent with reliability. The author agreed that with two units defective, all services could no longer be supplied, but, nevertheless, there was still adequate power, especially with the assistance of the Diesel generators, to get the passengers home in safety and in reasonable comfort.

Mr. Bolton seconded Mr. Nicholas' point about two generators in parallel being the worst combination, but as it could occur in most ships no matter how many machines were fitted, the consequences still had to be considered and appropriate protection fitted.

Mr. Crick had asked about a split bus medium voltage system. This had not been considered seriously because:

1) larger motors were too big for medium voltage;
2) two separate systems were more complex and would require surveillance separately;
3) switchgear would be at its largest and most expensive;
4) at least six generators required;
5) extra space requirements too great;
6) larger staff needed.

A combined HV/MV system employing three generators at HV and two at MV had at one stage been considered. This had the advantages of flexibility and the need for a minimum number of power transformers, but it was more complex and costly than the system finally adopted.

Power equipment costs and sizes had been questioned by Mr. Adams and Mr. Bolton commented that his conclusions had been correct for the smaller ratings of machines, but taken overall, including cabling, the statements in the paper were correct for the plant as a whole. As far as switchgear was concerned, the matter was never in doubt, and the deciding factor here had been the adoption of the high voltage switch-fuse. The latter incidentally, employed a switch of the finger and cluster pattern and was not a contactor.

Alternator design had received attention from several speakers and there had been sufficient difference of opinion upon such matters as chording to make any further comment by the author superfluous.

Regarding alternator subtransient reactance, Mr. Prager's correction to the tolerance figure quoted in the paper was confirmed as correct. Especially since the earlier figure led to some rather critical remarks in the discussion, an apology for this error was offered by the author.

Mr. Bolton did, however, take Mr. Prager to task about the machine enclosure. The main alternators were specified as CACW for two well known and widely accepted reasons, namely, to avoid the liberation of excessive heat into the machinery space and to avoid the need for frequent cleaning. With most machines of this type, migration of bearing oil into the machine was prevented by careful design, and emergency cooling doors, removable casings, etc., were fitted with effective sealing arrangments.

Mr. Coleman had said that aluminium-brass coolers were specified and that the alternator itself did not suffer leakage. The author agreed with the former statement, but not the latter; the leakages had occurred as described in the paper and they were in addition to the condenser leakages.

In reply to Mr. Ames' alternator question, the terminal boxes were not vented but were of the fault containment type. Earth current swings of small magnitude had occurred momentarily during synchronizing.

Mr. Adams asked about parallel running of the main with the emergency alternators. The answer to this was that the governor and the AVR characteristics had been selected so that stable running was obtained at moderate emergency alternator powers, which was all that was required.

The AVR over-voltage trouble had generated wide interest and Mr. Gray had suggested that there could be a case for two AVRs per machine. In effect, an equivalent facility was provided, because there were four AVRs for whichever pair of alternators it was decided to run. During changeover of machines, the hand control could be used, until the changeover links specially fitted for the purpose could be changed over. It would, in fact, be no hardship for the ship to be brought home with only one AVR operational, adjustments to the excitation of the hand controlled machine being made from time to time by the watchkeeper.

In reply to Mr. Ashcroft, it was doubtful if the provision of power factor meters would have ensured early diagnosis of the AVR failures, as the component responsible would have changed to the failure state practically instantaneously. For exciter faults, detection would in many cases be made by routine examination of the exciter field ammeters and voltmeters.

Mr. Gray had asked about power equipment failure due to induced overvoltage transients and he mentioned The Steel Company of Wales. It was, in fact, The Steel Company of Wales which had given valuable advice to the author, based upon the knowledge of insulation failures of several large machines simultaneously.

Referring to other protection problems, the author thanked Mr. Morton for his contribution. The 350 amp high voltage fuses had, of course, been specified before the alternator test results were known. The prospective currents would have been much greater if the alternator reactance had turned out to be at the lower design tolerance limit. In answer to Mr. Morton's question, the author could not recall any spurious earth fault protection tripping.

Mr. Nicholas had referred to the danger of both machines being tripped if one lost its excitation. Field failure protection was fitted to cope with this, and this was indicated, as was biased differential protection, in Fig. 4 of the paper. Discriminative overcurrent protection was fitted to the bus-section circuit-breakers between pairs of alternators and this would also guard against the tripping of both machines in the event of heavy current swings due to excitation trouble.

Upon potential damage at the seat of a fault, Mr. Adams had said that he would expect it to be the same for an HV system as for an MV system. The author agreed that this could be correct as far as electrical power release was concerned, but he differed with Mr. Adams in respect of electromechanical forces. These varied as the square of the fault current and so were potentially much greater in a medium voltage system.

In reply to Mr. Murray-Robertson who had wished to know how the earthing resistor values had been derived, Mr. Bolton said that reliability achieved through the use of tried and tested robust protective gear, plus minimization of transient overvoltages had been the main criteria. He had not, to date, received any adverse reports about the system.

Mr. Ames had enquired about the high voltage transformers and the tests applied. The author said that as far as magnetizing inrush currents were concerned, the only tests carried out on board had been operational and no readings had been taken. The peaks would not be expected to last for more than a few cycles and on the medium voltage side they would be attenuated considerably by the long cable runs between the transformers and the emergency generators. The interturn and high voltage tests agreed for the transformers when new and after repair were generally in accordance with British Standard Recommendations and were as follow:

| | *When new* | *After repair* |
|---|---|---|
| HV to LV and E for 60 seconds | 16·0 kV | 8·0 kV |
| LV to HV and E for 60 seconds | 2·5 kV | 2·5 kV |
| Induced voltage at FL temperature | twice normal at 200 Hz | |

Mr. Ames had suggested that the induced voltage test for the interturn insulation should be at ten times nominal volts, but this conflicted with BS 3399 which said that induced and high voltage tests on a repaired transformer should be at 75 per cent of the original test voltage. It would certainly seem unfair, said Mr. Bolton, to subject the high voltage winding to an induced voltage of ten times normal and it was doubtful if many transformer manufacturers would agree to it.

In answer to Mr. Adams on transformer costs, Mr. Bolton considered the cost advantage lay with the air insulated units. Oil-filled transformers would have required high voltage and low voltage terminal boxes plus costly and space consuming purpose-made oil catchment facilities to cater for transformer leakage. The method of installation in cells was in fact cheaper, because, in machinery spaces, transformer rooms would have been required anyway and in accommodation switchboard rooms the cells simply consisted of expanded metal barriers.

Several contributors had been interested in the reasons for choosing a frequency of 60 Hz and a voltage of 415/240. Mr. Bolton said that the question of spares, as raised by Mr. Gray, had received particular attention, because it was hoped that the ship would remain in service as long as her predecessors. For this reason a spare motor of every size had been ordered for important services and most of them were cocooned onboard ready for immediate service. This was not as expensive as it sounded because, with very few exceptions, all machines were from the same manufacturer, who had co-operated very patiently in reducing the number of machine sizes to a minimum.

Messrs. Crick and Adams had referred to the point of standardization upon off-the-shelf lighting control gear. This was very valid and it had been one of the reasons for choosing 240 V 60 Hz since it allowed the use of re-labelled standard 200/220 V 50 Hz equipment, which was expected to be available in Europe for many years to come.

Reference had been made by Mr. Adams to one solution to fluorescent tube ghosting—that of using double pole switches. In straightforward installations this did provide an answer, but not in *QE 2* where two-way and intermediate switching was required in most of the passenger cabins. Double pole switches meeting this need simply did not exist.

For the three-phase, four-wire system, Mr. Crick had enquired about the parameters used in deciding the number of 13 amp fused outlets. The basic one was that of safety, and it had been arranged that all of the 13 amp sockets in each cabin, normally not more than four, should be supplied via a 13 amp fused spur unit, the fuse of which, automatically kept earth fault and short-circuit currents to a low fire risk value. The U.S. socket circuits had been protected in a similar manner. Thus, a fault in one cabin would not affect another and furthermore it would be very easy to locate and re-fuse after repair.

Mr. Crick had also asked about the supplies to essential circuits on the bridge. These were exceptional and were obtained from separate transformers with unearthed neutral in one of the switchboard rooms.

In regard to stray currents, which could perhaps be present due to the methods of earthing used, Mr. Bolton replied to Mr. Stobbs that there had been no evidence of corrosion troubles. On the contrary, with the earthed neutral systems employed, all currents of any consequence would be interrupted at an early stage by protective gear or fuses.

Messrs. Victory, Gray and Murray-Robertson had shown interest in maintenance staff and safety. The author still remained unconvinced about the practical application of a "permit-to-work" system on board a ship of this type. Mr. Victory's remarks about being killed nicely and cleanly at 415 V were absolutely right, but they were also applicable at 240 V and the mind boggled at the inspection time and paper work which would be involved in the dozens of small electrical jobs tackled every day by the electrical staff. It did not seem a practical proposition.

Answering Mr. Victory's point about high voltage cable maintenance, the author said that no cable surface resistance tests had as yet been carried out. There should be no extensive need for these, as most such cables were protected from dirt and situated in areas which would not be painted.

As for maintenance of high voltage switchgear (Mr. Gray's point) arrangements had initially been made for a complete annual inspection and overhaul including secondary injection tests, by the makers. It seemed likely that this would continue.

Mr. Gray had also asked about noise pick-up from the power system into the control, signal and communication circuits. Mr. Bolton replied that careful screening and earthing, with suppression local to the radio receiving room, had dealt with most of it. During trials, extra attention had had to be paid to the thyristor controlled fluorescent light dimming.

# Related Abstracts

### Polyphase Shaft Generator with Line-commutated Invertor

An account is given of the operating principles of Siemens shaft-generator systems incorporating an a.c./d.c./a.c. static conversion scheme. It is shown that reactive power must be fed to the invertor; it is drawn from the ship's generators when declutched from their engines and running as synchronous idlers, or from a special machine. The arrangements for maintaining constant voltage and frequency are noted.

A short description is given of the 1250 kW plants of this kind installed in the refrigerated ships of the *Polar Ecuador* class. Extensive test data and experience have been acquired with these plants, from a prototype assembled in the works and from the ships at sea. The most significant results are illustrated by typical oscillograms with explanatory text; these relate to the behaviour of the system as affected by load surges, rapidly changing rev/min and short-circuits (which were systematically studied on the prototype). The normal voltage waveform obtained from the inverter (with characteristic commutation dips), and measurements (at the inverter output) of radio-frequency interference potentials, are also shown. In all these respects, the system appears to be satisfactory. It is noted that, in the *Polar Ecuador*, shaft-generator operation was carried on during a Force 10 gale.—*Meinhardt, W., Neubauten (New Ships), January 1970, Vol. 15, pp. 6–9; Journal of Abstracts, The British Ship Research Association, May 1970, Vol. 25, Abstract no. 29 351.*

### Latest French Research Ship

The *Triton* represents a new concept in the oceanological field by combining exploration and research with deep diving and submarine rescue.

She is not large, being only 243 ft long and drawing 12 ft. She displaces 1490 tons and carries a crew of four officers and 44 men plus five officer-divers and 12 rating divers.

Her propulsion consists of two Voith Schneider cycloidal propulsion units, one mounted aft and the other right forward. The after one is driven by two 660 kW Diesel engines and the forward one by two 400 kW electric motors. Her maximum speed is 13 knots and she has a range of 4000 n miles.

She is fitted for dynamic positioning which functions by lowering a sinker on a wire onto the bottom and then measuring the angle which the wire subtends to the vertical. When the angle is zero the ship is directly over the sinker.

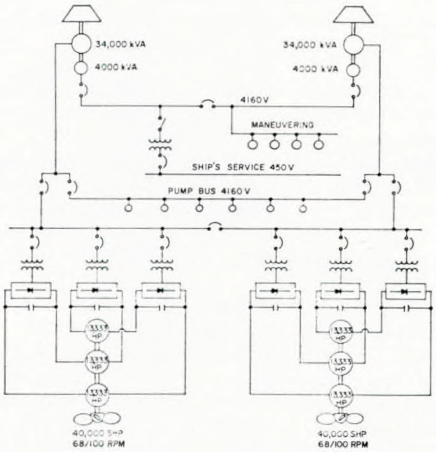
To operate the positioning mechanism there is a joystick on the bridge and all the operator has to do is to look into a display, rather like a radar PPI, which shows the position of the sinker at its centre, with a small circular marker showing the position of the ship. By operating the joystick, and thus the propulsion units, the operator can move the ship forwards or sideways until the ship marker coincides with the sinker marker. Alternatively the whole system can be computer controlled.

For deep diving work *Triton* carries a submersible diving chamber (SDC) capable of holding three men and fitted with the normal form of diver lock-out.—*Hydrospace, April 1971, Vol. 4, p. 50.*

### Electrical Transmission Systems for Arctic Tankers

The 1968 discovery of oil on the north slope of Alaska, Prudhoe Bay area, brings the problem of how to get this estimated 40 billion barrels of oil to the foreign and domestic markets.

One of several possible ways is the use of ice-breaking tankers to sail direct from the north slope through the arctic ice to these East Coast markets. Last summer's historic voyage of the 120 000 dwt tanker *Manhattan* through the Northwest Passage to Prudhoe Bay has proved the feasibility of such a task.




*Schematic of a.c. rectified d.c. system with triple-armature motors fed through rectifiers from a common a.c. bus line*

A propulsion plant for this application must have characteristics not normally required for large cargo ships and tankers.

Four different electric transmission systems were considered for this application. These transmission systems are:

1) a.c.—rectified d.c.;
2) a.c.—variable frequency;
3) a.c.—cycloconverter;
4) d.c.—acyclic.

*A.c.—rectified d.c.*

This system comprises one or more high-speed alternator sets, a silicon rectifier, and a d.c. motor, directly connected to the propeller shaft. The voltage supplied to the d.c. motor must be compatible with good machine design and ranges from 500 for the lower horsepower ratings to 1200 V at the highest horsepowers. However, present ABS rules limit the d.c. voltage to earth to 1000 V. The a.c. generators, depending upon size, can supply power directly to the silicon rectifiers, or the a.c. voltage can be transformed down to the correct level for the d.c. machine. Transformers are usually required for plants where the rating per generator is above 10 000 hp. The rectifier can be either six-phase or 12-phase. The 12-phase is preferred for larger motor ratings, because of the lower d.c. ripple.

It was decided that at this time only the a.c.-rectified d.c. and the variable frequency a.c. systems would be proposed for this application. This was not because of any shortcoming in the theoretical performance of the acyclic or cycloconverter, but because of the developmental nature of these plants, in the field of ship propulsion.

The system illustrated in the diagram is a twin-shaft gas or steam turbine plant rated 36 000 hp per shaft in open water (80°F water) and 40 000 hp per shaft for ice operation (40°F water). Each propeller is driven by a 40 000 hp, direct connected, triple armature d.c. motor. Current is supplied by alternators and converted to d.c. by transformer-rectifier units. Each transformer-rectifier unit supplies power to one d.c. motor armature. The two shaft systems are interconnected so that one power source can be used to supply power to both shafts, and switchgear is provided so that any transformer-rectifier unit can be removed or added to the system without reducing power.

The transformer-rectifier units and d.c. motor armatures are connected in series so that the most desirable speed-torque characteristics are obtained and the maximum d.c. fault current is limited by the resistance of the d.c. loop. Since the prime movers operate at constant speed, they are also used to provide the ship service power. A 4000 kVA ship's service generator is driven by each propulsion turbine-generator set. These generators provide auxiliary power for manoeuvring in ice, plus power for the propulsion auxiliaries and ship's hotel loads. The only other power generating equipment required is a port or auxiliary set rated about 1500 kW and an emergency set rated about 150 kW.—*Koch, R. L., Marine Engineer and Naval Architect, October 1970, Vol. 93, pp. 451–457.*

#### First Ship with Jungner All-electric Engine/c.p. Propeller Control

The 7150 dwt *Maria Gorthon,* first of four automated ships designed for unit cargoes such as cellulose, fruit, and containers, has been completed by the Rauma shipyard of Hollming OY. Built for Gorthon Lines *Maria Gorthon* is powered by a B and W 10U45HU medium-speed engine and is claimed to be the world's first ship fitted with all-electric bridge control for the engine and c.p. propeller mechanism.

Principal particulars are :

| | |
|---|---|
| Length, o.a. ... ... ... | 103·5 m |
| Length, b.p. ... ... ... | 102·5 m |
| Breadth, moulded ... ... | 16·7 m |
| Depth to shelterdeck ... ... | 10·5 m |
| Depth to 'tweendeck ... ... | 6·0 m |
| Draught (closed shelterdeck) ... | 7·9 m |
| Service speed ... ... ... | 15 knots |
| Accommodation ... ... ... | 29 persons |

A flexible coupling and reduction gear connect the 6000 bhp B and W 10U43HU main engine to a Liaaen c.p. propeller, the propeller shaft turning at 177 rev/min with an engine speed of 450 rev/min. A generator is driven at 1200 rev/min from the gearbox to provide main electrical supplies.

Unmanned operation in the engine-room for up to 16 h/day is permitted, the main engine and propeller being controlled by a Jungner FAMP-2 system. This all-electric equipment offers remote control from the bridge through a fixed programme giving optimum revolutions and pitch adjustment.

The Jungner FAMP-2 concept features inductive servo components throughout the system, the heart of which is a central control unit with all-electronic logic circuits incorporating micro-electronics. Among other things this central unit features a "programmed electronic combination" for computing the best combination of revolutions and pitch. Modular construction allows flexibility for owners' requirements.—*The Motor Ship, May 1971, Vol. 42, pp. 53–54.*

#### Electric Disc Brakes

In the past five years, marine designers have begun to realize that they have available to them electric disc brakes that are smaller, more compact, easier to mount and have a lower $WK^2$ of rotating parts.

$WK^2$ (the flywheel effect) is the moment of inertia of a rotating solid body: the weight of the body multiplied by the radius of gyration squared. $WK^2$ is usually expressed in pounds-feet squared.

An important factor is that disc brakes come completely enclosed in their own housing and can mount directly to the C-flange end bell of an electric motor. They can also be adapted for bulkhead or deck mounting separate from the motor if this is required. In all cases, they can be completely enclosed so that sea water and moisture will not create problems. They come equipped with heaters, drain plugs and corrosion-resistant material, all of which reduce maintenance problems and offer greater lengths of service between maintenance jobs.

The unitized construction of the modern disc brake contains the entire operating mechanism on a support plate so that maintenance can be performed in a matter of a few minutes. A complete disassembly of the brake to replace any part, including the friction elements, can be accomplished through the use of a screwdriver, normally in no more than ten minutes.

Disc brakes are available for both alternating and direct current operation, utilizing a solenoid in the release mechanism that limits the number of lead wires to two. The a.c. brakes are available in torque ratings of up to 1000 lb/ft torque, and special d.c. disc brakes can be made for torque ratings up to 150 000 lb/ft.

Today, disc brakes are being furnished for all shipboard applications, including cargo winches, at-sea provisioning winches and warping capstans.—*Miller, R. M., Marine Engineering/Log, June 1970, Vol. 75, pp. 40–41.*

#### Integrated Marine a.c./d.c. Electric-power System

This is a discussion of the application of an integrated a.c./d.c. electric-power system as a means of combining the advantages of alternating current for the general shipboard electric-power system, and direct current for electric-motor supply. The advantages of this system are particularly evident in cases where maximum power consumptions for the above needs are not coincident in time.

The possibility of electric-power redistribution makes feasible a reduction in the overall installed power of generators at the initial total installed-power level of consumers and an improvement in the economy of a ship's power plant. However, the setting up of an a.c./d.c. system on the basis of conventional synchronous generators and static rectifiers is seen as posing a problem. In this respect, ample opportunities are opened up by the employment of paired synchronous generators, which were first used on the British tanker *Auris.*

The use of paired synchronous generators in conjunction with uncontrolled rectifying facilities connected in parallel is first considered. Regulation of the rotational speed of the propulsion motor in this case is effected through an alteration in the voltage of the second generator. This control method is said to be unacceptable on ships fitted with multiple propulsion units and other heavy consumers making increased demands on control characteristics. *Borisov A. L., Sudostroenie, December, 1970, Vol. 12, pp. 38-40; Journal of Abstracts, BSRA, Vol. 29, May 1971, Abstract No. 30,882 (in Russian).*

#### The Influence of Thyristor Converters on Supply Networks

A thyristor converter, when connected to an electrical network, loads this in a manner that differs from conventional loads such as motors and lighting circuits. This difference is primarily associated with the following two characteristics of such converters:

1) high reactive power consumption in conjunction with a low direct voltage output, which results in, for example, voltage drops at the feeding point;
2) harmonic currents arising owing to the non-linear characteristic of the converter.

This article briefly describes these characteristics. Some methods of reducing their influence on the supply network and sensitive loads connected to this are also discussed. *Ivner S., ASEA Journal, 1971, Vol. 44, No. 2, pp. 37–40,*

#### Japanese Switchgear

The very large crude oil-carrying tanker and the high-speed container ship both involve propelling machinery of exceptionally high unit powers. As an extension of this trend the Japanese Ministry of Transportation is sponsoring an investigation of the power plant for a 500 000 dwt tanker which would be propelled by two 33 000 shp steam turbines and boilers with a total evaporation of 2 x 100 t/h. This ship would have commensurate auxiliaries including two 3200 kW turbo-alternators and 1650/900 kW forced-draught fans.

For such an installation incorporating alternators exceeding

2500 kVA and a.c. motors of over 350 kW output, Nishishiba Denki recommend the employment of a high voltage power supply system.

By employing high voltage power supply to otherwise costly and heavy rotating machines they can be designed more economically and without the need to use multiple cable connexions and abnormally large terminal boxes.

Nishishiba Denki, have extensive experience in the use of high-voltage power supply systems in the marine environment. These have been installed in tankers and bulk-carriers as well as on dredgers and other vessels which operate under conditions more severe than those of normal merchant ships. For such applications Nishishiba have developed vacuum circuit breakers and vacuum contactors for use instead of the conventional oil-immersed, magneblast and air circuit breakers.

**Panels in service**

| Ship | Owner | Type | Application |
|---|---|---|---|
| *Suzuka Maru* | Taikyo Tanker Co. | 150 000 dwt motor tanker | Vacuum circuit-breakers |
| *Nitta Maru* | Terukuni Kaiun | 56 000 dwt bulk-carrier | Vacuum contactors |

**Typical data for vacuum contact-breaker panel**

| | *Oct. 1969* | *Sept. 1970* |
|---|---|---|
| 1. Temperature, °C | 30 | 30 |
| 2. Relative humidity, per cent | 75 | 60 |
| 3. Total hours in service | 0 | 4121 |
| 4. Total switching operations | 0 | 631 |
| 5. Insulation resistance, megohms | 1000 | 2000 |

Note: The temperature range, recorded automatically, was from 18°C to 48°C and the humidity was from 40 per cent to 85 per cent RH. *Marine Engineer and Naval Architect, June 1971, Vol. 94, pp. 240–241.*

### Determination of the Optimum Output of a Marine Electric Power Plant

A modern ship has a large number of electric-power consumers whose operating time and power requirements depend on many factors. To set up a marine electric power plant (MEPP) that satisfies any peak loadings is clearly not always expedient.

This paper is proposed to discuss the alternative power shortage probability problem. An economic analysis of this problem is associated with the determination of optimum MEPP output (a definition of what is meant by 'optimum' is given). More specifically, the paper seeks to investigate, using as an example a large stern freezer trawler, the relationship between relative ship first costs and the power of MEPP composed of DGR 200/500-2 Diesel generators (DG). Calculation is performed for four MEPP variants consisting respectively of three, four, five, and six DG. The power probability density function is determined using a statistical test method (shown graphically) realised on a Razdan-2 electronic digital computer.

A formula is given for calculating the reduction in annual productivity due to a power shortage, discussion subsequently focusing on the probability of good DG working order (the possibility of forecasting gradual unit failure) and the time required to effect preventive maintenance. This is shown in a table. This productivity drop is further seen to entail an increase in relative ship first costs.

Also considered are construction, repair, and maintenance costs, fuel and lubrication economy, and weight. Expressions are given for determining the influence of construction costs and repair costs on relative first costs. There are further formulae for calculating the mean hourly fuel consumption and oil consumption. *Apollinariyev V. I., Dorovskikh R. S. and others. Sudostroenie, January, 1971, pp. 40–41 (in Russian). Journal of Abstracts, BSRA, June, 1971, Vol. 26, Abstract No. 30 972.*

### Fluctuations in the Generator Units of Marine Electric-power Plants

During the putting into service of new marine Diesel alternators, there occurs in some cases the periodic oscillation of rotors. At a constant loading, the generator's rotor fails to keep its synchronous position, as a result of which there occurs exchange electric-power fluctuations during the parallel operation of units. As experience shows, fluctuations of speed of rotation and frequency account for around 0·5–0·8 per cent, and of voltage 1–1·5 per cent. Tests show that exchange power fluctuations increase when there is a decrease in loading. When operating conditions are close to idling, their value becomes commensurate with the power usefully generated. This leads to increased losses and the reduced efficiency of the unit.

The authors adduce three reasons for the occurrence of these fluctuations: (a) non-uniformity of primary-engine torque; (b) an irrational relationship between the parameters of the engine, alternator, and their speed and voltage regulators; and (c) the presence of dead zones in regulators, backlashes, arresting devices in the mechanical transmission, and other non-linearities. *Kukharenko N. and Meleshkin G., Morskoi Flot, December 1970, Vol. 12, p. 34; (in Russian), Journal of Abstracts, BSRA, March 1971, Vol. 26, Abstract No. 30 715.*

### Determination of the Installed Power of a Marine Electric Power Plant on the Basis of a Power Balance

As a result of a study of a number of electric power plants installed in various ships, it was found feasible to calculate (using statistical methods) some parameters essential to the determination of a ship's electric-power balance. Among these were total electrification coefficient, partial electrification coefficient, power coefficient, and load coefficient. Using these factors, a method of calculating the overall installed power of a ship's plant is presented.

The paper is divided into the following principal sections:

1) choice of current type and voltage;
2) structure of marine electric-power plant loading;
3) ship electric-power balance;
4) compilation of electric-power balance.

There is a table showing the loadings of electric-power plants in tankers (with deadweights ranging between 19 300 and 79 600 tons and having propulsive powers between 7000 and 24 100 hp) according to groups of consumers. *Cisic M., Brodogradnja, No. 7, 1970, Vol. 21, pp. 416–425 (in Serbo-Croat). Journal of Abstracts, BSRA, June 1971, Vol. 26, Abstract No. 30 973.*

### Problems of Investment Economics in Marine Power Plants

Various extents of decentralized distribution of electric energy onboard ships are analyzed and compared to centralized distribution. The relations are determined between the components of the total price of a switchboard. It is demonstrated that savings due to optimum distribution of electric energy were obtained without worsening the operational properties of the ship's power plant. Further investments aiming at an optimum distribution of electric energy onboard ships are suggested. *Szczerba S., Kramarz W. and Bialek R., Polish Technical and Economic Abstracts, No. 1, 1971, p. 82. Budownictwo Okretowe, No. 9, 1970, pp. 291-294 (in Polish).*

### Automatic Control Onboard Ships

Some thoughts on the necessity for automation onboard ships are followed by a description of the DP 260 monitoring, logging and control system, as used by Brown Boveri for some considerable time. Experience has confirmed the reliability of this system as well as means of expanding it for future developments. *Wunderlin V., Brown Boveri Review, April/May 1971, Vol. 58, pp. 184–189.*