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COMMISSIONING AND OPERATIONAL EXPERIENCE OF 3·3kV ELECTRICAL SYSTEMS ON ESSO PETROLEUM PRODUCTS TANKERS

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3300 volt generation and distribution systems were installed on three Esso Petroleum vessels **Esso Mersey, Esso Clyde and Esso Severn.** These 20000 dwt products tankers now have a total of nine operational years, and experience of the plant and systems will be of interest to those involved in the design and selection of high voltage system equipment for ships, or other marine applications in the future. The basic design of the limited 3·3kV system and the equipment selected has previously been described, and this paper concentrates upon the commissioning and operational aspects, based upon operational experience of both the operator and the builder, and compares this experience with the original design intent. All three vessels have attained high orders of availability maintaining regular sailing and averaging about 15 hours out of service in their first year of operation.

INTRODUCTION

The three vessels **Esso Mersey, Esso Clyde and Esso Severn** provide useful data regarding the operation of high voltage equipment, for there are few ships where the complete cargo is pumped ashore every four days (on average) and where there is as frequent manoeuvring in and out of port.

Also because the ships are classed as coastal vessels, there has been frequent contact between the ships and the builders, extending outside the usual scope of a 12 month guarantee period.

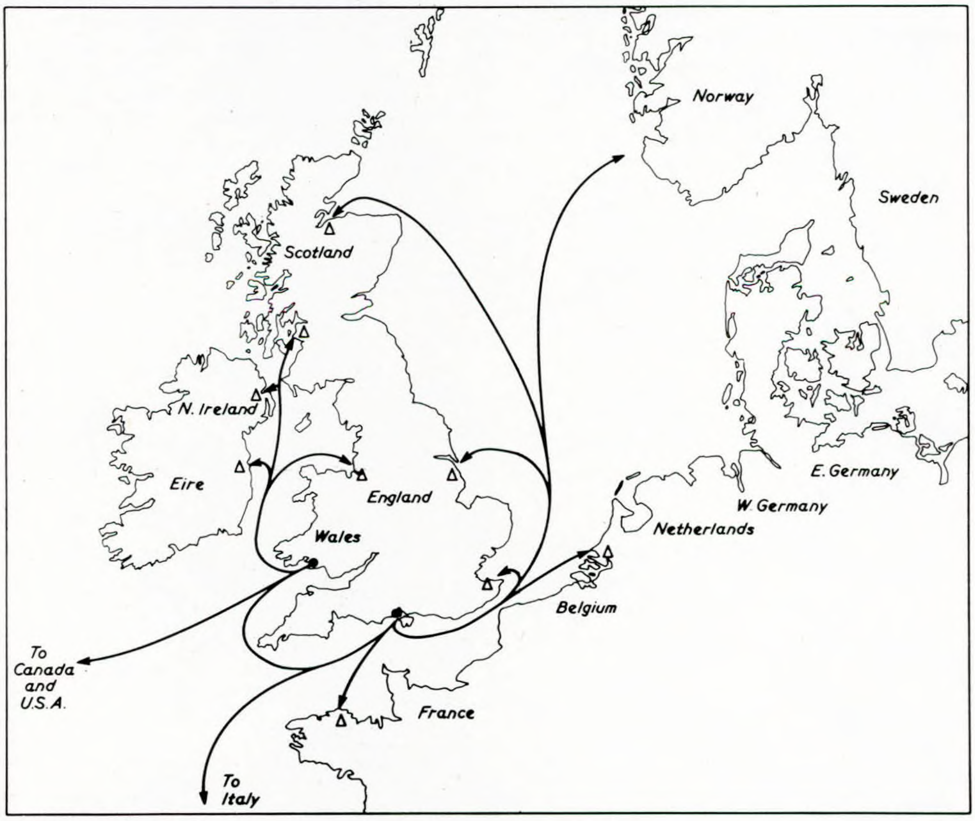

Fig 1—*Distribution routes*

* Cammell Laird Shipbuilders Ltd.
† Esso Petroleum Co. Ltd.

Some of the equipments used in the 3·3kV system are "firsts" in the marine field:

a) use of vacuum contactors;
b) use of high impedance neutral earthing;
c) use of electronic earth leakage unit for 3·3kV motor feeders operating at 250 MA;
d) use of main engine driven alternators rated at 2·4 MW;
e) 3·3kV cables on a tanker foredeck.

This paper discusses the commissioning and operational experience of the high voltage system and equipment and some items of the 440 volt system equipment where these impinge upon the operation of the high voltage system.

The aim of the paper is to outline the system, the operational experience to date and produce constructive ideas which will be of general interest to the marine industry, especially to owners who may require to consider applying similar systems or equipment to ships in the future.

THE SHIPS

The principal dimensions of the three vessels built for Esso Petroleum are given in Table I.

TABLE I—PRINCIPAL DIMENSION AND FEATURES

Length overall	166·50m
Breadth moulded	22·80m
Depth moulded	11·30m
Design draught	9·18m
Tonnage	20·250 dwt
Service speed	15·5 knots
Main propulsion	2 Crossley Pielstick 12PC2V developing 8030kW (10 920 bhp metric)
Cargo pumps	4 x 560 kW (750 hp)
Thrusters (bow and stern)	2 x 447 kW (600 hp)
Cargo — Clean products	— **Esso Mersey**
— Black oil products	— **Esso Clyde**
	— **Esso Severn**

These vessels entered service as follows:

		Operational times (June 1976)
Esso Mersey	June 1972	4 years
Esso Clyde	October 1972	3¾ years
Esso Severn	March 1975	1¼ years
	Total	9 years

THE SERVICE AND ROUTES

These vessels carry many grades of oil from refineries to Ports and Terminals in the U.K. and near European Ports as shown in Fig. 1. The normal routine followed by these vessels is to collect a cargo from the Fawley and Milford Haven refineries and deliver it to distribution points around the U.K.

Occasionally variations occur which necessitate the vessels

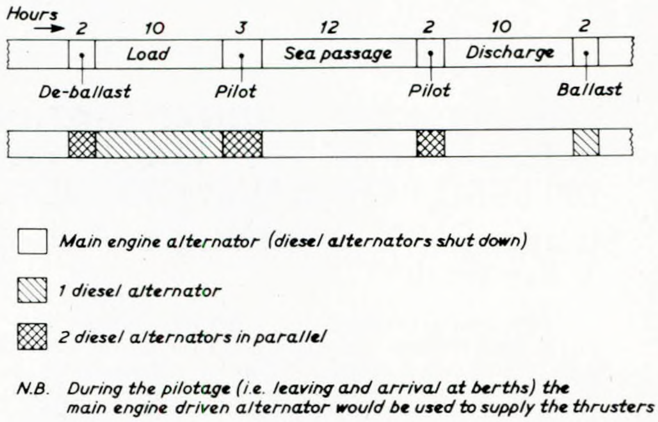

Fig 2—*Typical timescale for cargo discharge*

sailing across the Atlantic, across the North Sea to Scandinavia, or via the Mediterranean to Italy.

A typical timescale for these operations is shown in Fig. 2.

BASIC REQUIREMENTS

For maximum utilization, these vessels are required to berth quickly and discharge their cargo at the fastest possible rate consistent with the terminal's receiving capability. These vessels are designed to turn around on a single tide; this means that the vessels must pump cargo within nine hours, leaving three hours for manoeuvring berthing and unberthing.

Rapid berthing calls for a high degree of manoeuvrability and on the **Esso Mersey** class this is achieved by using bow and stern thrusters and a controllable pitch propeller. These reduce reliance on tugs at the various ports which, apart from being

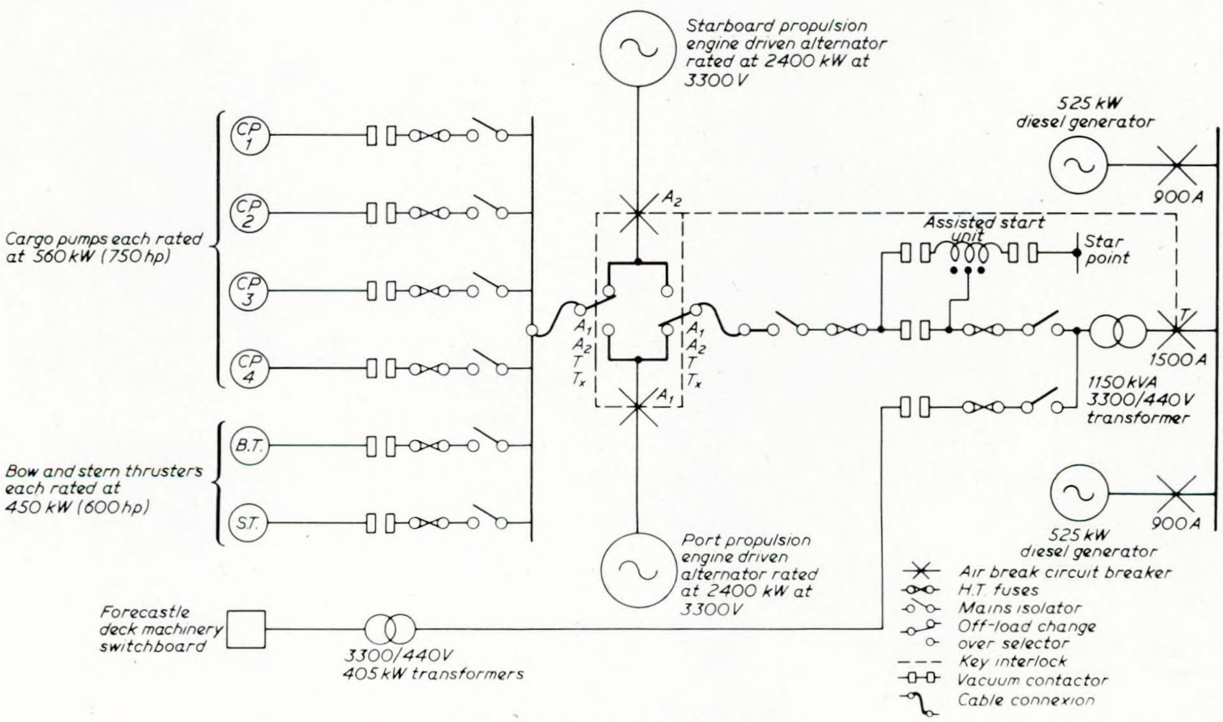

Fig 3—*Basic electric power distribution*

economically attractive, increases the reliability of the vessel for coastal trading, giving it greater independence of their activities. Also, by bringing the mooring operation within the vessel's control, there is less likelihood of incidents leading to damage and pollution.

The cargo handling installation, designed to achieve fast loading and discharging rates, comprises four high capacity, electrically driven, cargo pumps associated with remotely controlled cargo valves and the capability of one man being readily able to connect any cargo tank to any pump, subject only to the compatibility of cargoes carried.

The availability of plant to pump cargo is of paramount importance and for this reason the plant is arranged so that there are alternative power sources available to maintain pumping capability.

Reliability in meeting sailing schedules is also essential and this is enhanced by having two medium speed diesel engines which offer the opportunity of maintaining the schedule, even in the event of one engine failing.

Basic Electric Distribution System

This is shown in Fig. 3 and. as the major power users are four cargo pumps and two thrusters, a decision to use a limited 3·3kV system was taken, and was based primarly upon technical and practical considerations, although some economic advantages were gained.

The practical advantage in adopting the 3·3kV system was that the basic system was capable of meeting all foreseeable cargo pumping demands without placing restrictions on plant operation. Also because the currents involved were well below

TABLE II

PLANT	NO. AND RATING	SPECIFICATION	SUPPLIER
Engine driven alternators.	2 x 2·4 MW alternators operating at 3·3 kV, 3-phase, 60 Hz-with neutral earthed	Speed — 1800 rev/min Insulation — Class'B' Enclosure — Drip proof Bearings — sleeve/ pedestal.	GEC Machines
Diesel alternators	2 x 525 kW alternators operating at 440V, 3-phase, 60 Hz- neutral isolated.	Speed — 720 rev/min Insulation — Class 'B' Enclosure — Drip proof	English Electric
Emergency Alternator Esso Mersey and Esso Clyde	1 x 115 kW alternator operating at 440V, 3-phase, 60 Hz- neutral isolated.	Speed — 1200 rev/min Insulation — Class 'B' Enclosure — Drip proof	Dorman Diesel
Esso Severn		Speed — 1800 rev/min	Caterpillar
Cargo pump motors	4 x 560 kw (750 hp) supplied at 3·3, kV, 60 Hz.	Speed — 1720 rev/min Insulation — Class 'F' Enclosure — Closed air circuit — Air cooled	Laurence Scott Electro Motors,
Thrusters	2 x 447 kW (600 hp) supplied at 3·3 kV, 60 Hz.	Speed — 1200 rev/min Insulation — Class 'F' Enclosure — Closed Air circuit — Air cooled	Laurence Scott Electro Motors
Interconnecting transformer	1 x 1150 KVA, rated at 3·3 kV/440v, 3-phase, 60 Hz.	Insulation — Class 'C' Cooling — Natural Air Enclosure — Open	Foster Transformers
Forward deck machinery transformers	3 x 135 KVA, single phase, 3·3 kV/440V, transformer	Insulation — Class 'C' Cooling — Natural Air Enclosure — Open	Foster Transformers
3·3 kV Air breakers	2 type AM breakers, rated at 150 MVA		Whipp and Bourne
Off-load Isolators	2 x off-load isolators rated at 750 amp		G.E.C. Elliott Industrial Control Ltd.
Vacuum contactors	6 x HMC, 400W 1 x assisted start unit	Standard industrial vacuum contactors	G.E.C. Elliott Industrial Control Ltd.
440V air breakers for diesel alternators	2 type IF breakers, rated at 26MVA		Whipp and Bourne

the rating of the H.V. switchgear, it was anticipated that maintenance and spares requirements would be reduced.

A conventional 440 volt distribution system is employed for all other ship services.

Table II lists the major electrical equipment and the respective suppliers.

The two main engine-driven 3.3kV alternators are connected to separate busbars in the main switchboard by means of air circuit breakers. The direct on-line starting of the four cargo pumps and two thruster motors is carried out by the use of vacuum contactors. The starters are cabled to the main

diesel alternators with the 3·3kV and 440V systems isolated.

440V Distribution

The auxiliary generating plant rated at 2 x 525 kW alternators operates at 440V, 3-phase, 60 Hz with an isolated neutral terminated at the alternator, i.e., a conventional 440 V distribution system.

The emergency alternator rated at 115kW also operates at 440 V, 3-phase, 60 Hz, providing a supply to the emergency services in the event of a power failure of the main and auxiliary generating plant.

The emergency diesel engine has an automatic air start

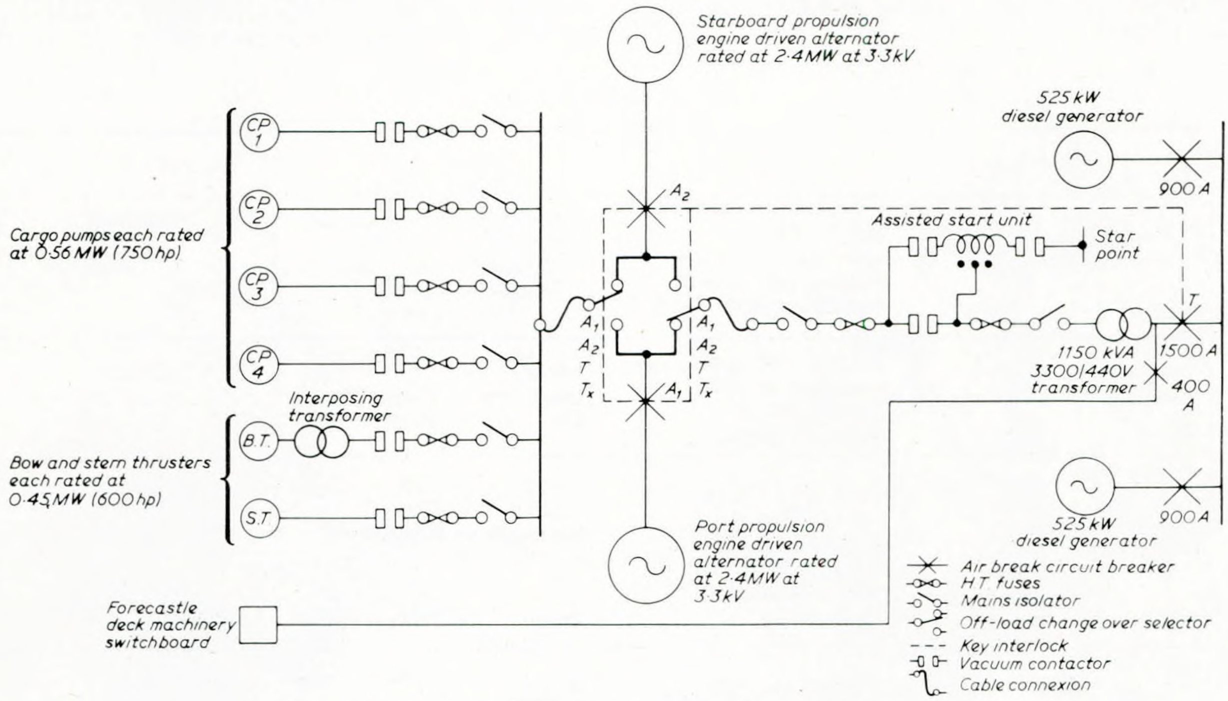

Fig 4—*Modified power distribution for* Esso Severn

switchboard and are capable of being switched to either set of 3·3kV busbars by the use of off-load changeover selectors.

To enable the ship services to be supplied from a main engine driven alternator at sea, or to enable a single cargo pump to be run from the two 440V auxiliary diesel generators in parallel, a 3·3 kV/440V transformer is provided rated at 1150kV. An auto-tranformer is provided for reduced voltage starting when supplying any one cargo pump from the diesel generators.

A changeover selector allows the transformer to be connected to either set of 3·3 kV busbars. Composite key interlocks ensure that the changeover selectors cannot be moved if the 3·3 kV busbars are energized. The same key interlock prevents access to the transformer enclosure, while switchgear is energized.

A 3·3 kV feeder to a set of three single-phase, 3·3 kV/440V transformers, located in the forecastle, provides a supply for deck machinery etc.

At the design stage, it was envisaged that a cargo tank ventilation system rated at about 186kW (250 hp) would be located here and the intent was to try to reduce large load switching on the 440 V system.

The basic 3·3kV system was slightly amended, see Fig. 4, for **"Esso Severn"**, to comply with Lloyd's Register Rules (June 1972) and an interposing transformer with an unearthed secondary was fitted in the bow thruster feeder circuit.

Also on this vessel, the forward deck machinery was supplied at 440 V from the main switchboard and the first two vessels have since been modified so that their forecastle equipment is also supplied at 440 V.

The forward deck machinery feeder is connected on the transformer side of 1500A HV/LV breaker so that, if necessary, it can be supplied from the engine driven alternators or the

facility with an alternative hydraulic method of starting.

Provision is made for the automatic connexion and disconnexion of the generator to the emergency switchboard. An independent manual closing method is also provided.

SYSTEM EARTHING

The relative merits and disadvantages of insulated or non-insulated systems for marine installations have been debated for many years. As the H.V. system is primarily intended for cargo pumping and thrusters, and as a bonus supplies the ship's electrical power requirements during sea passage, it is classed as non-essential and security of the supply does not enter into the basic considerations.

The 3·3kV system therefore utilizes a 3-phase and earthed neutral principle, and a relatively high value of resistance is used to limit fault currents to 7·5A. The earth fault relays are set at one amp which was considered consistent with system stability. The 440 V system utilizes a 3-phase and unearthed principle.

DISCRIMINATION

The power distribution system on these vessels is somewhat unusual in that there are two separate power sources and two switchboards, operating at different voltage levels and interconnected by a transformer. The systems are arranged so that power can be "exported" or "imported" to either switchboard.

In a conventional ship the power flow is usually one way, ie, from generating plant out to the user, but in these vessels power can flow in two directions. This makes the problem of discrimination and fault level at the various distribution points more complicated.

The purpose of the overcurrent discrimination is to maintain, whenever possible, services essential for ship's safety when faults occur on other parts of the system. When the 3·3kV and 440 V systems are operated separately, such discrimination can be achieved. If however, a main engine driven alternator was feeding the 440 V. switchboard, without a diesel alternator in parallel, and a short circuit occurred on a 3·3kV feeder circuit, discrimination could not always be achieved. The reason for this is the type of overload used on the 440 V breakers which operate on the under-voltage relays.

The under-voltage relays on the main engine driven alternator breakers have delayed drop-out times of the order of one second which give discrimination with the 3·3 kV feeder fuses. If the voltage dip resulting from a fault on a 3·3 kV feeder circuit is of sufficient magnitude and duration, the 440 V breakers may trip before the engine driven alternator breaker clears the faulty circuit. In normal circumstances this condition would only occure at sea in moderate weather, when the main engine driven alternator is used to supply ships services.

SYSTEM PROTECTION

The system protection equipment consisted of I.D.M.T. relays on the engine driven alternator breakers for under-and-over-frequency and under and over voltage. Current transformer operated, earth fault relays were provided in the neutral of the alternators and transformer. Differential protection of the main engine driven alternators was considered, but apart from the considerable increase in cost, the fact that the neutrals were earthed meant that comparative earth fault detection could be achieved, using a much simpler device.

GENERATING SYSTEM CONTROL

In the centre of the 440 V switchboard is a control desk on which are located the selector switches, by means of which a predetermined mode of operation of the generating plant and the required distribution may be effected.

The interlocking and sequence controls for the cargo

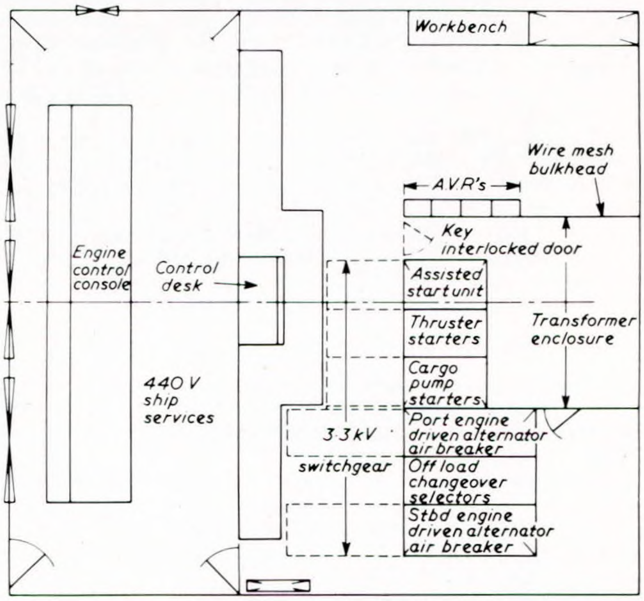

Fig 5—*Control room arrangement*

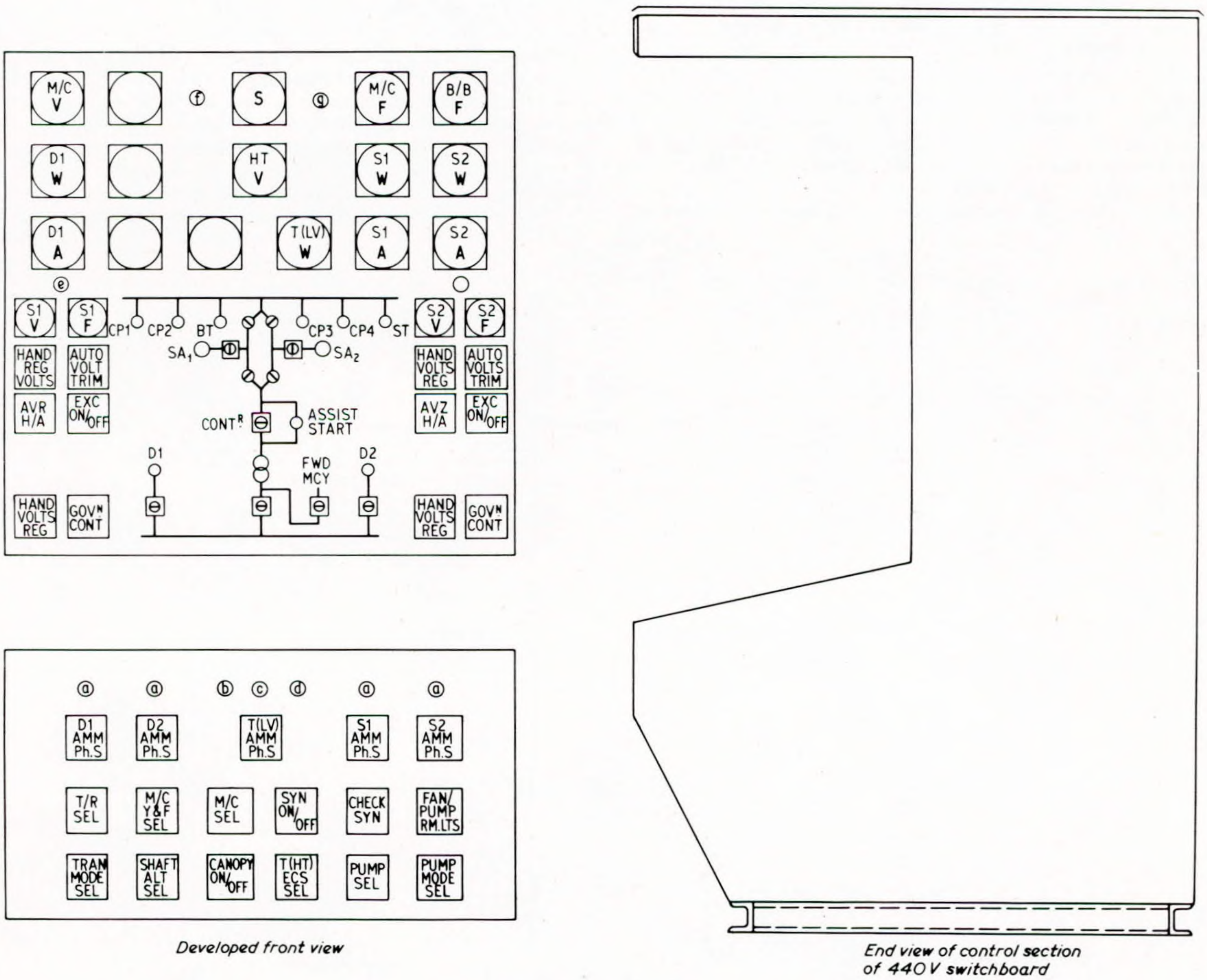

Fig 6—*Switchboard mimic*

pump and thrusters are carried out by low voltage interposing relays, situated in the rear of the mimic panel. These relays are controlled by the mode selector switches located on the control desk section.

Illuminated discrepancy switches incorporated in a mimic, sited about the control desk, show the state of each circuit breaker. Semaphore indicators show the position of the changeover selectors and indicating lamps identify which alternators are excited and the cargo pumps, or thrusters, that are operating.

The electrical control panel houses all the metering for monitoring generation and distribution, together with the synchronizing and breaker controls for these generators and alternators.

Fig. 5 shows the arrangements of the control room and the relative positions of the switchboards and the engine control console.

A drawing of the mimic panel is shown in Fig. 6.

HANDBOOKS AND TRAINING

On previous contracts, where specified ship systems were more complicated than normal, notes describing the system features and operation had been prepared by the shipyard and discussed with the ship's staff.

Because of staff movements, the knowledge acquired becomes dispersed and this situation is further complicated by general staff turnover problems. It was agreed that in addition to a special course for the ship's staff, a handbook would be prepared for the 3·3kV system.

Because of the involvement that other systems have with the 3·3kV system, it was essential to increase the scope of the handbook to describe all the electrical systems in the vessel.

This presentation, prepared on a system basis, is supplemented by the usual manufacturer's handbook and installation drawings.

The handbook was also used as a basis for a two weeks ship's staff course which took place some time before the ship was handed over. The first week of the course described and discussed all the ship's systems and was attended not only by the electrical engineers, but also the Captain, Chief Engineer, deck and engineering officers.

The second week involved visiting the manufacturers who had supplied the major items of the 3·3kV systems and who had similar equipment undergoing manufacture. At these visits, the ship's staff were able to discuss maintenance aspects with the manufacturers' personnel.

The aim has been to make the instructions in the handbook as comprehensive as possible, but where reference to a drawing becomes necessary this is facilitated by the fact that the handbook sections bear the same numbers as the relevant electrical drawings for the ship.

The courses were considered beneficial by the people who attended and proved a good basis for instructing experienced personnel on the operation of the ship's plant.

COMMISSIONING

One problem foreseen concerned the method of absorbing the power generated by the main engine driven alternators. So far as Lloyds Register were concerned, these could be demonstrated at sea by using the cargo pumps, discharging sea water as the load medium. as this could only take place during sea trials, just prior to handing over the vessel to the owners, it left very little margin for carrying out any corrective or setting-up work that might be necessary. It was, therefore, decided to provide a load test facility that could absorb the full output of the engine driven alternators of 2·4 MW at rated power factor.

In the shipyard, where traditional brine filled load tanks could have provided the kilowatt loading, problems would have been encountered regarding the safety aspects of operating tanks at 3:3 kV and also because the alternators have earth fault protection. Further, with only resistive power available the A.V.R. would not have been fully loaded.

A load test facility consisting of six, 500 kW, forced-air cooled, tapped resistors and four 375 kVAR and one 1259 kVAR oil-filled, tapped reactors were assembled, utilizing equipment already available within the yard. Remote operation of the breakers connecting the various load units was provided. The resistors and reactors were rated at 440V and, while they could be used for conventional shipboard generators, they required interposing transformers for the 3:3kV main engine driven alternators. Becsue of quay space problems and for flexibility, the load test equipment was mounted on two barges which could be towed round the fitting-out basin to suit

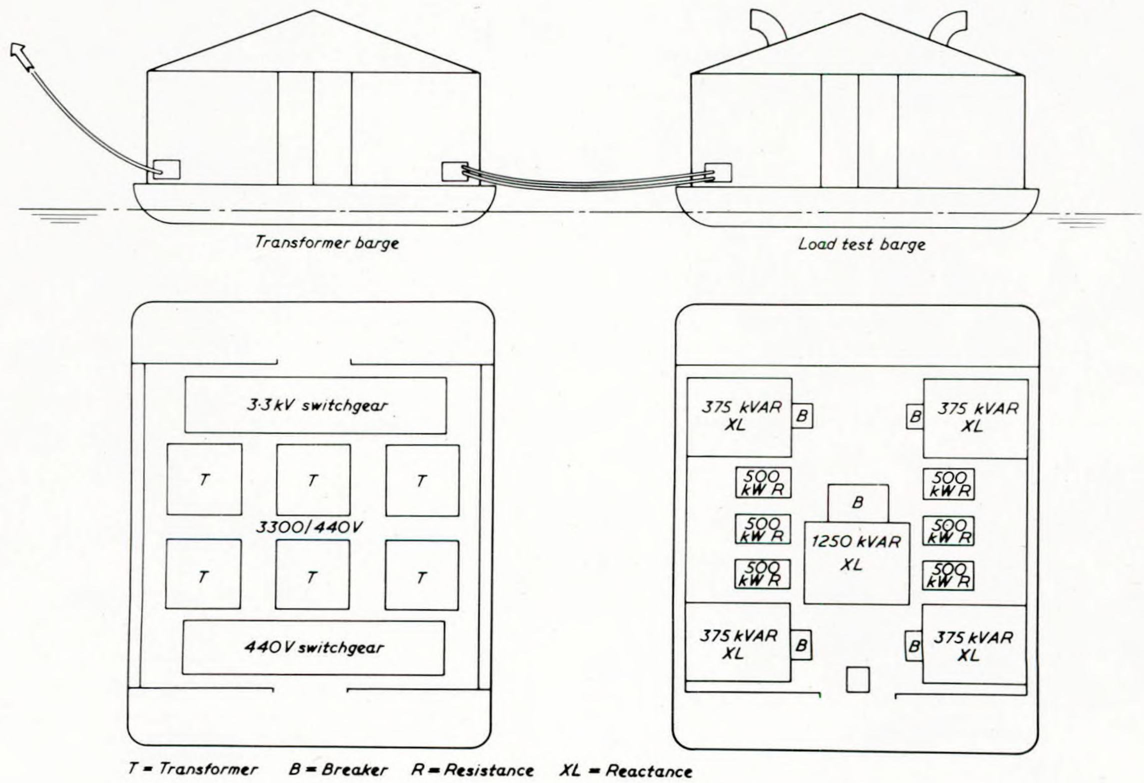

Fig 7—*Test barge arrangement*

requirements. Fig. 7 shows, in diagrammatic form, the electrical equipment arranged on the load test barges.

TESTS

Normal tests were carried out on the 440V system, such as generator load trials using the 440V test barge. It is also the yard practice to prove the calibration of all breakers by primary injection, prior to installation in the vessel, to the satisfaction of the local Lloyd's Register surveyor. While the switchboards were in the workshops, the interpanel wiring was connected and operational checks carried out. Since the boards were from various manufacturers and the builder was responsible for the overall scheme, it was considered a worthwhile effort to test in this manner.

An H.V. test was carried out on the 3:3kV cables and equipment to ensure correct installation and a test voltage of 8 kV d.c. for one minute was applied. Further tests were carried out on the system to determine system capacitance, but results were of doubtful value. The main engine driven alternators were loaded to full load in 25 per cent steps. The Lloyd's Register requirements for a 70 per cent step load to be applied to an unloaded generator could not be met, since the design of the governor and the inertia of the main engine system was unsuitable. In fact most main engine driven alternators, unless comparatively small, would have trouble meeting this requirement, because the shaft and propeller provide the rotating inertia and these are uncoupled when pumping cargo. The test did achieve approximately 40 per cent step load, which provided a useful check on the main engine governors settings.

Extensive paralleling tests were carried out between engine driven alternators and auxiliary alternators, including the starting of cargo pumps while the alternators were paralleled. Compounding was applied to the auxiliary alternators' A.V.R., but not the engine driven alternators, as the interposing transformer provided a compounding effect.

This series of tests confirmed the choice of governors for both the main and auxiliary engines as appropriate. Although Esso's requirement for paralleling was only for a limited period during the paralleling operation, the tests demonstrated that no limitations were required. To achieve optimum setting of the A.V.R. a recorder was used during cargo pump trials. The various timers in the assisted-start unit were set up and each pump was run in this mode from the two auxiliary diesels in parallel.

Extensive testing was carried out basically to prevent delays in handover, but also to give the operators some measure of confidence in the equipment and its operation.

OPERATING EXPERIENCE

The ships were soon in regular service after their handover and were discharging their cargo at rates restricted initially by the shore terminal capabilities and not those of the ship's plant. Since then facilities have improved and the vessels can now discharge at full rate at certain ports.

An extract from the Esso house magazine **Mariner,** dated April 1976, indicates their appreciation of the vessels.

"With regard to the Coastal fleet, Mr. Rae (Esso Transportation Manager) said how pleasant it was to record that the **Esso Severn** during her first nine months in service had delivered 1·5 million tons of cargo and had had less than a day out of service. In this she followed the pattern of her sister ships from Cammell Laird."

However, events have occurred on the vessels, during their operation, which will be of interest to those people involved in design of systems and plant operation. Some of these are related below.

In some instances the original design intent is defined and then followed by a description of the operation experience.

PLANT LOADING

In the initial design stages, a plant operation specification was produced which defined separately the four modes of plant operation and the accompanying electrical load sheet in Table III provides information regarding services to be supplied for each mode.

The appropriate modes are:

Harbour Idle

Design Intent

a) In this condition one diesel alternator is to operate and supply the essential services, lighting, galley, etc.
b) Alternatively, one main engine driven alternator is to supply power to the ship's service busbars via the 3:3 kV/440 V transformer; a duration of ten hours for

TABLE III
BASIC ELECTRICAL LOAD SHEET

System		Harbour Idle	Harbour Working	Enter leave harbour	Sea
Emergency services		12	20	20	20
230 V services		60	94	94	94
Domestic services		55	80	90	80
Engine room auxiliaries		90	279	445	413
Total load, kVA		217	473	629	607
Total Load, kW	Design	(174)	(378)	(503)	(486)
	Actual	170/250	310/360	420/520	350/400
Forward machinery		—	195	80	—
Aft machinery		—	220	220	—
Thrusters		—	—	1200	—
Cargo pumps		—	*3000	—	—
Total load, hp			3415	1500	
Total load, kW			2562	1125	

* The cargo pumping rate is a variable depending upon cargo, terminal facilities etc.

which the main engine could operate on this light load (approximately 300kW) was stipulated by the main engine supplier.

This condition to be considered as an emergency condition and the duration kept to a minimum.

Operation

In this mode one diesel alternator supplies all the ship's services operating at between 170 kW to 250 kW.

To date there has only been one occasion when it has been necessary to run a main engine driven alternator, to provide electrical power for the vessel, in this mode and this was carried out without any problems.

Harbour Working

Design Intent

One main engine is to operate and drive its respective alternator, which will provide power to the four cargo pumps only. One diesel alternator will supply ship services.

The engine main driven alternator and the diesel driven alternator will not be paralleled and will be electrically isolated.

Operation

It has been found that the main engine driven alternator can supply four cargo pumps at full capacity and the ship services. This allows the diesel alternator to be closed down.

Enter/Leave Harbour

Design Intent

One main engine driven alternator is to provide power to the stern and bow thrusters, while the two diesel alternators would supply the ship services. During this manoeuvring period, it is probable that the changing torque requirement of the propeller will cause the frequency of the engine driven alternator to vary. The diesel alternators and engine driven alternator would therefore be operated as electrically isolated systems.

In the event of one diesel alternator set failing, the remaining diesel set would continue to supply the ship service load of approximately 500 kW.

Operation

These vessels spend a considerable period, within the year, in the manoeuvring condition and it is standard Esso procedure for two diesel alternators to run in parallel while entering and leaving port, but as soon as practical the diesel alternators are closed down and electrical power provided by a main engine driven alternator.

Sea

Design Intent

During normal sea passage conditions, where propeller torque is relatively constant, one main engine driven alternator would supply the ship sea load. In the event of heavy weather causing large fluctuations in the alternator frequency, a diesel alternator would be started and paralleled with the main engine driven alternator for a short period. To facilitate changeover it may be necessary to reduce the pitch angle on the propeller. The engine driven alternator breaker would then be tripped.

Prior to entering harbour, the diesel alternator sets would also be paralleled with the main engine driven alternator for the purposes of changeover without a "black-out" occurring.

Operation

In practice, if rough weather is predicted in the area, the electrical system is changed over to the diesel alternator in anticipation. The propeller pitch controls are used to feather the propeller momentarily so as to facilitate changeover from a main engine driven alternator to diesel alternator, particularly if the sea state, or ship condition, is causing propeller torque fluctuations.

Generally

Although at the outset the shipbuilder felt that the 425 kW diesel alternator rating nominated by Esso was too small and advocated 625 kW sets, after a long debate on possible plant loadings, a compromise was arrived at of 525 kW which has proved to be adequate in service. On the third vessel, where the deck machinery was increased to 83 kW (112 hp) from 63kW (85 hp) the set rating was ideal, for a single generator operating at 520 kW could supply all ship service, deck machinery and ballast pump.

As far as possible, the ships' services are supplied from the engine driven alternators, rather than the diesel alternators, thus reducing fuel cost, diesel engine running hours and, hence, maintenance costs.

Typical running hours for one year are:

diesel alternator — 3500 h per year;

engine driven alternator — 2000 h per year.

The overall generating and control system, embracing main engine driven alternators, diesel alternators and a relatively large emergency generator, has proved to be flexible in operation, enabling the ship to maintain her programme.

SYSTEM PERFORMANCE

A system performance study was carried out by G.E.C. Electrical Projects during the design stage of the contract. The objects of the study were to investigate the effect on the system of:

i) starting sequentially the four cargo pumps;
ii) starting a single cargo pump from two diesel alternators;
iii) parallel operation of the diesel and engine driven alternators when the engines are subject to fluctuating loads;
iv) transformer inrush currents.

A computer simulation program was used, employing system design parameters, and this showed that generally the system was stable and that switching transients were acceptable, except when starting a single cargo pump from two diesel alternators. It did, however, cause a re-assessment of the diesel alternator A.V.R. rating to be carried out and larger A.V.R. were fitted.

Comment can be made upon these four aspects, now that substantial operational experience has been gained.

Sequential Starting

The cargo pumps are started remotely from the cargo control room and there are no interlocks, or other devices, to prevent the pumps being started in rapid succession. Practice has shown that there is no requirement to set a period, or minimum time, between starting successive pumps.

It is also becoming more commonplace to discharge cargoes, using all four pumps at full power as the terminal facilities are modernized.

Cargo Pump Starting

In the final stages of cargo discharge, it is usual to close down the main engine driven alternator and use two diesel alternators to supply ship services and drive a single cargo pump.

The previous experience of Esso was that, if only one cargo pump could be supplied from the diesel alternator plant, it was subjected to more wear than the others. The system is therefore arranged so that any one of the four pumps can be started from the two diesel alternators.

In order to reduce the starting current and the voltage transient seen on the 440V system during the start-up of the cargo pump, an auto-transformer is connected into the 3·3 kV line. This is a separate transformer with Korndorfer connexions operated by vacuum contactors.

In practice it has been found necessary to alter the timer setting on the assisted starter. Frequency and voltage swings in the order of 3 Hz and 40 volts have been observed at the instant of starting a cargo pump.

Starting problems and excessive voltage dips have occurred when attempting to start a cargo pump which contained a localized pocket of cold black oil. This problem has been eliminated by fitting trace steam heating around the cargo pump body in an attempt to prevent "slugs" of cold oil forming.

Parallel Operation of Diesel and Engine Driven Alternators

The main engine driven alternators cannot be operated in parallel with each other, but there are periods when a selected main engine driven alternator requires to be paralleled with the diesel driven alternator or alternators, i.e., for change-over purposes.

The change-over and paralleling operation will be more difficult when the engine output is fluctuating, as could be the case in heavy weather with a certain amount of propeller emergence, and also under manoeuvring conditions, as on entering port.

For the Esso project it was decided to adopt isochronous governors for the propulsion engines. This would ensure that during fluctuating load changes the main engine driven alternator would take the major loads and the diesel alternator would not be subjected to surging overloads.

In practice, the problem of paralleling is simplified by reducing the propeller pitch angle for a short period so that the main engines are running at a reduced load and maintain constant speed. After paralleling, the propeller pitch is returned to the original position. The propeller pitch controls are relatively close to the mimic panel located in the centre section of the main switchboard and can be handled by the engineer carrying out the laternator change-over. There are two basic methods of paralleling a main engine driven alternator:

a) by closing the repective alternator breaker on to the H.T./L.T. transformer;

b) by paralleling across the L.T./H.T. transformer by closing the L.T. breaker.

The paralleling of all machines is carried out usually by the watchkeeping engineer and, in normal operation, is carried out by using the respective machine breakers. This allows any of the watchkeeping engineers to switch generating plant.

In operation the usual frequency excursion of the main engine driven alternator is $\pm$ 2 cycles. In some instances frequency excursion in the order of + 5 cycles have occurred, but the main engine driven alternator breaker has not tripped because the over frequency has not exceeded the timer setting (3s). Paralleling has been achieved easily and without blackout.

In practice, the main engine driven alternators are used to provide ship's electrical services as soon as possible, as this allows the diesel alternators to be closed down, saving running time and hence maintenance time and fuel costs.

In planning the operational cycle of the vessel, account is taken of the time of the tide at the next port and the vessel may only need to use one main engine to meet the tide. Alternatively, it may need all the propulsive power available and in this case the diesel alternator(s) would be operated to supply ship services and to enable the engine driven alternators to run at no load—hence providing about 370 kW (500 hp) of additional propulsive power.

Transformer Inrush

During the design stages, various available papers dealing with the transformer inrush problem were studied and discussions took place with the transformer supplier to assess the magnitude of the problem and the precautions, if any, which could be taken.

The transformer operates in two modes:

a) step-down—this enables one of the engine driven alternators to provide power to the 440V system;

b) step-up—this enables the diesel alternators to provide power to the 3·3 kV busbars and, hence, any one of the four cargo pumps.

It was anticipated that during the starting of cargo pumping operation there would be a significant dip in the 440V system voltage, but this was avoided, or eliminated, to some extent by fitting a larger A.V.R. which forces the field of the alternator during the pump starting period. The other condition which could also give a significant dip occurs when one diesel alternator supplies the ship system and is required to energize the 1150 kVA transformer. The magnitude of the transformer magnetizing current that could occur was discussed with the supplier and, while guidance figures could be produced, it was difficult to assess accurately the effect on the 440V system.

The system performance study predicted a large transient voltage drop for one or two cycles' duration when the 1150kVA transformer was switched on to the 440V system and two diesel alternators were providing the power.

Operation has shown that with two diesel alternators in parallel, the closing of the H.V./L.V. circuit breakers can cause a voltage drop of sufficient magnitude to trip the starters of various engine auxiliary motors, but only one was supplying a significant circuit and this was replaced by a rectified d.c. oil coil with an inherent time delayed drop-out.

It is appreciated that the energizing of a transformer of 1150kVA will cause problems of inrush and residual magnetism, therefore all energizing of the transformer is carried out from the H.V. side when a main engine driven alternator is available. There are times, however, when a main engine is not available.

Also, initially, when the transformer has had to be switched on to one or both generators, tripping of the transformer breaker has occurred. This had been initiated by the short circuit lock-out relay acting instantaneously on the no-volt circuit. The circuit was altered to act on the normal time-delayed drop-out circuit of no-volt release. This modification to the H.V./L.V. circuit breaker overloads, which was carried out during building, also helps to prevent the dropping out of the breaker when heavy starting currents of short duration occur during the assisted start sequence.

In the initial scheme, where the fore deck feeder was supplied at 3·3 kV it meant that the 1150 kVA interconnecting transformer has to be energized. If a single diesel alternator was switched on to the low voltage side of the transformer often the magnitude of the inrush current was such that it caused the L.T. breaker to trip.

The action of re-closing the breaker could then be repeated and might be successful.

If two diesel alternators are available and the L.T. breaker closed, again depending upon the magnitude of the inrush current, the L.T. breaker may or may not trip.

As far as is practical the transformer is energized from the 3·3kV side and paralleling carried out across the L.T. breaker rather than across the contactor.

Because of the random nature of transformer inrush, it is difficult to quantify and eliminate, but in practice it does not cause any problems in the operation of the system or ship, although the limited spurious tripping is a nuisance.

SYSTEM EARTHING

The advantage of the earthed neutral principle is that earth fault detection can be directional which makes the location of earth faults simple. On unearthed systems once a fault has been indicated, detection is carried out by a method of elimination by isolating individual circuits. If the earth fault happens to be on an essential service which cannot be duplicated it has to remain until a suitable occasion occurs when the plant can be shut down.

On the third vessel, the 440V distribution system had to incorporate earth indication and alarm facilities to comply with Lloyd's Register 1972 Regulation.

At first it was thought that the fitting of the earth indicator and alarm unit on the 440V system might tend to be of nuisance value. However, combined with the direct read out insulation meter, it has turned out to be a great advantage in the early detection of fall-off insulation value and possible prevention of equipment damaged.

Experience of a high impedance earthed system and some research into practices used in coal mining etc, shows that there would be advantages in applying high resistance earthed principles to all a.c. systems, with the facility of being able to switch out the neural earthing and revert to an all insulated system.

This would allow a choice of systems to suit various circumstances. Earth faults could be indicated and alarmed on essential circuits, otherwise non-essential circuits could be arranged to trip. This method is considered safer, even on circuits through hazardous areas, since it provides speedy location of faults. Even with an unearthed system, the capacitive currents to earth are often in excess of an intrinsically safe value (on a new installation, the value of capacitive current on the 440V system is 50-60mA). At present there seems to be some conflict as to the system to be adopted for oil rigs with the proposals ranging from solid earthed neutral to an unearthed system. The system of selective earthing would give the optimum solution enabling the system to be earthed or unearthed to suit conditions. For example if a tanker is required to have an earthed system when moored to a particular production platform, but the normal mode of operation is unearthed, then both conditions can be catered for. The majority of existing systems can be modified for selective earthing.

DISCRIMINATION

During the design stage and in the selection of breakers, fusegear, moulded case breakers etc, a great deal of effort was spent in producing an electrical system that would provide discrimination.

During the ship's operational life, certain minor changes have taken place in the method of obtaining supplies in certain areas and discrimination has sometimes suffered, but as these are non-essential services this has been accepted.

Generally a switchgear scheme, in which a wide range of different devices is used, makes discrimination difficult to prove and obtain. In an all-fuse gear distribution scheme, the initial engineering is easier and modifications to the system at later stages can be simpler yet retaining discrimination.

PROTECTION EQUIPMENT

Generally the I.D.M.T. relays have provided reliable service. the only alterations to the protection have been on settings. The over and under frequency relay settings have been opened up to the maximum settings 64 and 56 Hz and a time delay of three seconds provided. Problems have been experienced in obtaining thermister power packs of a specific type.

ENGINE DRIVEN ALTERNATORS

The main engines are connected to the gearbox via external flexible couplings and clutches. The main engine drives are extended via concentric gearing and shafts through the gearbox to the two alternators. Thus each alternator is coupled to its respective main propulsion engine by a quill shaft. This arrangement allows each alternator to be driven by its respective main engine without having the main propeller shaft connected.

The basic arrangement of the alternator is shown in Fig. 8 and the rotor is supported by the pedestal bearings.

These bearings are of the plain sleeve type and because a flexible coupling is fitted between the alternator drive shaft and the gearbox, and a relatively large bearing clearance was provided. It was also decided initially in the design stage that the bearing should not have a thrust capability.

ROTOR SHUTTLE

During the basin trial prior to sea trials, it was observed that the alternator rotor shaft was oscillating about its centre. This could be seen at the slipping clutch and at the non-drive end of the exciter, the extent of movement being between the extremities of the bearing clearance. Little effort was required to stop this movement and observations during sea trials showed that the magnetic effect of the excitation and a small load of about 100 kW was sufficient to stop the movement.

The cause of this movement was investigated and it was found that the flexible coupling, besides having axial tolerance, also had a longitudinal tolerance of 7·62mm.

To remove the free floating action of the alternator rotor it was necessary to change the drive and bearing clearance and this was amended ± 11 mm. Also the bearing was modified to provide a thrust capability using a tilting pad arrangement.

The rotor axial movement caused the oil seals on the bearings to be subjected to abnormal wear and the local oil mist was taken into the alternator cooling fan.

Because the ships were in service, each set of alternator bearings had to be replaced in turn, therefore, due to the time delay, the alternator windings became covered in an oil mist and atmospheric dirt. At a convenient time the alternator covers were removed and the completed machine cleaned. The oscillating movement has been eliminated.

On the third vessel, the sheet metal alternator enclosure was modified to allow easier access and provision of fit air filters has been arranged.

The alternators on the third vessel were opened up for inspection after nine months service. They were found quite clean except for a small carbon deposit in the windings. However, at the one-year dry-docking, pints of clean lubricating oil were found in the base of the machine.

The alternators were cleaned in dry dock and fitted with filter units which will reduce the ingress of dust and carbon considerably.

The location and size of these engine driven alternators is sure that a failure of the machine would incur a very high cost because, to remove the machine from the ship, would mean

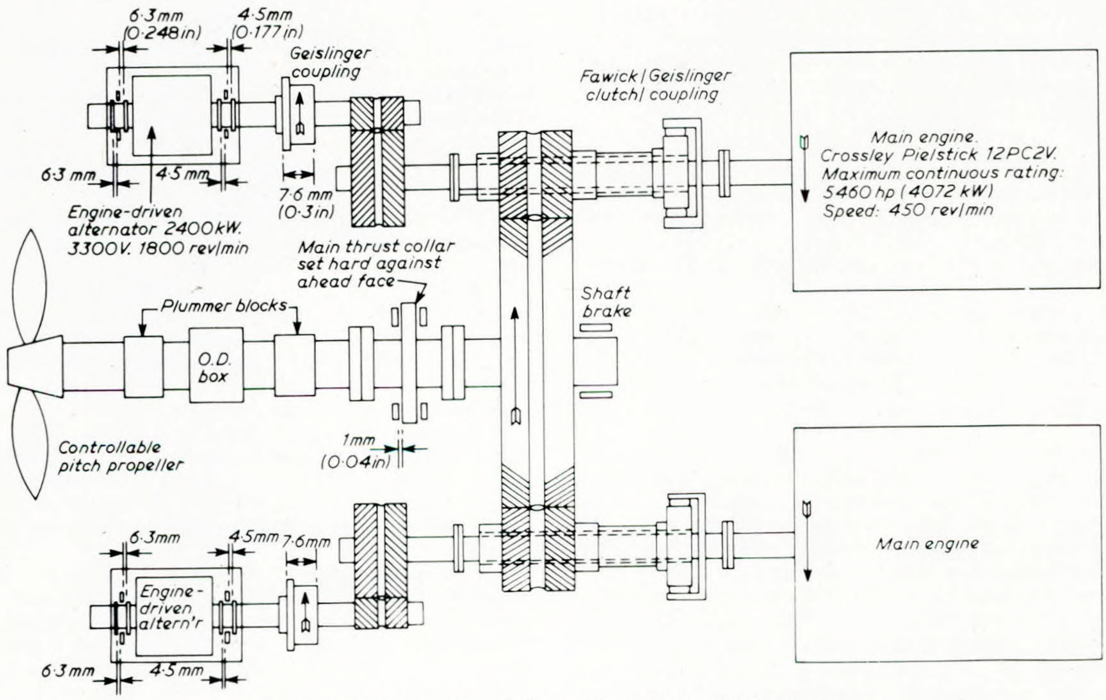

Fig 8—*Main engine driven alternator arrangement*

drydocking and making an opening through the ship's side. Therefore, a simple air cooled machine, with an enclosure which could be dismantled within the confines of the engine room space around the machine, was selected for this would allow on site machine winding repairs or maintenance to take place. This has been necessary on one vessel where the rotor was removed from the machine and the stator rewound on the ship; The rotor was also re-insulated. The whole set was then tested.

The possibility of using a water cooled alternator was briefly considered at the design stage and rejected on the basis that:

a) alternators on the **Esso Fawley** and **Milford Haven** vessels were also drip proof protected air cooled machines and operating experience did not give rise for any grounds to change;

b) there was insufficient space for water cooled machine.

However, considering the alternator design (with initial capital available) it is a pity that the alternator drives were not de-clutchable. This would have greatly reduced the running hours and coupled with "F" class insulation and a filtered clean air supply, would have resolved some of the problems at the start. It is appreciated that the space restrictions prevented the alternators from being totally enclosed.

The soot and dust found in the windings has been traced to the engine room ventilation outlets being sited too close to the alternator air inlets and they have been repositioned.

All three ships now have air-filters, with alarms, fitted to their air-intakes. **Esso Clyde** and **Esso Mersey** have had their conductor insulation changed from an "asbestos" based insulation to "main made fibre" (this was already changed during construction for **Esso Severn.**

The oil ingress into the alternator on **Esso Severn** was traced to the joint leaking on the casing to the bed plate seal and extra holding down bolts were fitted to allow a more level pull-down on this joint. An oil drain and save-all has also been incorporated.

Whilst experience has shown that the alternators on the vessels can be repaired or rewound **in situ** and it is not necessary to remove them via the ship's side as originally foreseen, it is not a recommended practice.

DIESEL ALTERNATORS

The auxiliary generating plant consists of two diesel driven alternators, rated at 525 kW, having static excitation and field forcing to provide quick response of alternator to meet the large cargo pump starting loads.

In service, the windings of the alternators became extremely dirty and required to be cleaned at the two-year drydocking period. Filters are now fitted to the air intake.

The static excitation, employing thyristors, has been reliable, although noises caused by iron core vibration originating from a reactor within the A.V.R. cabinet sometimes gave cause for alarm. These reactors have now been replaced.

EMERGENCY ALTERNATOR

The automatic start-up and shut-down sequence of the alternator has worked perfectly at all times. On one occasion, the emergency alternator was used to start up a main engine because both diesel alternators were unavailable, and this enabled an engine driven alternator to supply the ship's services.

This proved the value of having an emergency set of this rating.

The emergency alternator is operated every Saturday as a matter of procedure. The set, which is located in a space together with the accommodation ventilation equipment, has oil and water heaters, and these elements have failed twice within the first three months of service. Experience has shown that they are not normally required, as the air conditioning equipment keeps the space relatively warm.

SWITCHGEAR

3·3kV Air Breakers

In service there have been problems with auxiliary contacts and relays but, to date, no spares have been used. The siting of control fuses at the back of the board, within the transformer enclosure, has been a nuisance in that access is only possible providing the transformers were de-energized. For the third vessel the transformers were re-located and the fuse panels are not now within the transformer enclosure.

Vacuum Contactors

After the first two vessels had been in operation for some months, it was reported that, while the general operating experience of vacuum contactors had been good, there had been suggestions that some failures of motor insulation were attributable to the use of vacuum contactors.

Obviously, there was concern that the installations in the Esso vessels were not at risk and meetings were held with the manufacturer, Lloyd's Register and Esso in order to clarify the situation and relate the manufacturer's experience to date with the Esso application.

The manufacturer had carried out a number of field trials in order to resolve the source of the trouble that was causing motor insulation damage.

In late 1972, a series of guidelines were published by the supplier which indicated applications to which vacuum contactors could be applied without the need for suppressors. The Esso vessel application, with regard to motor types and to size, came within these guide lines.

As more knowledge of reported plant failures was gained, the source of the trouble became more defined and it was agreed with Esso and Lloyd's Register that switching transient measurements be taken on the Esso vessels. This data served as further confirmation that the vacuum contactors were not subjecting the motors and system to over-voltage or excessive high frequency transients. While the vacuum contactor supplier would be responsible for carrying out and analysing the recordings, these were available to Lloyd's Register and the motor supplier, and from the latter assurance was received that their motors would not be affected. They also commented that the transient amplitude was lower than that which they had experienced on air break and oil break equipment on other applications.

Vacuum contactors were installed on the third vessel, and on all three vessels have given reliable satisfactory service.

Only auxiliary timers have proved to be inconsistent in operation and incapable of providing a consistent time with repetitive operation.

440V Switchboard

Generally satisfactory, but the Rotherham timers on the breakers have required attention. The check synchronizer also had to be replaced on one vessel.

3·3kV TRANSFORMERS

Interconnecting Transformer and Assisted Start Unit

The purpose of the 3·3kV/440 V interconnecting transformer is to allow the 440V ship services to be supplied from one main engine driven alternator while at sea. It also enables one cargo pump to be supplied from the 440V switchboard with the two diesel generators operating in parallel and the main engines shut down. In this case an assisted start unit is provided to reduce motor starting transient. This transformer is a standard unit used in connexion with the vacuum contactor switchboard and, because it was sited in the interlocked tranformer enclosure, its standard cover was removed.

In the same enclosure was housed the 1150 kVA inter-connexion transformer and this is also of open type construction.

Two basic reasons for having the transfomers of open construction were:

a) to aid heat dissipation;

b) to enable the ship's staff to inspect, generally, the condition of the transformers easily without removing covers etc; this may be of aid in detecting insulation breakdown.

The enclosure access is interlocked with the supply contactors/breakers, thus ensuring the equipment is de-energized before entering.

Unfortunately, the pump room lighting fittings are mounted on the forward bulkhead of the transformer enclosure and lamp failure rate has been high, necessitating frequent lamp changes, and to change the lamps involves not only de-energizing the transformers, but also uncoupling many nuts and bolts on the fittings. Generally there have been no problems experienced with these transformers, although difficulties have been experienced with obtaining thermistor power packs.

Forecastle Feeder Transformer

Initially three single-phase 135 kV transformers were provided in the forecastle area and connected for 3-phase operation supplying the forward deck machinery.

The services supplied by this feeder comprise:

1—34kW (45 hp) windlass hydraulic power pack
2—(63kW (85 hp) mooring winch hydraulic power packs
1—7kW(10 hp) bilge pump
Lighting Transformer

At the design stage it was envisaged that a cargo tank ventilation system employing a fan of about 186kW (250 hp) would be employed. In an attempt to limit the switching of these large loads on to the 440V generators it was decided to use 3·3 kV feeder so that no restrictions were placed on the operation of the forward deck plant.

The forecastle electrical loads are now defined and the forecastle supply system has been simplified to a 440V system on all three vessels. The transformers when used in service worked satisfactorily.

THRUSTERS

Two transverse thrusters are provided, one located in the stern and the other in the bow of the vessel.

The starters are located in the engine control room and electrically interlocked to ensure that the motors are started under "no load" conditions.

On **Esso Mersey's** first voyage after handover, the ship's captain reported failure of the bow thruster controls and the possibility that the drive motor was damaged. During the return voyage to the shipyard, the motor was checked as far as practicable without dismantling and while there was a pronounced smell of hot insulation, meter readings indicated that the insulation was in good condition. The thermister protection had not operated. This throws in doubt the effectiveness of thermisters located in the stators of large motors. It would also appear that the overload was enough to slow the motor down to half speed. In this condition the machine is rotor critical and the rotor would overheat long before the stator.

The vessel was docked, for other reasons than the thruster, and the motor was removed. The motor was completely dismantled, examined and tested. The insulation was found to be in perfect order and the motor was re-assembled.

The state of motor insulation could have been more readily checked if the star point of the winding had been brought out and terminated in the connexion box, unfortunately it was terminated within the machine.

The bow thruster control system was examined to ascertain the cause of failure and the magnitude of the overload to which the motor had been subjected.

The basic thruster system has a current control feature which monitors the drive motor current and modifies the pitch angle of the thrusters to prevent the motor becoming overloaded. This system uses a position reset signal to define the pitch angle and it was found that loss of the reset signal causes the propeller blades to be driven at full pitch and the motor to go into an overload condition.

The equipment is sold on the basis of having a non-overload characteristic!

The system has now operated for more than two years without any operational problems, but for the thruster direction indicating lights which continually flash when at full pitch. As these lamps are located on consoles in the wheelhouse area, they are a nuisance and embarrassment, especially at night time or when a new deck officer joins the vessel.

Because the bow thruster compartments on both **Esso Mersey** and **Esso Clyde** have been flooded as a result of heavy weather damage, it has been necessary to remove the bow thruster and motors for repairs.

On **Esso Clyde,** the unit was removed via the compartment access trunking which involved considerable removal of ladders, gratings, etc.

On **Esso Mersey,** an access hole was cut in the ship's side and this has been shown to be the quickest and simplest way. To facilitate any subsequent removals of the units, lifting beams and trolleys have been fitted on all three vessels to enable the motors to be handled with ease and safety.

It is essential that adequate time is allowed for commissioning the thrusters prior to sea trials and, if pitch position marks were engraved on the rod driving the position indicator, this would be of value in setting up the system.

In operation the thrusters have been used for 24 hours to hold the vessel alongside in extremely bad weather and have been used to manoeuvre the vessel up to the pilot boat.

CARGO PUMPS

Four 560kW (750 hp) motors are used for driving the four vertically mounted cargo pumps.

The starting equipment for the four cargo pumps is housed on a group starter board located in the engine control room, but the pumps are capable of being started and stopped externally from the cargo control room.

Initially, the limitation to developing full pumping capacity was imposed by the port terminal facilities, involving pipeline sizing etc, but this restriction is no longer in operation as Esso have carried out an extensive upgrading of a number of terminals to facilitate single-tide turn arounds. A single-tide turn around means the vessel must pump within nine hours, leaving three hours for manoeuvring, berthing and unberthing.

A number of successful single-tide turn arounds have been completed by both **Esso Clyde** and **Esso Severn.**

Cargo Pump Controls and Monitoring

Because the cargo pump is located in a hazardous area, the cargo pump room, the remote manual stop and automatic stop (bearing "over temperature") are initiated by pneumatic signals. Also, because the cargo control room is classified by Esso as a hazardous area, the cargo pump controls for stop/start are initiated by pneumatic signals. Remote cargo pump "stops" fitted on the fore/aft gangway are also pneumatically initiated.

These pneumatic signals operate pressure switches which are grouped together for ease of checking. In service the system has worked well, but the push-buttons fitted on the remote stops and exposed to the weather, have been removed and replaced by a simple cock opening to atmosphere.

CABLING

Some time during the second year a cable fault occurred on the 3·3kV cable feeding the forward deck machinery, in way of an expansion joint on the fore and aft gangway. Since the "evidence" was destroyed, it was difficult to determine if the cable failed to earth or between phases. The authors' opinion is that an open circuit occurred on one phase under load, since this particular service has an instantaneous earth fault trip of 250 m. The second vessel, **Esso Clyde** was at the time undergoing hull repairs and it was possible to X-ray the cables at each expansion joint to establish the condition of the cable. This showed that the copper conductor was being stretched because there were signs of "necking". Subsequently the method of attachment at the expansion joint was changed and wood cleats are now used to hold cables together, but are not connected to the joint and are free to move.

Because of cable damage during installation and the initial operating period, some cable repairs were effected by jointing. This was carried out by representatives from a well known cable maker and although the joints passed electrical tests (flash testing) X-ray examination showed that the soldered in-line joint had not been correctly made. Obviously cable jointing should only be carried out where essential, but for future applications, in-line cable crimped connectors and X-ray examination as well as electrical tests would be required to ensure that the joint is correctly made.

CONCLUSION

The success of these vessels is a result of the combined efforts of an experienced tanker owning company who demanded high standards and an experienced shipbuilder, with a management keen to show that a British shipyard could deliver the goods on time.

At the outset of the project, when the feasibility of a high voltage system was being considered, a series of meetings took place with Lloyd's Register of Shipping to discuss the proposals for the 3·3 kV systems. Their close involvement throughout this project was greatly appreciated.

The shipbuilder's policy at the outset of the contract was that little or no development of new ideas was to take place on these contracts, because of the possible delays they could have inflicted on the overall project.

In fact a number of new ideas/innovations did take place which did not delay the contract completion, mainly because of the tremendous enthusiasm of the individuals concerned and the response of the Esso engineers in appreciating the effort being made.

Electrical developments can be short-listed as:

1) the installation of a high voltage system using vacuum contactors, high resistance neutral earthing and electronic earth leakage detectors;
2) the use of isochronous governors on the main engines to improve the range of parallel operation with the diesel generating plant;
3) the use of pneumatic/electric pressure switches for cargo pump controls in a place of flameproof equipment;
4) production of a detailed commissioning network and standard test sheets;
5) change in mehod of drawing presentation;
6) production of electrical systems handbook for the vessel;
7) arranging of electrical load test barge facility which could be used for the Esso vessel and other contracts.

Throughout the period of the contracts a good personal relationship has been developed and maintained between Esso operating staff and the shipbuilder and, as a result, feed-back from the vessels was not restricted to guarantee claims, but included constructive operational ideas which have enabled the systems to be improved.

ACKNOWLEDGMENT

The authors wish to thank their respective companies for permission to write a joint paper and making available records and information.

The success of these vessels can be attributed to many factors one of which is the high order of reliability of the H.V. electric cargo pumping system and its equipment. This system the result of pooling the electrical experience of engineers from Esso, the various subcontractors, Lloyd's Register and the shipbuilder, which enabled each vessel to be completed on time and prove successful in operation.

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Discussion

MR. E. M. ADAMS stated that one of the main reasons for adopting the 3·3kV system as indicated in the paper was to give unrestricted operation of the plant. This point was often under-valued at the design stage, since it was difficult to put a monetary value on this feature. It was a point however, to which his company would always give priority in the design of any electrical distribution system for a ship.

His view was that an insulated 3·8kV system would have been a better application to the ship than an earthed system, thus avoiding the changes necessary to the supplies for the forward bow thruster and retaining the integrity of supply on occasion of an earth on an essential item of equipment.

The change to supplying the remaining services forward at 440V instead of 3·3kV appeared to be economically correct in view of the relative light load involved.

Mr. Adams did not agree with the author in treating the bow thruster as a non-essential duty. The period of time for manoeuvring, especially with no tugs, was a time when the bow thruster was a most essential item of equipment.

He presumed the level of insulation of the 3·3kV earthed system was tested to 8kV. Some manufacturers of switchgear and machines offered the same equipment which was suitable for either an earthed or an insulated system at no extra cost. This should be particularly borne in mind when comparing costs of an earthed versus an unearthed system.

He referred to the change of supply to the bow thruster via an isolating transformer, and hoped to learn what test voltage was used, for the 3·3kV cable forward and the bow thruster motor. For an insulated system this should be in the order of 15kV.

The experience of the authors in service had underlined the importance of choosing the correct enclosure for the engine driven alternators. Mr. Adams had no doubt from his company's experience, that ships' alternators should always be totally enclosed fan cooled or, alternatively, totally enclosed and water cooled.

The authors had mentioned a problem of restricted space, which dictated the type of enclosure to be used. With all due respect, he thought the priorities were wrong, which influenced the decision in this case.

He endorsed the authors' views that major repairs of alternators *in situ* were not recommended practice and should only be adopted as a "get-you-home" policy.

The use of an auxiliary diesel alternator set to parallel with the main engine driven alternator for change-over purpose was an accepted practice. The system was, of course, very much dependent upon the response of the main engine governors.

Mr. Adams was recently aboard the **Australian Emblem,** a ship built in Japan, which also had two main engine driven alternators and one auxiliary diesel alternator, the paralleling change-over facilities, similar to the subject of the paper. However, the Australian electrical officer on that ship, unknown to his superintendents, had a much simpler method of change-over from one main engine alternator to the other, as was demonstrated during his visit. The latter officer set the stand-by alternator circuit breaker ready for electrical closure on sensing no volts and tripped the circuit breaker of the alternator in service. The change-over was effected in less than 0·25 second and no starters dropped out during the interruption of supply. Mr. Adams presumed the back EMF of the motors in service contributed to this smooth change-over.

He noted that some troubles were experienced when energizing the 1150kVA transformer from the secondary side, using the 650kVA auxiliary alternator. He would be interested to learn the transformer reactance.

In the case of the 3·3kV system, which his company designed for container ships, they were energizing a 3 MVA transformer with a 1·56 MVA alternator. The impedence of the transformer was 5·8 per cent. The alternator circuit breaker was set to trip at twice the full load current after a delay of one second. Tripping of the circuit breakers was not experienced on the various occasions when the transformer was energized from the 1·56 MVA alternator.

He noted that a larger A.V.R. was fitted to the auxiliary alternator to counter voltage dip. He presumed that, in fact, the larger A.V.R. would decrease the time of recovery of the alternator, and not affect the actual volts dip, which was governed by the sub-transient reactance of the machine.

Their experience confirmed the advisability of fitting simple current overloads to protect the bow thruster motor, in addition to the fitting of thermistors. In connexion with overloads, it should be noted that the loss of hydraulic control pressure also increased the control to full pitch.

He concluded by saying that the paper had well related operational experiences and problems—a pattern which he thought should be considered in all areas where innovation was present.

MR. A. CLARIDGE stated that when his company had considered the use of vacuum contractors some years ago they had been very dubious about their resistance to mechanical shock, either as vibration or particularly as single accelerations due to heavy weather. The authors had reported no troubles of this kind, but he wondered whether there were any special precautions taken in the installation of this gear. For example, were the starter cubicles resiliently mounted. Next, a slightly different question: it might be expected, in that context, that vacuum gear would require appreciably less maintenance than conventional airbrake, had that been the case?

Turning to the question of switchboard control, Fig. 6 in the paper showed a mimic representation. He suggested that it was really little of a mimic. It had a very simple diagram in the middle, instruments at the top and controls at the bottom. He was not sure whether an operator needed three eyes or three hands to work it. He was not certain whether, in its design, any serious consideration had been given to the idea of combining a mimic occupying the whole panel, with instruments, line illumination, perhaps of energized supplies and controls, all on a single diagram. There was now some evidence experimentally to suggest that the number of operator errors would be materially reduced with a panel design of this nature. Did the operating experience suggest any number of operating errors which were, perhaps, related to the construction of the switchboard? Were human factors in general given consideration during the design?

MR. K. GOODMAN said that he also was a supporter of the all-insulated principle. The authors claimed that the bow-thruster drive was not essential, but surely, once the ship was manoeuvring, it was very essential and, he would have thought, ought to be an insulated system. Later on, they had claimed that the bow thruster was used for 24 hours; it must surely, therefore, have been essential most of that time.

Arising from this, his company was still frequently being asked for bow-thruster motors with half an hour rating and he hoped that this paper would have cleared that point.

As to thermistors, these were not really meant to protect high tension motors. They were not brought out for 415V and 230V machines. On the 3kV systems, there was much more insulation and the thermistor could really only detect gradual changes and these could be more beneficial when cooling tubes became blocked and cooling air fell off.

He was surprised to see that the cooling air was drawn in from the drive end on the H.T. generators.

MR. R. E. PRAGER, referring to points raised by two of the previous speakers on the question of insulated earth systems or high resistance earth systems, said that something not pointed out in the discussion so far, was that if one operated an insulated system with an earth fault for any length of time, there was bound to be a reduction in the life of that machine unless it was insulated for a very much higher voltage level, i.e. insulated for continuous operation. He thought that this was fairly well understood, but it seemed to be appreciated less frequently in the hurly-burly of commercial dealing, at the time when tenders were being made.

He endorsed Mr. Goodman's comment about thermistors. Far too many thermistors had been used on large, high voltage machines and he would go further to say that they were not intended only for low voltage machines, but they were really intended for rather small machines. He thought that they tended to be chosen because of the cost, not so much of the thermistor but of the associated equipment. He felt that it was an unwarranted saving, something that was not worth having on a machine of any size, as they had seen high lighted that evening on the motors and the generators.

He agreed with Mr. Adams on the enclosure of the generators. It would have been much nicer to have seen them totally enclosed, but he did appreciate the problems of the shipbuilder in getting the very much larger volume necessary with a totally enclosed machine. Perhaps he ought to point out that a water cooled machine, or an air cooled machine, with an air-to-air or water-to-air heat exchanger, was not strictly speaking totally enclosed. He thought that this was something that was frequently misunderstood by manufacturers and users of machinery.

As a machine designer, he was understandably horrified at Mr. Adams' "Australian crash change-over". He was sure it worked, but for how long? Not very long before, he had had occasion to have a high speed (slow-motion) film made, of a machine under short circuit. The movement of the end winding was quite frightening. The sort of forces that arose, or were likely to arise, in the machine, windings and couplings etc., on a crash change over, he would think were likely to be as one saw on a short circuit and possibly worse, because of the power that was being fed into the system by the driven machinery. It might work well for quite some time, but undoubtedly the strain on the system was likely to have an effect in the end. It was not, therefore, something that he would like to see used frequently.

On the design intent and operation of harbour working, the paper read: "It has been found that the main engine-driven alternator can supply four cargo pumps at full capacity and the ship services. This allows the diesel alternator to be closed down". Did this mean that the voltage dip was not critical and that a 15 per cent voltage was not needed? Were Lloyd's Register of Shipping requirements frequently more stringent than they needed to be?

The CHAIRMAN Mr. G. Victory, F.I.Mar.E., President of the Institute, said that he was sure that there were many who could contribute, particularly on the "to earth or not to earth", the neutral question. Being a little ignorant of the commercial aspects, he wondered whether anyone would give an opinion about the relative costs of this system compared with a 440V system, and with 3·3kV generating with 440V distribution system. He also wondered whether there was any history of automatic shut-down due to the earth fault monitoring employed. From the security aspect, he wished to know how the cables were protected from circulating currents. Would earthing be advisable at reasonable intervals, or would high surface resistance be relied upon? If they relied upon high surface resistance, how would the cables be protected from oil and oil vapour, dust and dirt, which could rapidly nullify a high surface resistance.

With respect to the alternators, it was not obvious whether there was any protection from flooding and, regarding the fact that these appeared quite low in the space, had the authors considered the need for flooding protection, and were the feeders taken upwards from the alternators to avoid water on the tank tops. Finally, was any difficulty experienced with the unbalanced effect on the engines when operating with one engine driving the alternator and the other one merely driving a propeller. Would one adjust powers on the propellers, or would one keep each propeller power the same and merely add the alternator power to one engine.

MR. M. J. A. BOLTON, F.I.Mar.E., said that, during his experience with a large, high voltage marine electrical installation, he had encountered several failures of significance in high voltage machines and switchgear. Had the three **Esso Mersey** class ships been quite trouble-free in this respect? If not would the owners comment briefly on the failures and their causes?

MR. G. E. WOODLIFF, B. Eng., F.I. Mar.E., commenting on earth leakage protection, said that high resistance earthing systems had been used for many years for propulsion systems because of Lloyd's Register requirement for such systems, i.e. "In alternating current systems the earth leakage fault current is to be interrupted or limited to a safe value."

The application of earth leakage to these ships by the authors was interesting since—referring to their previous paper—it was their intention to achieve earth leakage discrimination by means of current levels and time delays. The practical value of such a system was dependent on the value of the system capacitive current and the writer would be interested to know whether the objectives were achieved in practise.

To overcome the problems associated with the load testing of the a.c. generators, there was now available a 4·5 MW containerized load resistance suitable for a voltage range 3·3 to 11kV. This unit, which he must emphasize was resistive only, had proved very popular in load testing for marine and offshore use. It was skid mounted, had to be lifted as a unit, had a gross weight of 20 tonnes with approximate dimensions 6m x 3·75m x 4m.

The high voltage test requirement, for equipment to be used on a high resistance earthed system, was not precisely defined and he was interested to note that the authors had conformed to the industry's interpretation and used the test figures applicable to an earthed system, rather than those relevant to an unearthed system, even though the lines would not be limited to the phase voltage above earth as they would be with a solidly earthed system.

Since, apparently, it had proved impossible to meet the Classification Societies' requirements for the generator transient voltage response and since the authors' statements merely referred to load it would be most interesting to learn what was the load p.f. At the lower p.f.s. the A.V.R. was possibly just as significant as the engine governor and the inertia. The actual figure achieved at approximately 30 per cent of the engine rating did appear rather low, even considering that the engine, being basically for propulsion, had a relatively low inertia.

One of the most important electrical aspects of a shaft generator type of scheme was the frequency variation actually experienced. The authors did not give any details of the pitch control system; presumably no attempt was made to maintain the prime mover speed constant by shedding pitch to offset torque increments underway.

Although reference had been made to the usual frequency variations of ± 2 cycles, which corresponded to Lloyd's Register tolerances (±2·5 cycles), other Classification Rules permitted a wider frequency tolerance. Could the authors comment on whether the permitted frequency tolerances had proved unduly restricting.

There had been many comments regarding the voltage transients experienced with vacuum contactors and the authors were to be thanked in effectively dismissing this aspect by quoting their motor supplier's comment that the transients experienced were less than those they had experienced on conventional air and oil break contactors. It was significant that problems had been experienced on both vacuum contactors and the circuit breakers with timers of presumably quite traditional design.

Authors' Replies

In reply to the discussion, the authors said that the first point made by Mr. Adams regarding the flexibility of, and hence unrestricted operation of, the plant was appreciated by the seagoing staff. They disagreed that an insulated 3:3kV supply would have been a better application to the ship than an earthed system and it raised a fundamental question of integrity of supplies. While they could fully appreciate Mr. Adam's concern for maintaining plant operating, especially if it was essential for the propulsion of a vessel, this situation was not applicable to the Esso vessels, for the high voltage system was limited to cargo pumping and thrusters, and these services were not classified as essential for the operation of the ship.

The authors would all agree that loss of a thruster, especially while manoeuvring, would be of concern, but at present there were no Rules or Regulations to say that they should treat a thruster in the same way as steering gear. If this was necessary, it would be necessary to have duplicate supplies, run separately and motors could not be tripped under overload conditions. While agreeing that thruster controls, as offered at present, left something to be desired they would not agree that they should enforce, or employ, part of the steering gear regulations. This aspect really required to be considered further by Classification Societies, etc.

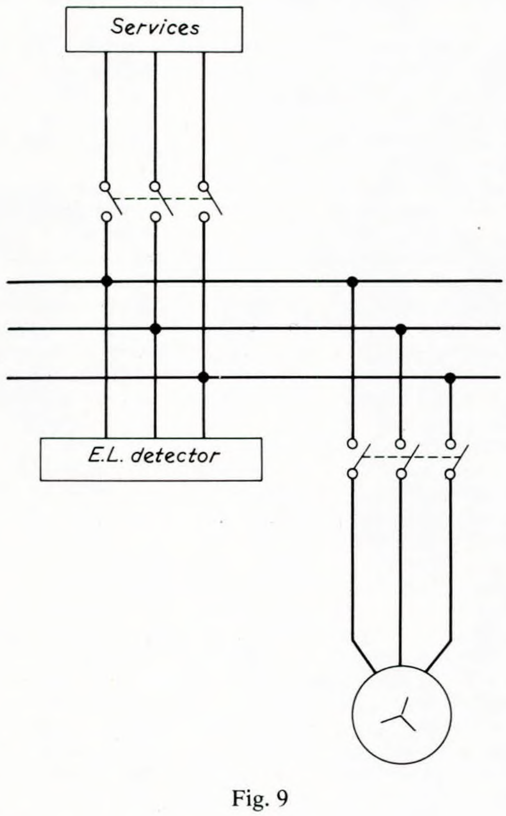

Fig. 9

Regarding the fitting of an isolation tranformer in the bow thruster circuit of the **Esso Severn,** basically they believed, from the electrical safety aspect, that this was a backward step. The H.V. system supply to the thrusters, used on the first two Esso vessels, employed a high resistance earthed, which limited the earth current to 7·5A and tripped an offending circuit if an earth leakage current greater than 200mA was detected.

When an isolation transformer was introduced, the thruster circuit became an insulated 3-phase supply and they now needed to consider the type of fault that could occur with the thruster feed cables. Practical experience showed that the cable faults occurred on the Fwd/Aft gangway, due to the flexing of the cables at the expansion joints (it might well be that modern vessels had more tendency to flex than previous ones and it might be necessary that the rule of thumb for expansion loops should be reconsidered). This flexing caused, initially, an open circuit fault which, through arcing, became a phase to earth fault (as a result of this experience the cable-lay at the expansion joints was changed on the **Esso Severn).**

In any insulated system, this type of condition could exist, unless detected and cleared, which could be quite a task in itself, until another phase fault occurred elsewhere on the system. The resultant phase-to-phase fault which would flow, probably via the ship's structure, would be limited only by the protective device on the primary side of the transformer.

Obviously if the insulated system could be confined to the engine room area, the potential fire hazard in the cargo tank area that could occur from arcing faults was eliminated.

The authors would suggest that a selective, high impedance earthed system was the best compromise where operational conditions dictated whether the system be connected to earth or not. Figs. 9 and 10 showed "the principles involved". Fig. 9 showed the conventional 440V distribution and earth leakage was indicated by earth lamps or similar. A fault on this type of system was usually cleared only after the offending circuit was identified or another phase fault occurred. It was appreciated that simultaneous phase faults were unlikely, but phase/phase faults could occur because individual faults were not cleared immediately. Under fault condition, relatively large currents with respect to capacitive currents, could circulate until the protection equipment operated. Fig. 10 showed a possible method by which the basic idea of high impedance earthing could be added to an existing

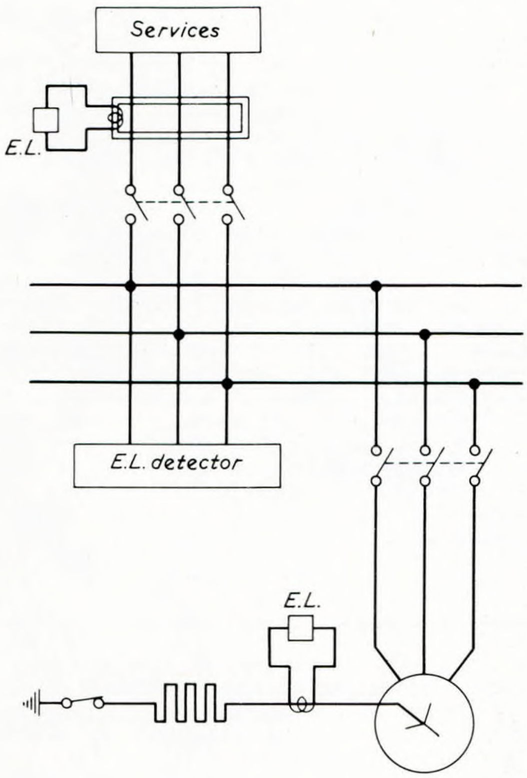

Fig. 10

ship plant and provide a selected earth detecting feature. Because the prospective earth current was low value, then the switch rating was also of low capacity. Outgoing circuits could be monitored and if necessary automatically tripped. The authors believed that there was relevant experience of these techniques in mining and other industries, and felt that they would improve the safety of the marine electrical systems.

Regarding the enclosure of the engine driven alternators, the same type of enclosure as the cargo pumps, i.e., closed air/air cooled, had been initially considered, but there was insufficient space for a cooler. For the same reason, clutches could not be fitted between the alternators and the gearbox, which would have reduced the running hours of the alternators.

They disagreed with Mr. Adams on the use of water cooled alternators as a generalized solution, as they could bring their own set of problems, as Esso knew to their cost. During the past years, the owners had experienced the failure of alternator water cooler tubes on their vessels and had since reverted to air cooled, totally enclosed machines. Even though water cooler leakage detection equipment was fitted, this appeared to tell the operator that water cooler leakage existed, usually after the damage to windings had occurred.

On the third Esso vessel, the alternator enclosure was re-designed to have the inlets and outlets on the top of the machines, with air filters on the inlets.

Regarding dirt in the alternators, a point that should be stressed was that these vessels spent a considerable amount of their time maneouvring and this increased the opportunity for soot and exhaust gases to "fall-out" upon the upper decks of the vessel and be "sucked" into the engine room ventilation supply. Initially the majority of the deposits within the alternator came from this source. The use of filters and repositioned engine room ventilation ducting would prevent this occurring in future.

Oil and oil mist had been a problem and a variety of methods had been employed in order to prevent oil entering the machine, but this caused less concern than the dust and soot.

They would leave Mr. Prager, as a machine designer, to comment on the advisability of paralleling by the method described. Maybe, with the machine breakers working "upside down", they would hold-in better in the Southern Hemisphere.

On the Esso vessels there were no problems when energizing the 1150kVA transformer from the 3·3kV system. They would suggest that the contributor would have greater problems than they if he tried to energize the 3 MVA transformers on his vessels from the 145V system. Adequate shore supplies would also be required if they were to be connected to the 3 MVA transformer.

Inrush problems, on large transformers, could be reduced if the residual magnetism in the core could be reduced to zero, and some ideas on how to reduce the voltage to zero before switch-off or provide a d.c. winding on the core to eliminate the residual might be of assistance on future applications.

Again the authors would suggest the use of a selective earthed system to provide the "best of both worlds", in reply to Mr. Goodman's first point. Regarding the second point, one needed to differentiate between systems that were classified as essential, and those treated as essential. They felt that the bow thruster had been treated as essential service by:

1) supplying it from a generator five times it size;
2) providing a duplicate service, i.e., stern thruster;
3) providing directional earth detection on all individual 3·3kV circuits, thereby ensuring that the earth fault was actually on the circuit concerned, rather than on the circuit concerned, rather than on the 3·3kV system.

As stated previously, the point regarding classifying bow thrusters as essential services should be taken up with Lloyd's Register and the D.T.I., but first they would suggest that existing classified essential services should be examined, e.g., steering gear.

Regarding the bow thruster motor rating, the authors would agree that a continuously rated machine was required for these vessels, but would not be so presumptious as to say this should apply to all thrusters, it depended upon the duty cycle required.

The limitations of thermistors were now recognized by the motor manufacturers, but were not known at the outset of the Esso contract.

It could be deduced from the comments that:

1) they should not be applied to high tension motors—presumably greater than 440V;
2) that they were intended for small low voltage machines.

The authors would have preferred P. and B. Gold's relays for motor protection, but, at the outset of the Esso contract, they were not available as a solid-state unit and the 3·3kV thermal unit was not acceptable to Lloyd's Register for cargo pumps and thruster. Motor protection was provided by stall protection relays.

The air inlets, on the drive end of the engine driven alternators, were on the opposite side of the gearbox to the engines that were driving them and, therefore, not in as close a proximity to the drive engines as one might expect, though the authors would agree with Mr. Goodman that a better solution would have been to have the air drawn into the machine from the none-drive end and discharged at the drive end. Esso asked, during the building of the first vessel, if this could be re-arranged, but the whole design of the alternator would have been affected and delivery delayed, which was unacceptable.

Mr. Goodman had indicted that there might well be other problems with water cooled sets, e.g. blocked tubes, and changing to water cooled sets might not necessarily be an improvement, but just introduce a different set of problems as the owners had experienced on other vessels.

Mr. Prager's opening remarks would seem to favour a high resistance earth system, from a machine designer's point of view. Regarding thermistors, the authors would repeat that, at the time, they appeared to be a cheap and dependable method of over-heat protection for machines generally. Regarding the enclosure of machines, whether totally enclosed or not, they required to be maintained from time to time, or sometimes repaired. It was possible, therefore, to concentrate on the enclosure aspect above and thereby make maintenance or repair impossible *in situ*. One, therefore, had to compromise on what was desirable and what was practicable, within limits of cost and size.

They were also surprised to hear of the Australian "Crash change-over" system and did not believe that many owners would tolerate their plant being handled in this way, and would favour a controlled paralleling operation and then close-down of one alternators.

Regarding voltage dip, Lloyd's Register Rules did allow for dips greater than 15 per cent (covered in Lloyd's Register recommendations Chapter M).

Mr. Prager had raised the point, related to cargo pumping, about the 15 per cent voltage dip and asked if it was critical. The initial design intent was that an engine driven alternator would be fully loaded if the four cargo pumps were operating at full discharge rate and, therefore, a diesel alternator would be required to supply ship services.

In practice, it had been found that, after all four cargo pumps had been started and settled down, there was sufficient spare capacity within the generating plant to supply the ship services. Voltage dips had been recorded at the vessel and a maximum dip of 12 per cent had been indicated.

Mr. Claridge's company had expressed doubts about vacuum contractors for marine applications, but, considering that this was the first marine application of vacuum contractors, there was very little trouble. Regarding vibration and shock aspects, the vacuum contractor "bottles" had been subjected to tests by the MOD(N) Laboratories and were acceptable for use in warships. Details of these tests were made available to Lloyd's Register and the only the test required was a humidity and ambient temperature test at the maker's works.

The only precautions taken on vacuum contractor gear were to a fit a safety catch on the pull-out drawers, in case of ship movement during maintenance. The vacuum contractor panel was mounted on an inverted channel plinth with no special lining-up procedures or resilient mounts. Vacuum contractors did require considerably less maintenance than conventional switchgear.

It might not be clear to the contributor, but the switchboard control was a true mimic diagram with discrepancy switches controlling machine breakers. The desk section contained all the switches necessary to set up the plant. The normal operators were watch-keeping engineers and, because of the trade pattern of the vessel, the frequency of switchboard operating was much higher than on a conventional vessel, but few operational errors had occurred.

The advantage of this particular mimic was that, before operating any breaker, its respective illuminated control switch could be turned 90° to its operating position against the flow of the mimic and the discrepancy relay operated and cause the illumination to flash "off" and "on". The operator then had visual indication that this was the breaker to operate, this assisted in preventing accidental mal-operation.

In reply to Mr. Bolton, the authors said that the failures that had occurred to the 3·3kV equipment on the three vessels had all been mentioned in the paper. These failures had not numbered any more than one would expect in a conventional 440V system. In fact the 3·3kV system, having more comprehensive protection, e.g., earth leakage protection, etc, had given the operator greater confidence in the possible prevention of damage to machinery.

The vacuum contractors had proved far more reliable and maintenance-free than conventional air-break contractors.

In reply to Mr. Woodliff, the authors said that they had intended to achieve earth leakage discrimination between one alternator and the motors by means of current levels, and between one alternator and the 1150kVA transformer by time delays. Because the incidence of faults was so small, they did not know if the objectives were achieved, but had had no complaints from the ships' staff.

As Woodliff had pointed out, the value of the system capacitance current and associated switching transients could cause system instability, but practical levels had been set and tested frequently at the vessel.

Regarding the containerized load unit for testing alternators, they could see one limitation in the fact that the load was purely resistive and, therefore, would not fully test A.V.R.

They would point out that there were no specific rules defining the tests to be carried out on a main-engine driven alternator, and it was not possible to test the main engine on these vessels in accordance with the Lloyd's Register requirement for auxiliary diesel generators. However, a 40 per cent step load at a power factor of 0·8 was achieved.

Mr. Woodliff had raised the question of frequency variations, etc. and details of the propeller pitch control system. Basically the propeller pitch was set by the engineer, or bridge, to achieve a service speed and no attempt was made to vary the propeller pitch to maintain a constant torque. This would be very difficult to achieve in practice and would be a further complication in a basically complex system.

The frequency variation of ± 2·5 cycles had not proved restrictive. As stated in the paper, sea conditions were normally anticipated.

The load sharing, during a paralleling operation of a main-engine driven alternator and auxiliary diesel set, had been entirely satisfactory. During a normal change-over from auxiliary diesel to main-engine driven alternator, at sea, the alternators had been left in parallel and only a very slow acceptance of load by the main-engine driven alternator occurred.

Mr. Victory had questioned the relative cost of the 3·3kV system compared with a 440V system. As stated in the paper, the decision to use a limited 3·3kV system was based primarily upon technical and practical considerations, rather than purely economic reasons. One of the fundamental practical aspects was that the basic scheme was capable of meeting all foreseeable cargo pumping demands, without placing restrictions on plant operations.

Regarding costs, the obvious saving by using 3·3kV, rather than 400V, was in cable, but since the 3·3kV system on these vessels was basically restricted to the engine room, the saving was not pronounced. Regarding the switchgear, it was the size that favoured the use of 3·3kV equipment. The difference in size of machines was not great but, cable connexion was much easier with the 3·3kV system.

There had been only one shut-down on the 3·3kV, involving the earth leakage trip, and the authors were inclined to believe that this was due to cable fracture which led to an earth fault. For the point regarding surface resistance and possible deterioration of the cable resistance because of exposure to oil, dust and dirt, they would refer the contributor to a paper by Mr. Teasdale of B.I.C.C. on the subject (Report No. WGC-L/G/711). However, the practical results after five years of operation showed no deterioration in the cable insulation resistance and none was anticipated. Also, as the cables were unscreened, the problem of circulating currents in the sheath did not arise.

Mr. Victory had raised the point about the possibility of flooding of the engine-driven alternators. These machines, which were on the tank top, were not essential to the propulsion of the vessel and no arrangements were made to ensure that they were watertight.

With regard to the question "Any difficulty with the unbalanced engine etc.", the situation, as mentioned, did not occur, as both engines were clutched in to drive the propeller, at all times, when both engines were available for manoeuvring.

The c.p. propeller system automatically shed load under an overload condition and, during a practiced emergency manoeuvre (Williamson Turn), the alternator remained on the switchboard during the total time involved. An overload condition on either engine was detected by the governor and through a "Kinetrol" control valve, a signal was then sent to the automatic pitch reduction system.