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# DESIGN CONSIDERATIONS FOR ELECTRIC PROPULSION OF SPECIALIST OFFSHORE VESSELS

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# Design Considerations for Electric Propulsion of Specialist Offshore Vessels

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## SYNOPSIS

*In recent years an increasing number of specialist vessels have entered service to meet the needs of offshore exploration, production, emergency and maintenance roles within the oil industry. BP Shipping's technical design staff have been extensively involved in producing the designs for vessels of this nature which are now in service and those which are still at the conceptual stage. The designs of these vessels have to meet many varied requirements. The choice of propulsion and power plant, be it dedicated for the transit propulsion mode or integrated into a dynamic positioning system, is often far from straightforward. The authors look at some of the options available to the design engineer and discuss the choice of systems on two vessels recently delivered to their company.*

## INTRODUCTION

The earliest records available indicate that the first introduction of electric propulsion was approximately a century and a half ago. This was a small Russian ferry (1839) which was propelled by an electric motor fed by a storage battery. Little development occurred until 1903 when another Russian vessel, a tanker, was built having three diesel engines driving d.c. generators which each supplied a motor coupled directly to a propeller. In 1908 the Germans introduced turbo-generation with two propulsion motors and in the same year similar installations were made in the USA. The d.c. installations were supplemented in 1913 by the introduction of a turbine-electric a.c. propulsion plant in the US Navy vessel *Jupiter*. The first diesel-electric installations made in the UK were on a trawler and a yacht in 1919.

In general, the types of vessel which have been supplied with electric propulsion systems have tended to be specialist craft, where conventional methods of propulsion could not be modified to provide the desired operational requirements; or where the multiple functions called for a centralized power distribution system. Examples of the type of vessels to which this applies are submarines, factory trawlers, T2 class oil tankers, icebreakers and hydrographic survey vessels. These types can be put into four categories:

(i) No alternative to electric propulsion, i.e. submarine use.
(ii) Fuel economy coupled with low speed, high torque requirements, as is necessary for vessels operating in ice.
(iii) Multiple function vessels requiring high power services in addition to the propulsion requirements, e.g. factory trawlers and hydrographic survey vessels.
(iv) Vessels where mechanical constraints and the time available for building tipped the balance towards electric propulsion, as with the T2 class of oil tanker.

It is interesting to look at the reasons for the choices made for the propulsion systems on the T2 tankers and icebreaking craft. The T2 tankers were built under the Liberty Ship Scheme where the ability to manufacture components ashore, and then to install them ready to use, was essential. The tonnage (14 000 dwt) of the class was in excess of that afloat at the time and the propulsion would have required development work to obtain suitable gearboxes using conventional systems. For these reasons electric propulsion was chosen having a.c. motors and generators with a steam turbine plant. These combined to give a very simple system to operate which, it is purported, ran continuously between drydocking periods.

The icebreaking class of vessels was initially propelled by the reciprocating steam engine which was considered the ideal prime mover, offering immense reserves of low speed torque with a capacity for rapid manoeuvring. Considerations of fuel economy gave rise to the replacement of this system by medium speed diesel engines, which gave better fuel economy, more compact installations and, by avoiding the need for boilers, cleaner operation. The inability of the diesel engine to develop high torque at low speeds was remedied by the use of d.c. electric transmissions which could give torque characteristics, with fixed propellers, similar to those of the steam engine.

It is evident from these approaches to the design of propulsion systems that the electric options were selected to overcome the shortcomings of conventional systems. This is not entirely the case with present day technology, where options exist on merit for either type of installation. In this paper we shall look at the requirements of two specialist offshore vessels and discuss the decisions that were taken with regard to the selection of the power distribution and propulsion drive systems, and how these decisions may be revised by developments in technology or application to specific cases. This is approached in terms of selection of the power system, thruster/propeller units and drives, distribution system and control requirements. In conclusion, future trends of control facilities and motor drives, together with the problems that may be encountered, will be discussed.

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## THE POWER SYSTEM

The design of this system involves consideration of a number of factors associated with the propulsion requirements, other large power consumers and essential auxiliary services. Some of these are:

(i) The type of drive for the thrusters and/or propellers.
(ii) The system control features and their interfacing.
(iii) The necessary levels of plant redundancy implicit in the various operating roles.
(iv) The type of distribution system.

For specialist offshore vessels, it is frequently the case that an electric propulsion and power system emerges as the best techno-economic solution.

## THRUSTER AND PROPELLER SELECTION

The selection of the drive system for thrusters and propellers obviously depends upon the choice of the units themselves. A brief examination of the merits of the units available is worthwhile before considering the type of system employed to drive these units.

The hull configuration and operating draught are important factors when considering the merits of tunnel, retractable or underslung thruster units. The types of thruster normally considered are azimuth, Voith Schneider and tunnel, with a selection to be made between fixed and controllable pitch.

Azimuthing thruster units offer a high thrust/low driving power ratio (the power required to achieve a given thrust output), in both the ahead and astern modes. Their disadvantage is the large space requirement necessary when operating draught is insufficient for an underslung unit.

The Voith Schneider unit's advantage of rapid reversal of thrust is attractive when considering the requirements of a dynamically positioned (DP) vessel. However, transit speed requirements and its lower thrust/high driving power ratio can make this choice unattractive.

The tunnel thruster has the advantage of being available when there are draught restrictions. A disadvantage is the inability to vector the resultant thrust. Both fixed pitch and variable pitch units can be used within the tunnel (as is also the case for the azimuth units). Some of their merits are discussed as follows.

Fixed pitch units are attractive in terms of blade strength, blade maintenance, absence of complicated hydraulic systems in inaccessible positions for blade control, and low capital cost. These must be weighed against the disadvantages of difficulties associated with blade repair, the time taken to reverse the direction of thrust, the compromise in blade design to achieve ahead and astern thrust balance, and the need for a variable speed drive.

The advantages of variable pitch units are a thrust/drive power ratio more in balance due to one leading blade edge, readily achievable blade replacement, a good thrust reversal response time and a fixed speed drive. The disadvantages are higher starting loads, shaft complications, inaccessible hydraulics, high capital cost and blade stress that can be higher than for a fixed pitch unit.

## THRUSTER AND PROPELLER DRIVE SELECTION

Given a choice between fixed pitch and variable pitch propulsive units and the need for a centralized power source (direct drive diesel engines being not suitable), it is necessary to examine the electrical drive units available. Constraints that can be imposed on the choice of drive are limited space availability, the need to minimize weight and large drive power requirements. The systems available can be categorized into three main types:

- variable speed a.c. (alternating current);
- variable speed d.c. (direct current);
- constant speed a.c. (alternating current).

Variable speed a.c. drives have developed considerably during the last decade, principally owing to the advances in electronic power control systems. These control systems are necessarily complex but an advantage exists in that the motors can be of the robust, relatively maintenance-free squirrel cage construction, and thus can be mounted in inaccessible locations.

In the early stages of the development of the static inverter, the speed ranges offered and the drive capacities were limited. However, more recently the motor outputs have been substantially increased. The overall efficiencies for these systems are now being claimed to approach those of the thyristor-fed d.c. drive. A disadvantage of using a standard induction motor with these systems is that for wide speed ranges the motor torque will tend to fall off at both upper and lower ends of the speed range and some derating of the motor may be needed. Other complications exist, such as the need for forced ventilation which reduces the reliability.

It also follows that a motor designed for a given output at a set frequency may not necessarily be directly transferable for use satisfactorily as a variable speed drive.

Other forms of variable speed drive exist which employ a.c. motors such as the commutator motor and switched reluctance drives (low power machines) which are not suited to propulsion applications.

As propulsive motor power requirements increase, there would seem to be an advantage in developing the Kramer type of drive (this is a wound-rotor induction motor which uses its slip-frequency rotor power for control). Although a small disadvantage exists in having to utilize a wound-rotor slipring machine, the advantages of being able to supply the main stator winding at high voltage could be considerable.

Variable speed d.c. drives have been in existence for decades and have dominated the market. The more recent of these are separately excited d.c. motors, having their armature fed at variable voltage from a thyristor bridge. This domination appears likely to continue in the near future for reasons of:

- high levels of efficiency;
- versatility;
- wide speed ranges achievable.

The range of output capacities can also be attractive, being available from fractional horsepower through to standard controllers of up to 1000 kW (although the smaller machines would not be suitable for propulsion considerations).

The a.c. drives in the style of the long established and well known squirrel cage induction motor remain the cheapest solution for applications where fixed running speeds are adequate. The inherent characteristic of the squirrel cage induction motor is that it draws a high current on starting and tends to have correspondingly high starting and accelerating torques with short run-up times. This has some advantages when considering DP requirements but has disadvantages when considering the power plant, having to cater for the high starting currents in both cabling and power availability, and the machinery itself, which could be subject to excessive wear or damage.

The starting performance can be modified either by design of the machine or by using some form of reduced voltage starting. More recently thyristor controls have been developed to give a 'soft start' facility, which is a current-limiting feature to enable the motor to accelerate with a constant current or preset rate. This also provides a degree of energy saving. The capacity of these devices is limited to outputs of around 900 kW. For economic reasons, motors above 1000 kW would usually be operated from higher voltage sources (e.g. 3.3 kV, 6.6 kV or higher) utilizing vacuum contactors. Where there are significant periods of running at fractions of full load, the designs of motors need to be enhanced in terms of efficiency and power factor, although on marine installations this can be a trade off against resistance to flexing. Poor power factors can be improved by using synchronous motors and adjusting the motor excitation, but this is more applicable to constant running loads and reduces the machine's performance in terms of accelerating and overtorque capabilities.

Both a.c. and d.c. variable speed systems incorporate thyristor drives which generate harmonics that are imposed on to the power system. This means that the effect on other delicate communication and control systems would have to be catered for; although this is surmountable, careful consideration is a vital part of the design study.

## THE DISTRIBUTION SYSTEM

Electrical distribution system design follows on from the selection of thruster and propulsive unit drive systems, generation systems and the control and redundancy criteria. The design of a distribution system must fulfil certain requirements:

- security of supply to essential circuits;
- reliability;
- flexible operation.

### Security

The security of supply to essential circuits—the vessel's switchboard arrangements and the switchboards themselves—must stand up to the same scrutiny as the elements of the control system. There is no point in having a sophisticated control system with inbuilt redundancy if a failure of a busbar system results in the loss of all the thruster or propulsive units.

Very close attention must be given to the auxiliary circuits required for the prime movers and associated systems, as well as those forming part of the propulsive and thruster packages, to ensure that common mode failures cannot occur.

### Reliability

The reliability of the equipment must be examined and must at least meet the minimum requirements. Many types of circuit breaker are at present available and their use compared with contactors has to be examined. The merits of the two systems are discussed later.

### Flexible operations

To achieve a good design, the aspects of flexibility must be applied equally to the distribution layout and the method of control. The ability to keep plant operating by using back-up interconnections can be essential for a vessel operating in an emergency role, whereas the reduction of manpower achieved by easy-to-use centralized control can make the vessel more commercially viable in its support and maintenance role. It can be argued that there is a trade-off between a more complex control arrangement and a simplified system when considering the security and reliability of the overall system. We would agree with this; however, if a case is made for such a system, the onus is on the designer to ensure that the right levels of security, reliability and flexibility are achieved.

### Vacuum contactors and vacuum circuit breakers

Vacuum contactors and circuit breakers are similar in that both have contacts that are encapsulated within a bottle from which the air has been removed. This provides a vacuum in which the phenomenon of ionization, which is associated with air contactors/circuit breakers, is not experienced. The advantage of this is that the contacts are not subject to the same wear, maintenance or replacement within the operational life of the circuit breakers/contactors. These advantages are important for the marine industry, where staffing levels are less than in industrial applications, and for DP diving vessels, where downtime has to be minimized.

The mechanism of contactors and circuit breakers in a vacuum is little different from their operation in other mediums. However, there are features associated with vacuum equipment which are more severe owing to their fast operating times, and the rapid recovery of dielectric strength after arc extinction. This is clearly a detailed subject and will not be addressed in this paper. However, the result can be quantified as an increased stressing of the system insulation due to the generation of voltage spikes caused by 'pre-strike reignition surges' and 'multiple reignition surges' occurring at contact breaking.

The main differences between vacuum contactors and vacuum circuit breakers are:

(i) Contactors require back-up fuses for short circuit protection.
(ii) The amplitude of voltage spikes is generally less for contactors.
(iii) Circuit breakers have a reduced capability for frequent operation and a shorter life.

### Motor starting

Of the three most commonly used methods of motor starting, direct on line (DOL), star delta and auto-transformer, DOL has advantages in terms of weight and space. However, the generator's ability to provide the necessary starting voltamperes (VA) required by the motors also has to be considered. This can be countered by the design of the generators and motor themselves.

## 'IOLAIR'

### General description and functions

*Iolair* is a semi-submersible purpose designed and built to enable her to respond quickly to an offshore disaster. This is her primary function, the secondary function being that of an inspection and maintenance vessel. *Iolair* was thus built to provide emergency cover for BP's Forties Field; however, the design was based on a wider use of the vessel.

The requirements of the vessel for the emergency role were:

(i) To act as a secure in-field command and control centre from which all, or any, of the vital activities necessary to deal with a major offshore platform disaster could be conducted close to the scene of the emergency.
(ii) To provide fire-fighting and cooling to a platform for prolonged periods of time.
(iii) To provide rapid rescue facilities for platform personnel.
(iv) To have the facilities necessary for life saving and advanced medical treatment.
(v) To be able to withdraw safely from a dangerous gas concentration.
(vi) To be able to carry out a well-kill operation.
(vii) To be capable of holding position close in to a platform, using a computer based DP system and accepting any single mode failure.
(viii) To have a transit speed in excess of 12 knots.

The requirements of the inspection and maintenance role were to provide:

(i) A saturation diving complex that would allow divers to remain under pressure for long periods.
(ii) An operational base for shore-to-field helicopters, with in-field transportation provided by a small helicopter garaged, maintained and fuelled on the vessel. The provision of fuelling and defuelling of the long range helicopters was also required.
(iii) Workshop and crane facilities to carry out subsea repairs and maintenance work. The cranes were required to operate either through the centre deck moonpool or over the side. For salvage work, *Iolair* was required to lift loads of up to 500 tonnes off the sea-bed, using her own buoyancy.

(iv) Living accommodation to cater for over 220 berths, with a range of rest and recreation rooms, a first class galley and a cinema.

(v) A four-point mooring system capable of mooring in depths up to 150 m.

The design of the system evolved as a semi-submersible with an operating displacement of 19 676 tonnes. Buoyancy is provided by twin pontoons each 102 m long and 11.6 m wide supporting, via six vertical columns, a deep superstructure of three decks and a double bottom. Three inverted V-shaped bracings supply extra structural support while leaving a large clear area between the pontoons. The vessel platform is arranged into three basic areas—machinery spaces, accommodation and a self-contained diving complex. The upper deck houses the bridge control, helideck, helicopter hangar, cranes and workshop. Accommodation is spread between all three decks, while machinery spaces and the diving complex are mainly in the two lower decks. In the centre of the vessel is a large, rectangular moonpool.

The multirole function of the vessel meant that the power requirement was diverse; Table I indicates the range of loads for some different operating conditions. The generation voltage was selected at 6600 V owing to the size of the system, this being a function of the environmental conditions and the operational procedures taking place. Considering this requirement together with the provision of the necessary redundancy associated with a dynamically controlled diving vessel, a detailed design evaluation had to be undertaken to determine the type of system needed to power and propel the vessel. This evaluation was no different to that which would be needed for other specialized offshore craft. The decisions and processes that follow are particular to *Iolair* and its electric propulsion system but they can equally be applied to other situations.

The drive for *Iolair* was ultimately selected on consideration of the following factors.

The d.c. variable speed option had the disadvantages of the motors' physical size, weight and maintenance. The power required meant that motors would have to operate in tandem, which involved more machines, larger cables and more of them. Space, weight and weight distribution were critical and the siting of the control equipment was difficult. Another factor to be considered was the environmental conditions that would exist. Other considerations were that there was no other requirement for d.c. on the vessel, and additional transformation of the supply voltage would be necessary for the 720 to 900 V range needed for the d.c. system.

The a.c. variable speed drives available at the time of the *Iolair* design did not offer the capacity which was necessary; Table II shows the sizes of drive motors required. Variable frequency was still a novelty at that time, and the a.c. commutator motor system involved the same disadvantages as the d.c. variable speed system.

The comparison of costs for equipment/installation requirements for *Iolair* also came out in favour of the variable pitch thruster/propeller system with fixed speed induction motor drives.

*Iolair* incorporated a vacuum circuit breaker switchboard, mainly as a result of:

(i) A preference for low maintenance (compared with other mediums).

(ii) Thrusters, propellers and transformers would have no fuses subject to fatigue, as would be the case if vacuum contactors were used.

(iii) Space savings (busbar conversion boxes for contactors would not be necessary); and similar purchase costs between vacuum contactors and vacuum circuit breakers.

**Table I: *Iolair* load analysis**

| Operating condition | Electric load<br>Total mean MW | Total peak MW | No. engines for security |
|---|---|---|---|
| 1. Anchor | | 3.17 | 2 |
| 2. Free running | | 10.78 | 4 |
| 3. DP and diving[a] | 10.47 | 12.64 | 5 |
| 4. DP, diving and crane[a] | 19.7 | 12.87 | 5 |
| 5. Close-in emergency (DP and anchors)[a] | 14.71 | 16.26 | 6 |
| 6. Stand-off cooling (max.)[a] | 18.05 | 20.22 | 6[b] |

[a] Electrical loading assumes maximum thruster power allocation is being utilized to maintain station in limiting weather and sea state conditions.
[b] No security in event of one engine trip.

**Table II: *Iolair*'s main electrical loads**

| Drive | Number installed | Individual power (kW) |
|---|---|---|
| Main propulsion motors | 2 | 2240 |
| Thruster motors | 4 | 1500 |
| Main propulsion/fire pump motors | 2 | 2240 |
| Fire pump motors | 2 | 2240 |
| Electrode boilers | 2 | 1200 (kVA) |
| HV/MV transformers (6.6 kV/415 V) | 3 | 2250 (kVA) |

## Control features

The philosophy of the control system for a vessel incorporating DP with diving facilities must bear careful consideration. This must extend to all the individual components of the design, in addition to the overall system. The type of system selected, be it a fixed pitch variable speed drive or a variable pitch constant speed drive, together with the associated upstream facilities, have differing importance when considering their reliability or redundancy. When these aspects are interfaced with the computerized DP system, power management system and electrical distribution systems, the designer has to ensure that they come together in a way which not only is cost-effective but also retains the intended operational features. This is no easy task, as control signals between different manufacturers' equipment may not be matched, failure modes of equipment may be undesirable and require design changes, and the unit construction may require adaptations to accommodate the operating philosophy.

Particular aspects to consider are:

(i) Propeller pitch hydraulic control system and failure modes.

(ii) Speed of response of thruster hydraulic system.

(iii) Step-change demands from the DP computer systems.

(iv) Available power.

(v) Redundancy.

### *Propeller pitch hydraulic failure modes*

The operating mode of the vessel has to be examined together with the inherent failure mode of the pitch hydraulic system. If the vessel is operating in a DP role close to a fixed structure, it may be desirable to have a failure mode which enables the Master to drive the vessel away from the structure. However, a failure mode which removes the pitch applied is less demanding on the power system and also allows the remaining thrust units to attempt to take up the immediate shortfall. A third option is that the hydraulic system locks up under failure and the pitch remains in the 'as was' condition. This system is generally the most attractive but is not the standard employed by many manufacturers. The ability to jack the pitch manually is desirable. This has to be done with the shafting in motion, as restarting the motor with pitch applied may exceed the torque run-up capabilities.

### *Speed of response of thruster hydraulic systems*

The rate at which pitch can be applied or removed from the thruster units is important to the successful operation of a DP system. It has to be responsive to provide good station keeping ability, but also has to take account of the transients which can be imposed on the power system and be a controllable system. If the gain of the system is too high, then intermediate control of the pitch range can be impossible and cause oscillations to occur. Repeatability and minimal hysteresis of the control system are essential. These aspects can require departures from the standard range of equipment on offer and must be thought through and well defined.

### *Step-change demands from DP computer systems*

This can be a problem with the interface between the thruster control system and the DP system, as one is analogue and the other digital. Generally speaking, the design of the equipment caters for this problem and matches the responses by the introduction of ramp functions in the computer or smoothing the signal at the thruster control package.

### *Available power*

Under fault conditions, it is feasible that the power demanded from the thruster drive motor or the power available from the central source is insufficient to meet the demand. To meet this situation, a protective scheme is necessary which reduces the applied pitch on the thruster units to within the available power. This is important for two reasons. The first is that maximum power for DP must be retained to avoid loss of station. Second, the power must be held stable to allow other generators to be synchronized to the busbars. This situation should only exist for short durations as the total design philosophy requires that additional generation must be called up to meet the power required.

Faults which could cause a shortfall of power on *Iolair* and effect a pitch reduction are:

- Loss of two generators.
- Exceeding the pitch electronic stop position.

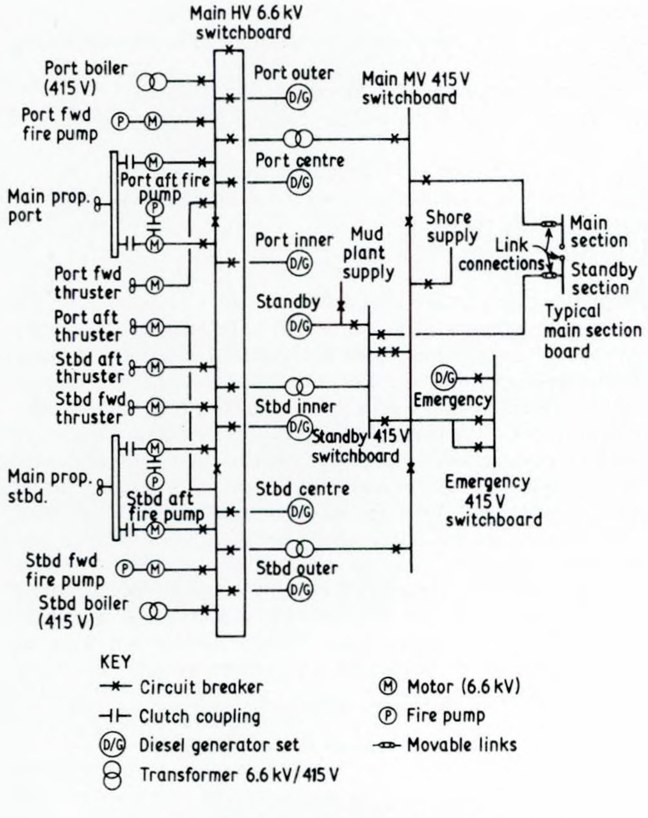

**FIG. 1** ***Iolair's*** **distribution layout**

### *Redundancy*

The operating philosophy of a vessel required to undertake a manned diving role whilst holding its position without the use of an anchor system must be based on having a high degree of redundancy. The philosophy on *Iolair* was one of accepting any single failure fault condition, be it at component level or system level. This requires detailed examination of the individual items of equipment, the specification of back-up units where the item of equipment cannot meet the criteria, and a changeover system which gives a smooth transfer of control or power. At system level, fall-back control centres should be provided, these ranging from alternate spaces to local control at the item of equipment. The system fall-back philosophy has to be considered very carefully as it can be expensive, involving complicated controls which reduce the redundancy by introducing common mode failure.

These redundancy aspects resulted in designing the propulsive and thruster switchboard in a way which minimized the effect of a busbar fault. The construction of the switchboard was such that faults on one section could not spread to other sections and would even have difficulties in spreading from one cubicle to another.

As Fig. 1 shows, the services on *Iolair* can be connected via alternative routes in the event of a cable or switchboard failure.

The primary control positions of all prime movers, generators, and high voltage and main medium voltage circuit breakers on *Iolair* are centralized in a machinery control room with back-up control local to the high voltage switchboard.

It can be seen from Fig. 1 that all essential circuits have a separate source of supply from their standby units, as well as an alternative route should a supply feeder be lost. This system may not be required for all applications; however, the same logic can be applied so that philosophy and operational requirements are matched.

## 'SEAGAIR'

### General description

*Seagair* was designed to fulfil a different role to *Iolair*, providing first line intervention only. To increase her overall usefulness, the vessel is also equipped to perform other tasks. *Seagair* is used to provide a safety support facility for the Magnus oilfield. In appearance, this 2997 dwt vessel resembles a highly sophisticated supply ship.

The principal requirements of the vessel are:

(i) To provide first line fire fighting.
(ii) To carry out pollution control.
(iii) To carry, launch, operate and recover remote controlled vehicles.
(iv) To service field marker buoys.
(v) To land and take off S61N helicopters.
(vi) To carry not less than 1200 tonnes of deck stores or portable houses or workshops.
(vii) To rescue from a platform in an emergency approximately 300 men and provide shelter and first aid.
(viii) To provide a rescue/man overboard facility with rapid-launching, powered, inflated boats.
(ix) To act as a 'command' ship in a field emergency.
(x) To transfer fuel oil and water between ship/platform/ship and ship to ship.
(xi) To be able to withdraw safely from a hydrocarbon gas cloud.

Manoeuvrability and accurate positioning when alongside a platform, when operating helicopters and carrying out fire fighting and rescue duties are of prime importance. The vessel is equipped with a diesel electric propulsion system driving twin controllable pitch screws, two stern thrusters and two bow thrusters. To perform the fire fighting role, four fire monitors and two drenching pumps are fitted. These systems constitute the main loads directly connected to the power system (Table

**Table III: *Seagair's* main electrical loads**

| Drive | *Number installed* | *Individual power* (kW) |
|---|---|---|
| Main propulsion motors | 2 | 1865 |
| Bow thruster | 2 | 600 |
| Stern thruster | 2 | 600 |
| Fire monitor pump | 4 | 770 |
| Drenching pump | 2 | 277 |
| HV/MV transformers (3.3 kV/415 V) | 2 | 800 (kVA) |

III). The total vessel power requirement can vary considerably depending on the operating mode (Table IV). To have met the power requirements using individual diesels would have entailed a plant comprising too many machines to be considered practical. Although the initial costs would have been cheaper, the increased fuel and maintenance costs would have been considerable.

A diesel electric installation was chosen since this provides a highly flexible arrangement, together with good fuel economy and low maintenance costs.

## The electrical system

*Seagair's* principal electrical system (Fig. 2) has several major differences to *Iolair*, one being that a generation voltage of 3300 V was adequate. These arise principally due to the differences in operational philosophy. Although the machinery systems are designed so that no single failure will affect the ability of the vessel to fulfil its designed role, there is no provision for segregation to contain the possible effects of fire since time is available to suspend operations and deal with the fire.

To enable the vessel to perform satisfactorily under single failure conditions, the main high and medium voltage switchboards are equipped with bus-section circuit breakers and all the duplicated items of plant are supplied from opposite sections of these switchboards. The two 3.3 kV/415 V transformers are sized such that either can supply the maximum demand of the medium voltage system.

The various propulsive systems are all fixed speed a.c. motors driving controllable pitch propellers. An alternative scheme could have utilized fixed pitch propellers driven by variable speed a.c. or d.c. motors. This would have entailed a scheme similar to those shown in Figs 3 and 4. The scheme finally chosen was adopted for the following reasons:

(i) Smaller space requirement.
(ii) Less weight.
(iii) Lower cost.
(iv) Switchboards with adequately fault-rated busbar systems were more readily available.

## The control system

To enhance the high degree of manoeuvrability required for its duties, all four thrusters are linked to a single joystick control. This integrated remote control system incorporates a gyro repeater which can interface with joystick commands to keep the vessel on a fixed compass heading.

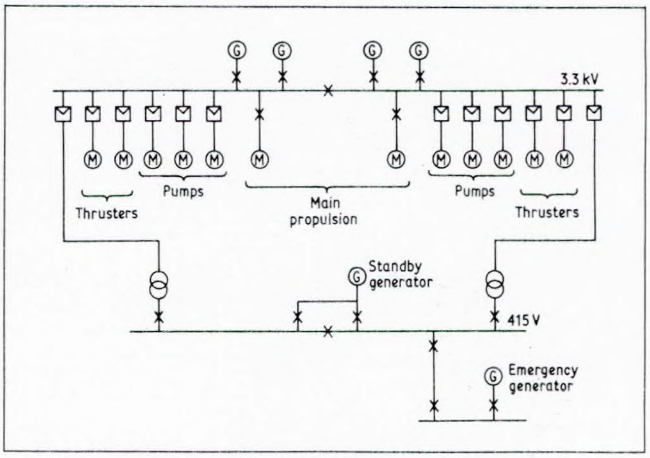

**FIG. 2 *Seagair's* principal electrical system**

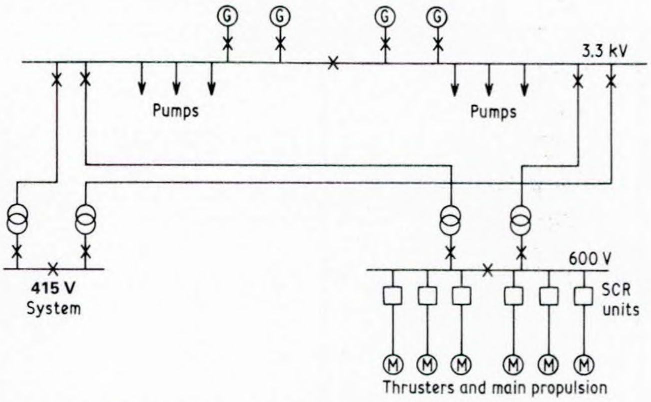

**FIG. 3 *Seagair*: alternative power system utilizing variable speed propulsive drives**

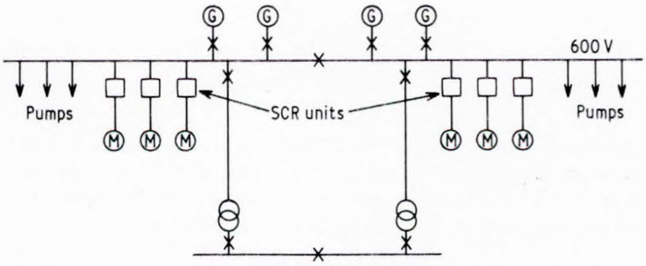

**FIG. 4 *Seagair*: alternative power system utilizing variable speed propulsive drives**

The vessel does not have a DP system since this was considered unnecessary for its intended duties. The individual and joystick controls of the propulsion equipment are electronic and incorporate analogue valve control. This control system is

**Table IV: *Seagair*: typical power requirements for various operating conditions**

| *Operating condition* | *Maximum power* (kW(e)) | *No. of diesel generators* | *Percentage generator load* | *Instantaneous generator load if one set shuts down* |
|---|---|---|---|---|
| 1. In transit | 4260 | 3 | 57% | 86% |
| 2. Station keeping average condition (6 knots) | 1328 | 2 | 31% | 62% |
| 3. Deploying remote controlled vehicles | 3913 | 3 | 54% | 81% |
| 4. Fire fighting | 7379 | 4 | 77% | 103% |
| 5. Rescue | 3781 | 3 | 53% | 80% |
| 6. Platform transfer | 3904 | 3 | 54% | 81% |

s.s./m.v. No. 00965

ELECTRICAL PERMIT-TO-WORK

**1 ISSUE**

To

I hereby declare that it is safe to work on the following apparatus, which is dead, isolated from all live conductors and is connected to earth: –

All OTHER APPARATUS IS DANGEROUS
Points at which system is isolated: –

Caution Notices posted at: –

The apparatus is earthed at the following points: –

Other Precautions: –

The following work is to be carried out: –

Signed
CHIEF ENGINEER

Time

Date

**2. DIAGRAM**

The above diagram details the system on which the work specified in 1 is to proceed and shows that points of isolation and application of Circuit Main Earths

Signed
CHIEF ENGINEER

Time

Date

**3. RECEIPT**

I hereby declare that I accept responsibility for carrying out the work on the apparatus detailed on this Permit-to-Work and that no attempt will be made by me, or by the persons under my control, to carry out work on any other apparatus.

Signed

Time

Date

NOTE: After signature for the work to proceed this Receipt must be signed by and the Permit-to-Work retained by the person in charge of the work until the work is suspended or completed and the clearance section has been signed.

**4. CLEARANCE**

I hereby declare that the work for which this Permit-to-Work was issued is now * suspended/completed, and that all men under my charge have been withdrawn and warned that it is no longer safe to work on the apparatus specified on this Permit-to-Work, and that gear, tools and other equipment are all clear.

Signed

Time

Date

*Delete As Applicable

**5. CANCELLATION**

This Permit-to-Work is hereby cancelled.

Signed
CHIEF ENGINEER

Time

Date

BP Printing England. 0682

**FIG. 5 'Permit to work'**

interfaced with the vessel's high voltage power system to limit pitch according to total vessel power demand and the amount of power available at any one time. Should generator overload occur, then automatic pitch reduction is initiated.

## HIGH VOLTAGE SAFETY

The introduction into the BP fleet of two vessels having extensive high voltage systems necessitated an examination of the safety procedures and working practices to be adopted for this plant. This resulted in the publication of a 'High Voltage Safety Rules' booklet which is issued to all personnel concerned with these systems. These rules are based upon British Standard 5405[1] and UK electricity supply industry practice, with suitable amendment for the marine situation.

These rules lay down specific procedures that must be followed before work is commenced and include the issue of a 'permit to work' (Fig. 5) or 'sanction for test' to the person under whose supervision the work is to be carried out.

This system has been well received by the regulatory bodies with whom it has been discussed; a more detailed description is given in Ref. 2.

## THE FUTURE

Recent trends in the design of equipment can offer useful features to the design engineer. Some of these are:

- Control units in modular form, allowing the machine builder or user to incorporate the package into his own equipment whilst providing other control equipment appropriate to his own application.
- Monitoring and self-diagnostic facilities, thus enhancing fault finding and leading to a reduction in downtime.
- Digital feed-back controls.
- More extensive use of programmable controllers and microprocessors, allowing the design to be fitted closely to the application.

The use of superconducting machines for propulsion duties in the marine sector is worth consideration. These motors are able to produce high torques and are extremely robust. Also, with careful optimization of the design parameters, machines can be produced with torques and powers far in excess of the performance of any motor based upon a traditional design approach; for example, a superconducting d.c. motor may be produced with a rating of 60 000 hp at 80 rev/min. The performance of the motor can be defined as follows:

1. Full load torque is available at any speed from zero to maximum.
2. Within limits of available power, overload torque is also available at any speed. The overload torque may typically be 150% continuous and 200% for 10 or 20 seconds.
3. Speed control is available over the entire range by control of armature voltage.
4. Within the maximum speed design limits, normal field weakening may be employed to go beyond the nominal full load speed.

The characteristics of the superconducting motor are ideally suited to the requirements of a marine propulsion system. Of particular relevance are the needs of icebreakers, where very high ratings and good manoeuvrability are essential.

The increasing growth of high power thyristor and other non-linear loads connected to vessels' electrical networks will, unless specific countermeasures are taken, give rise to increasing levels of harmonic pollution. The effects of harmonic distortion include:

- Increased temperature rise in generators and motors.
- Interference with control and communications circuits, electronic equipment and computers.
- Reduction in the accuracy of metering and settings of induction-type protection relays.
- Accelerated ageing of cables and capacitors.

The design engineer encountering the types of equipment likely to cause harmonic problems must ensure that adequate countermeasures are implemented.

## ACKNOWLEDGEMENTS

The authors wish to thank the Directors of British Petroleum Company PLC for permission to publish this paper; and their colleagues both within and outside BP Shipping Limited for their assistance and advice.

## REFERENCES

1. BS 5405: 1976, 'Code of practice for the maintenance of electrical switchgear for voltages up to and including 145 kV'.
2. H. Rush and S. K. Taylor, 'Electrical design concepts and philosophy for an emergency and support vessel'. *Trans. I. Mar. E.*, Vol. 94, Paper 28 (1982).

# Discussion

**N. V. ALMY** (E. C. Goldsworthy & Co.): In this very interesting paper the authors state that they considered Voith-Schneider propellers but that transit speed requirements and their lower thrust/high driving power ratio can make this choice unattractive. In their introduction to the paper, however, they showed a slide of a Voith water tractor with the propellers in the fore body. This is, of course, a special type of application where the propeller position is governed by factors other than optimum propulsion efficiency.

A more usual arrangement would be with the propellers aft, where they can be used very effectively for main propulsion but also providing all the transverse thrust required to control the after end of the ship in the dynamic positioning mode. Such an arrangement was adopted for the seabed operations vessel HMS *Challenger*, whose many roles include diving and other operations requiring the vessel to be dynamically positioned over long periods. She has a speed of well over 14 knots on a displacement of about 7500 tonnes and with an open moonpool, using two Size 36G Voith-Schneider propellers aft. Each propeller has two vertical electric motors each of 1150 kW giving a total of 2300 per propeller. Two motor speeds are available—1200 and 900 rev/min—so that power appropriate to any particular operating condition may be chosen.

As the authors have mentioned, the rapid reversal of thrust is an attractive feature of this type of propulsion and, in fact, full reversal can be achieved in about 7 seconds. For dynamic positioning, however, it is usually small adjustments about a given thrust condition that are required, rather than full reversal, and, in such cases, the time taken is approximately proportional to the amount of change. Thus, the time for half to half would be only about 3½ seconds. Such rapid response means that positional corrections can be made immediately and before the vessel has been able to deviate from the required position. The full reversal is, however, available if required and the vessel in question was able to stop from full speed in about 1½ minutes and about 1½ ship lengths.

**K. BROWNLIE** (Stone Vickers Limited): This paper highlights many of the factors which must be considered when selecting machinery for specialist vessels and the two examples described clearly illustrate that there is no general optimum solution.

There are just two points which I wish to raise. First, under the heading 'Thruster and Propeller Selection', it is stated that one of the disadvantages of the variable pitch units is 'higher starting loads'. In fact the starting torque for a variable pitch propeller is much less than for a fixed pitch propeller, as it is normal to select the pitch for zero thrust before starting the drive motor and in fact we provide an interlock to prevent starting unless zero thrust has been selected. (A variable pitch unit, if started in design ahead pitch, would have a very similar starting torque to a fixed pitch unit.) The lower starting torque of the variable pitch unit is one of its advantages.

Second, in the same section, another disadvantage of the variable pitch unit is said to be 'blade stress that can be higher than for a fixed pitch unit'. We would design fixed and variable pitch units to have the same maximum blade stress. This does not cause any difficulty in the variable pitch propeller design.

**J. H. DAVIDSON** (Shell Tankers (UK) Limited): I have two questions for Messrs Taylor and Williams. First, why was the voltage of 415 V chosen for the LV board? I should have thought that 380 or 440 V would have attracted more manufacturers to tender, unless of course the frequency was 50 Hz and not 60 Hz (not mentioned in your paper).

Second, I assume that an unearthed HV system was employed?

# Authors' Reply

Mr Almy's comments bear out the content of the paper in terms of selecting the equipment best suited for the application.

However, it is important that all aspects are considered before making a selection, as is the case when matching speed of response of a thruster to the power system needed to drive the thruster. It may not be the case that the fastest response of thrust reversal is the best suited for an electric propulsion system even operating in the dynamic positioning mode.

The first point raised by Mr Brownlie is in fact correct, but in the context of the paper is incorrect. The paper compares fixed pitch propeller, variable speed drive with variable pitch propeller, constant speed drive. In this instance the starting load when considering the induction motor supplying a variable pitch propeller is in fact higher than that of a fixed pitch propeller as seen by the induction motor during its run up period.

The second point is accepted although this may not be the case for all manufacturers.

In reply to Mr Davidson, the two vessels described were both designed primarily for specific fields: *Iolair* for the Forties and *Seagair* for Magnus. The fixed installations in these two fields all have 415 V 50 Hz systems. The choice of voltage and frequency were therefore dictated to the vessel designers as it was a requirement to be able to supply power to a platform should the need arise.

An unearthed HV system is utilized on both vessels.