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BEYOND ELECTRIC SHIP

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Ministry of Defence

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Beyond Electric Ship

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Biographies

Commander John Newell joined the Royal Navy as an Artificer Apprentice in 1976 and joined BRNC Dartmouth on promotion in 1978. On completion of his degree at RNEC Manadon and initial training as a marine engineer he served as the Deputy Marine Engineer Officer in HMS SIRIUS. He subsequently took a MSc in Electrical Marine Engineering and served in the MoD as the project officer for Pollution Control equipment. He then served as the Marine Engineer Officer in HMS BOXER before undertaking the French Staff Course in Paris. On return to the UK he spent 15 months with the Joint Planning Staff (precursor to the Permanent Joint Headquarters - PJHQ) before becoming one of the appointers. He was promoted to Commander in 1997 and was appointed as the head of the Electrical Power Distribution and Propulsion Systems specialist group within the Ship Support Agency in March 1998. Commander Newell joins HMS ALBION as Senior Naval Officer and Marine Engineer Officer in January 2001.

Commander Stuart Young joined the Royal Navy in 1977 and completed undergraduate and post-graduate training at the Royal Naval Engineering College in Plymouth. He has undertaken a number of appointments at sea, including Marine Engineer Officer of HMS NORFOLK, the Royal Navy's first CODLAG frigate. Shore appointments have included project officer for the procurement of Warship Machinery Operator and Maintainer Trainers, lecturer at the Royal Naval Engineering College and the Marine Engineering Liaison Officer with the United States Navy, based in Washington DC. He is currently the Electric Ship Programme Manager within the UK's Defence Procurement Agency.

1. Introduction

The use of a common power system for both propulsion and ship's services is now standard commercial practice for the cruise market and specialised shipping and is termed Integrated Full Electric Propulsion (IFEP). Efficient operation is obtained through the use of the minimum number of prime movers which are necessary to meet the required load, all running near their optimum efficiency, selected from a relatively large number of smaller units. Partial Integrated Electric Propulsion has been employed with considerable success in the Single Role Mine-Hunters. The first of this class, HMS SANDOWN, entered service in 1989. Partial Integrated Electric Propulsion was also selected for the Type 23 in a CODLAG configuration. The first of class, HMS NORFOLK, was commissioned in 1990. The first full IFEP ships for the Royal Navy will be the Auxiliary

Oiler (AO) and the Landing Platform Dock (Replacement) (LPD(R)). The first AO is due to enter service in 2002 and the first LPD(R), HMS ALBION, is due to enter service in 2003. These platforms follow the accepted Royal Navy practice of maintaining a minimum of two generators running at all times.

In the All Electric Ship (AES) concept fewer but more highly rated prime movers are fitted to reduce Unit Production Cost (UPC). In order to restore the fuel savings conceded by the reduced efficiency obtained from these fewer, larger prime movers operating away from their optimum operating point, it is proposed that the AES should run fuel efficient and power dense gas turbines under a regime of Minimum Generator Operation (MGO). This will often be with only one prime mover operational in Single Generator Operation (SGO) mode. This brings significant gains in both fuel consumption and maintenance costs due to the minimised engine running hours and hence Through Life Cost (TLC) reductions. With only one generator running, limited energy storage to provide electrical power for some essential services will be required. The AES concept also proposes widespread electrification of auxiliaries and gives the opportunity to use upgradeable and flexible layouts.

The Marine Engineering Development Programme (MEDP) continues to be the means of delivering the Marine Engineering Development Strategy (MEDS) for future RN warships. Although some developments will be available for the Type 45 Destroyer, the MEDP is primarily focused on delivering de-risked technologies for the Future Surface Combatant (FSC), Future Aircraft Carrier (CVF) and Future Attack Submarine (FASM).

The implementation of the MEDS is now moving from the Development Phase, which produced the Electric Ship system concepts, to the De-risking Phase. This phase aims to demonstrate the advantages of the Electric Ship concept and provide sufficient de-risking to allow future warship prime contractors to include Electric Ship technologies in their designs without demanding significant financial contingency to carry residual technical risk. This paper looks at the development phase, the derisking phase and considers future issues key to the success of the Electric Ship.

TECHNOLOGY REVIEW

2. LPD(R) and AO Propulsion Systems

As a result of a TLC study comparing diesel mechanical and diesel electrical solutions for the LPD(R), the option of diesel electric was chosen for HMS ALBION and HMS BULWARK (Figure 1). The diesel electric option proved slightly more expensive to procure, but significantly cheaper in terms of TLC. The TLC assessment took account of fuel consumption, oil consumption, spare parts and operating hours. Other design factors which influenced the choice of diesel electric include operational flexibility, equipment redundancy, maintenance flexibility, spares, efficient operation and reduced emissions.

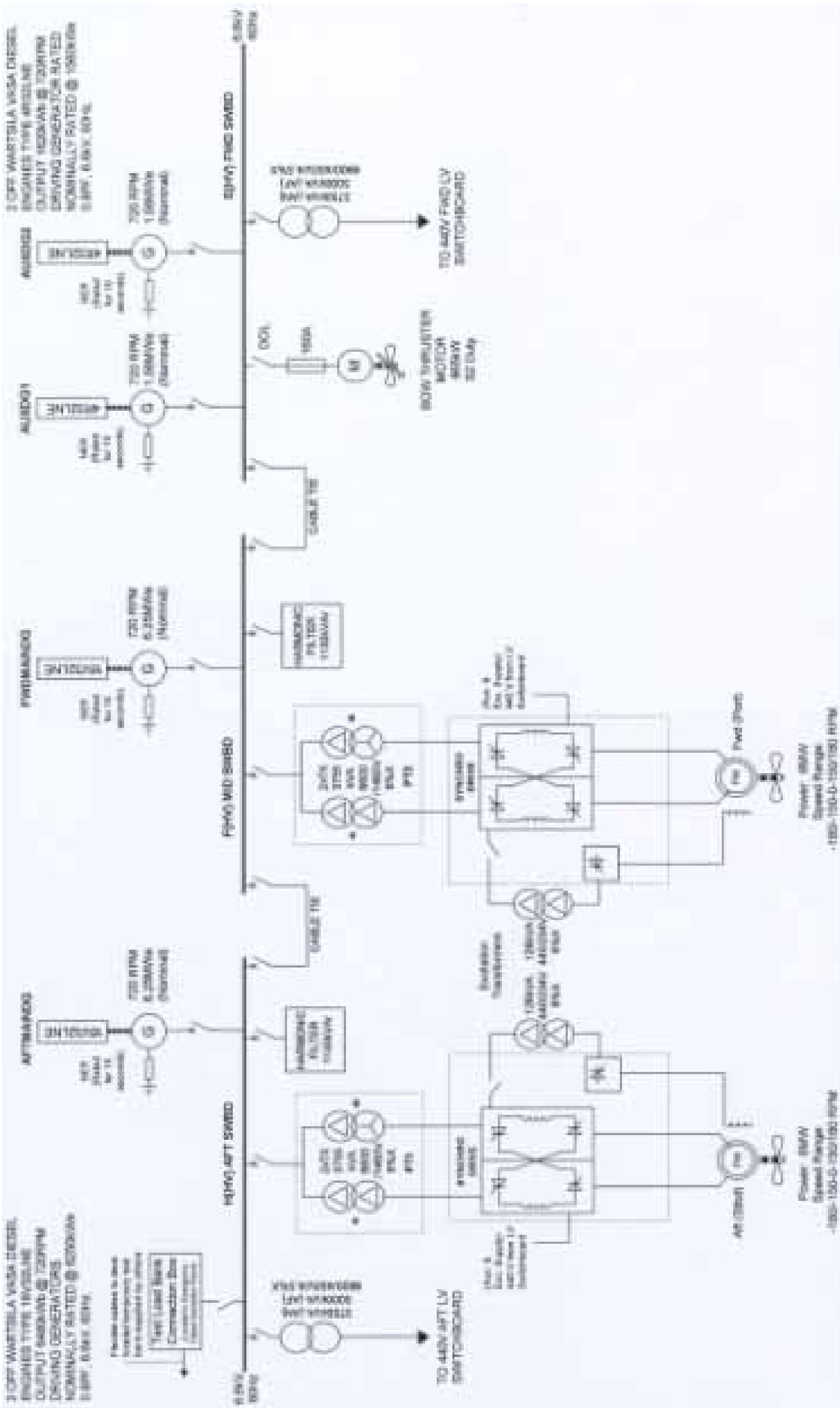

Figure 1. LPD(R). HMS Bulwark/HMS Albion Power & Propulsion System


Figure 2. LPD(R) power system.

The LPD(R) power system configuration, illustrated in Figure 2, is a basic IFEP system with the power conversion between the propulsion system and the ship services system achieved using a transformer. The propulsion motors are each variable speed AC synchronous machines driving fixed pitch propellers. Each propulsion motor is controlled through a synchrodrive converter. Similar equipment is used in the AO, albeit in a single shaft configuration.

3. Type 45 Propulsion System

The Prime Contract Office (PCO) for the Type 45 has recently selected an Integrated Electric Propulsion (IEP) system for this class. The system is likely to be based on similar technology to the Advanced Induction Motor (AIM) and associated converter built by Alstom for the US Navy's Integrated Power System shore based test site in Philadelphia. The architecture (Figure 3) has a mix of large Gas Turbine Alternators (GTA) and Diesel Generators as prime movers but is otherwise similar to that of the LPD(R).

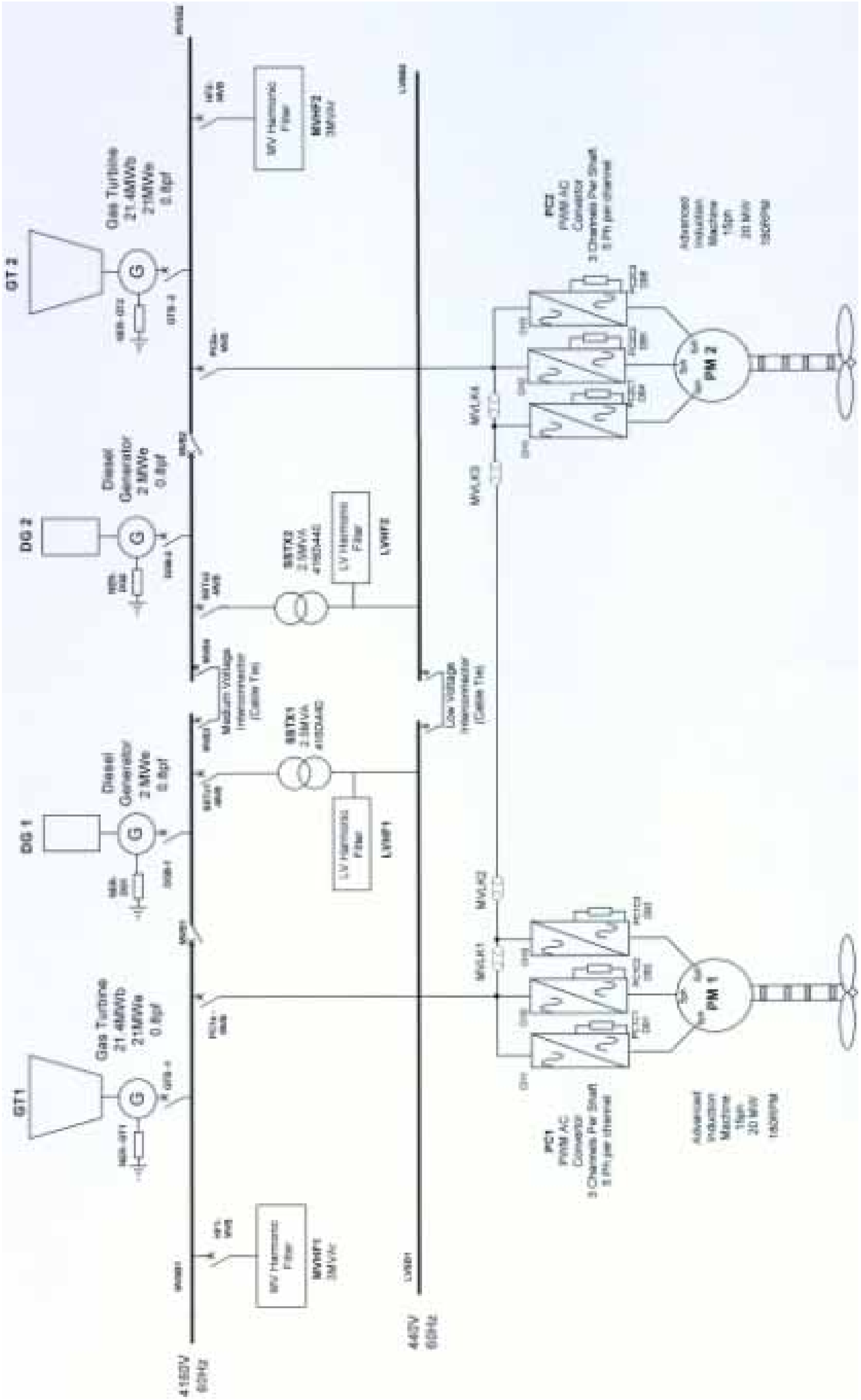

Figure 3 – Type 45 power system

4. Future Options for IFEP

Future developments of an IFEP architecture and equipment are not constrained in the same manner as the LPD(R) or Type 45 design. In systems of the future we can look at optimising the architectures both technically and in terms of UPC and TLC. There is the opportunity to review technology developments which are currently progressing. In particular, it may become possible to take advantage of the devices and converter topologies emerging from the power electronic revolution.

Distribution System				Propulsion system				Link		
AC	AC	DC	DC	AC		DC				
Tree	Ring	Tree	Ring	VVVF	FVFF	VV	FV	RC	SC	TX
✔				✔					✔	
✔					✔			✔	✔	✔
	✔			✔					✔	
	✔				✔			✔	✔	✔
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			✔			✔		✔	✔	
			✔				✔	✔	✔	

VVVF = Variable Voltage Variable Frequency
VV = Variable Voltage
RC = Rotating Conversion
TX = Transformer
FVFF = Fixed Voltage Frequency Fixed
FV = Fixed Voltage
SC = Static Conversion

Table 1. Potential IFEP options.

Under an IFEP architecture there are several options which can be employed for the propulsion system architecture, the ship's services system and the link between them. Table 1 indicates the many options which could be applied to the modern warship IFEP system and which are being investigated by MoD. It should be noted that for each of the options identified the prime mover can either be operated in variable speed or fixed speed modes. With this level of installed power the propulsion bus will be based on a high voltage system in order to minimise the fault currents.

5. Prime Movers

5.1 Gas Turbines

Gas Turbines have been selected as the future prime mover primarily because of their high power to weight ratio. In addition there is also a significant reduction in the amount of routine maintenance required when compared with diesel generators. The other significant factor is the low emissions. Figure 4 indicates that there could potentially be three different size gas turbines.

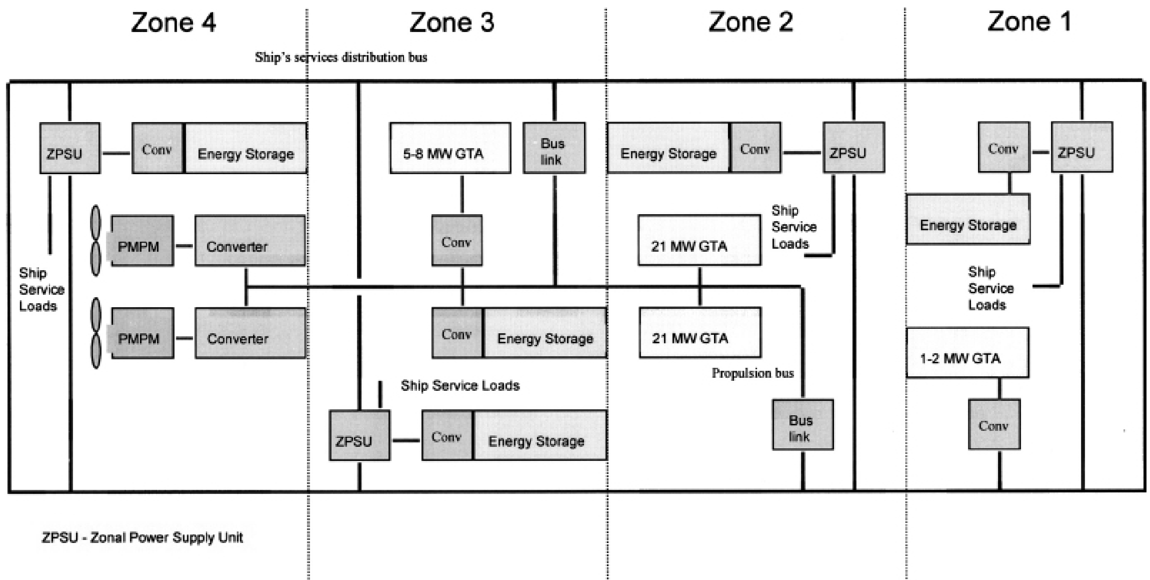

Figure 4. Basic IFEP architecture.

5.2 Fuel Cells

Fuel cells can be used as a prime mover in an Integrated Full Electric Propulsion (IFEP) system providing DC electrical power output, and are being developed as a replacement for diesel generators and gas turbine alternators. The fuel cell stack operates by utilising electrochemical reactions between an oxidant (air) and a fuel (hydrogen), with two electrodes separated by a membrane. The voltage of the fuel cell output can be controlled by a converter and it is therefore able to connect to any point in the ship service or propulsion distribution system. The fuel cell stack is modular, and very compatible with all the benefits of IFEP. It has the additional advantages of zero noxious emissions, and low thermal and acoustic signatures.

In the short term the fuel cell system is required to use marine diesel fuel. Diesel fuel will require reforming within the fuel cell stack, or using an external process, to produce a hydrogen rich gas which the fuel cell stack is capable of processing. The reformer will clearly add both size, weight and complexity to the fuel cell system. In the longer term technologies such as the Solid Oxide Fuel Cell (SOFC) are contenders, which are more forgiving of impurities and can use a fuel available world-wide, either methanol or gasoline.

6. Propulsion Motors

For IFEP to be adopted in fighting vessels of 6000 tonnes in displacement or less there is a requirement for a compact, power dense, rugged electrical machine to be utilised for the propulsion motor. For the full benefits of electric propulsion to be realised the machine should also be efficient, particularly at part load, as warships and submarines spend much of their time at low speed. In order to achieve suitable compact designs rare earth permanent magnet materials may be required.

6.1 Permanent Magnet Propulsion Motors

The machine topologies available are deemed to be those based on radial, axial and transverse flux designs. In 1997, the Transverse Flux Motor was selected for development by the MoD as it was considered to be the optimum machine configuration to meet the high efficiency and power density requirements and a contract for a Technology Demonstrator Programme (TDP) was awarded to Rolls-Royce. The aim of the TDP is to produce designs for propulsion motors in the range 16 to 24 MW which have been validated through the design, build and test of a reduced scale representative machine (Figure 5) displaying identical electro-mechanical characteristics. Rolls-Royce are teamed with ALSTOM Drives and Controls, who are supplying the power electronics expertise, and the Defence Evaluation and Research Agency (DERA), who are providing a test facility.

Figure 5. Reduced scale representative machine.

6.2 Advanced Induction Motors

Alstom Drives & Controls have developed a family of Advanced Induction Motors (AIM) based on a Pulse Width Modulated (PWM) converter fed AIM rated at 19MW, 150 rpm, supplied for testing as part of the Integrated Power System programme for the USA (Figure 6). This motor was manufactured to US Military Specifications and had related requirements for shock, noise & vibration and EMC/EMI. Alstom's AIM development has been underway for some 12 years with the first machine for a steel mill delivered in 1992.

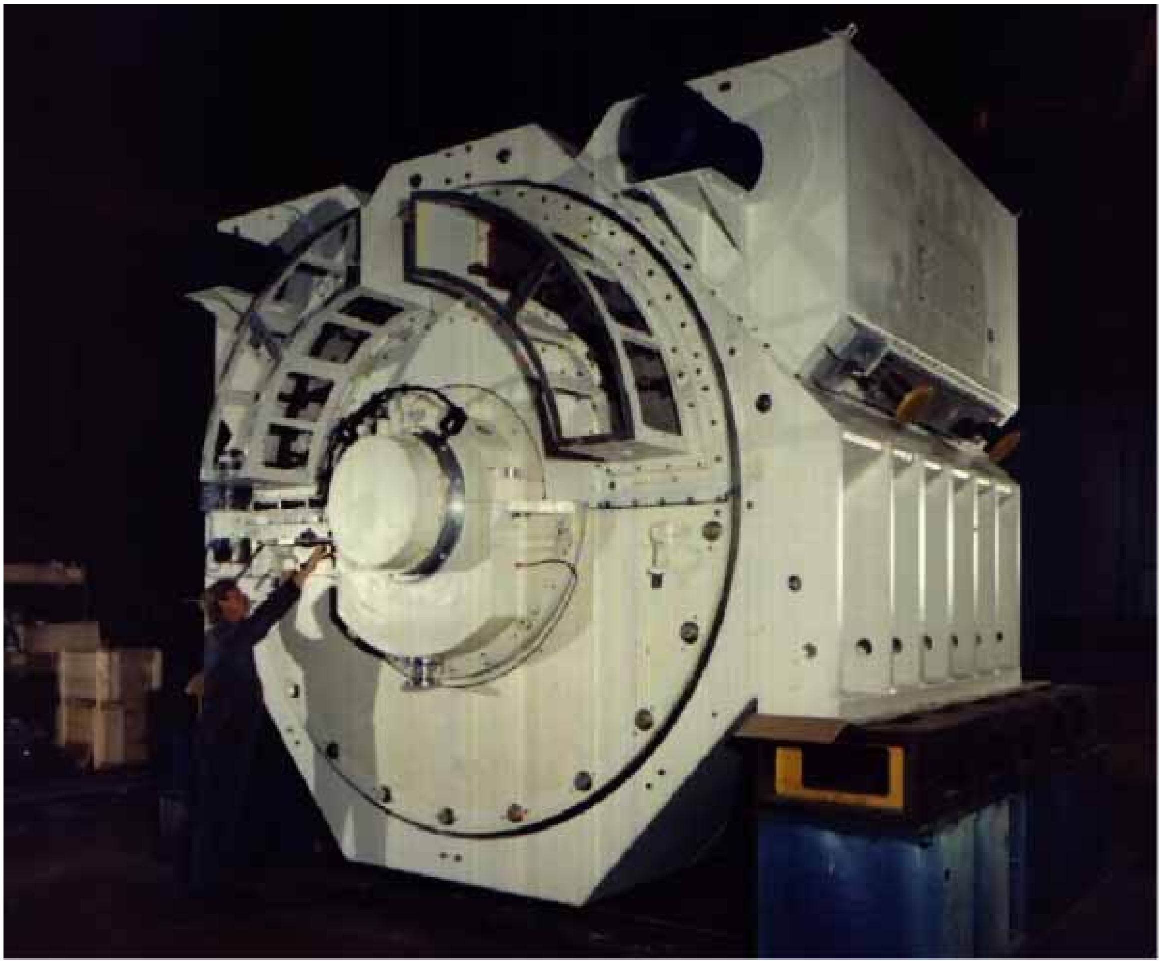

Figure 6. Advanced Induction Motor.

6.3 Podded Drives

Podded drives offer greater propulsion efficiency and increased space within the hull by moving the propulsion motor outside the ship's hull and placing it in a pod suspended underneath the hull as shown in Figure 7. Podded drives are also capable of azimuthing, improving ship manoeuvrability. Indeed, podded drives have been widely adopted by the cruise ship community for these reasons. The motors being manufactured now are as large as 19.5 MW, and could provide the total propulsion power. The suitability of podded drives for warships, including their noise and shock characteristics are currently being investigated. Podded drives prescribe an IFEP system.


Figure 7. Podded drive.

7. Single Generator Operation

The adoption of SGO to change prime mover utilisation from the customary Royal Navy practice of running a minimum of two generators to a single running generator does not mean that in the event of the on load generator failing that there is a total loss of power. Classes currently in service already have a level of energy storage for CCI and some other equipment. It is perhaps the additional requirements which need to be addressed, in particular what duration of energy storage is required and whether Energy Storage should be provided for:

Propulsion and essential services;
Propulsion only;
Essential services only;
CCI only (24 volts maintained); as today.

Energy storage for propulsion may not actually be a requirement. Current classes such as the Type 22 frigate and Type 42 Destroyer often operate just one shaft on passage with the other shaft trailing. If the propulsion engine trips then it will take in the order of two minutes to start and select another engine. These issues will be fully investigated at the Electric Ship Technology Demonstrator as discussed later.

SGO would be used during operations in benign conditions, for example on patrol in a low threat environment and of course only applies at lower powers; once the power requirement rises beyond the output of one of the two main GTAs a second generator will be required. Depending on the final hull form and displacement of the Future Surface Combatant (due to replace the Type 23 from 2012 onwards) this is likely to be in the range of 26 – 28 knots. A second generator would be started when in restricted waters, during Replenishment at Sea or if the operational threat increased. Perhaps the term SGO is inaccurate. The on-load generator will always be ‘in-parallel’ with one or more energy storage devices and thus this concept of operation presents probably less risk of loss of power supplies to services considered essential than current systems.

Selection of a second generator would be determined by the Command but will include any occasion when the likely power or speed requirement exceeds the power available from the ride-through energy source and the speed of response in starting a second prime mover (2 minutes) is unacceptable. Thus Special Sea Dutymen (SSD) would not in itself be a criteria for two or more engines. For future platforms the decision which needs to be taken early in the design process is which services the energy storage will back-up and for how long.

8. Energy Storage Options

The technologies being assessed for energy storage include flywheels such as the URENCO device shown in Figure 8, electro-chemical batteries (both conventional and advanced), regenerative fuel cells (otherwise known as redox flow cells or Regenesys), Superconducting Magnetic Energy Storage (SMES) and Supercapacitors.

Figure 8. URENCO flywheel.

Regenerative fuel cells (Regenesys$_{TM}$ by Innogy) store or release electrical energy by means of a reversible electrochemical reaction between two salt solutions (the electrolytes). The reaction occurs within an electrochemical cell. The cell has two compartments, one for each electrolyte, physically separated by an ion-exchange membrane. In contrast to most types of battery system, the electrolytes flow into and out of the cells and are transformed electrochemically inside the cells. The power is therefore determined by the size of the cell but the endurance is determined by the size of the two electrolyte tanks (Figure 9).

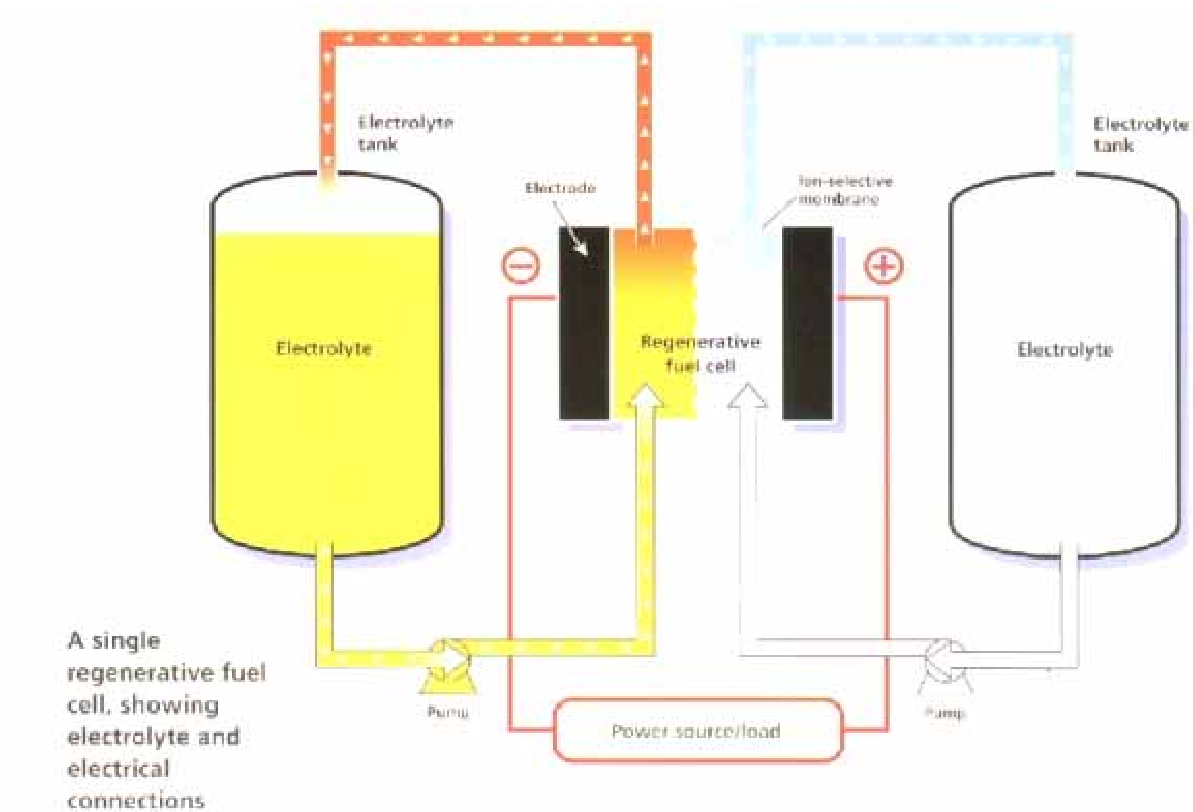

Figure 9. Regenesys$_{TM}$ by Innogy.

The concept of providing uninterrupted power supplies already exists for Command, Control and Indication (CCI) equipment and navigation and emergency lighting. It is currently provided by Uninterruptable Power Supplies (UPS) either embedded in the parent system or more usually through the battery backed 24 volt transformer rectifier units. In future power systems this could be in the form of Distributed Energy Storage (DES) in each zone providing enhanced survivability to many more key systems and equipment.

9. The Zonal Concept

The concept of dividing future classes of ship into zones to maximise survivability also extends to the power system. Each zone would be autonomous and include ventilation systems, cooling systems, power distribution and other services which could be affected by damage to another part of the ship. At least two supplies would be provided for all essential loads. Current classes, using split generation and distribution, rely on the provision of normal and alternative supplies via Automatic Change-Over Switches (ACOS) to essential services to ensure a suitable level of survivability.

In future classes this could be taken a step further by incorporating energy storage from independent sources to key weapon systems and sensors. It requires an instantaneous changeover of supply (no break) and is currently provided by UPS embedded in the parent systems but in the future would be supported by energy storage embedded in each zone, providing power to essential services until power is restored to the zonal distribution point. The duration of this energy storage could be as little as 100ms, the time to clear a fault on the distribution system, or longer, say 10 minutes.

10. Electrical Standards and Training

Since the inception of Engineering Branch Development (EBD) there has been a gradual but significant reduction in electrical standards, particularly in the appreciation of electrical safety. This may have three primary root causes; the first is the dilution of electrical expertise with the demise of the old specialist Electrical Artificer (MEA(L)). The second is the lack of in-depth, coherent training for the new MEA(EL), where the training has remained biased towards the mechanical aspects of the training curricula. This has not been helped, perhaps unknowingly, by the third cause, which is the lack of numbers of suitably electrically trained Marine Engineer Officers.

IFEP systems at sea may require voltages up to 13.8 kV to minimise fault levels and it is therefore essential that all Marine Engineering personnel are trained in safe working practices for these voltages. The Electrical Artificers of the near future must be fully trained to carry out maintenance and defect rectification on Medium Voltage (MV) systems. This will mean a considerable increase in the electrical content of all training. Training will also need to be given to non-technical personnel to ensure everybody is aware of the dangers of these higher voltages.

11. The All Electric Ship

The AES concept goes beyond an IFEP system in that it proposes widespread electrification of auxiliaries and gives the opportunity to use upgradeable and flexible layouts. It will include a low risk, cost effective and comprehensive Platform Management System that has a standardised Human-Computer Interface and remains supportable for its entire service life and the goal to be an Environmentally Sound Ship. The goals of the Environmentally Sound Ship work are: freedom of operation in MARPOL special and restricted areas; unrestricted littoral operations; port independence; minimum onboard storage of waste and reduced manpower whilst reducing cost of ownership and port reception costs. Work is also underway to investigate the potential for replacing the current traditional systems used in steering gear, fin stabilisers and submarine control surfaces with compact, power-dense actuators. These may be either an electric drive or aerospace derived devices. The aerospace derived actuators are significantly smaller than the current steering gear systems, have the required ARM attributes and, potentially have significantly lower acquisition and support costs than existing systems. Studies have been carried out to investigate the possible advantages of electric valve actuators in ship and submarine systems. These actuators offer the potential to simplify system architectures at a comparable cost to the alternatives. MoD in conjunction with DERA are working on all aspects of upper deck machinery to ensure the systematic integration of upper deck machinery into future surface ship designs.

ELECTRIC SHIP CONCEPT - IMPLEMENTATION AND BEYOND

12. Electric Ship Technology Demonstrator

The principal means by which the Electric Ship concept will be implemented is through the Electric Ship Technology Demonstrator (ES TD), a contract for which was placed with Alstom Power Conversion Limited in July 2000. The ES TD takes current state-of-art equipment and integrates them in an IFEP system which is representative of a generic system for a frigate or destroyer sized ship. An outline of the system is given in Figure 10.

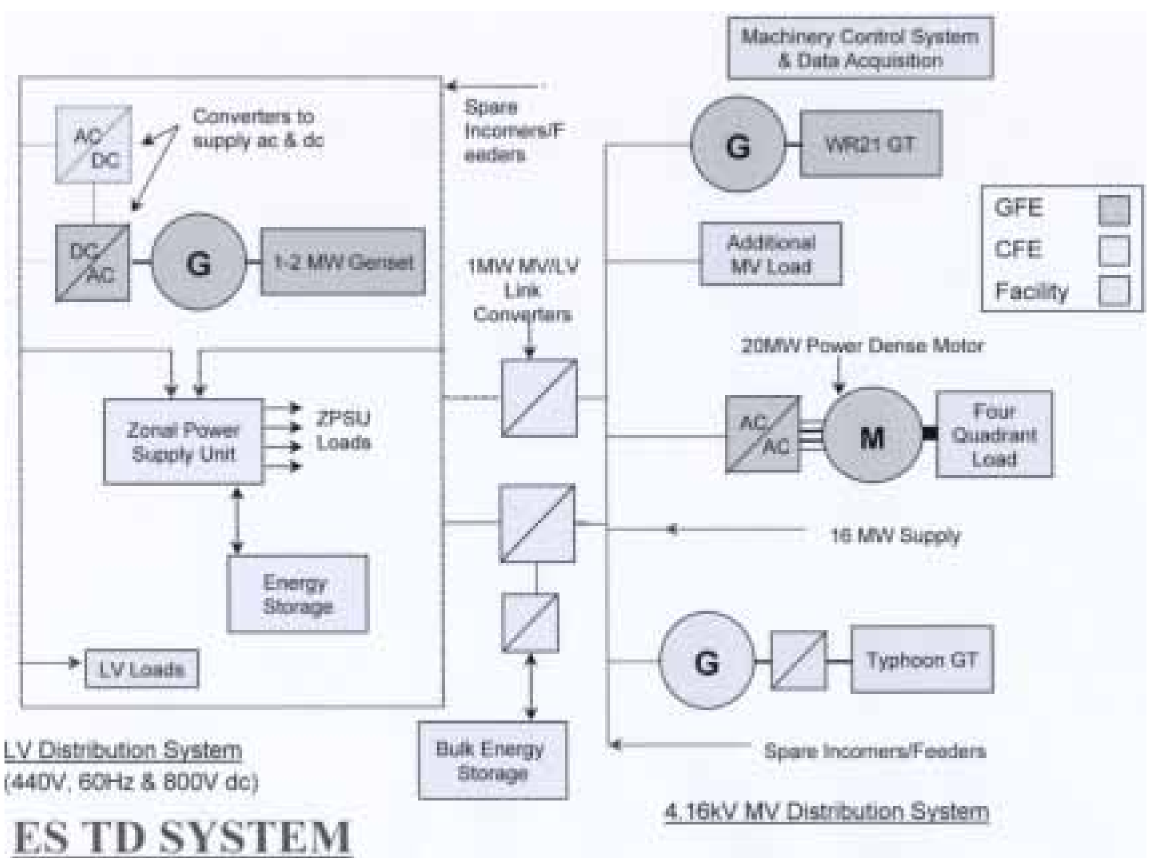

Figure 10. The ES TD System

Particular points to note include:

- The WR21 GTA providing the main power source for the system.
- A 20MW Advanced Induction Motor driving a four-quadrant load enabling full operation throughout the ahead and astern modes.
- Dual solid-state link converters between the MV and LV systems.
- A Regenesys bulk energy storage device to investigate further the concept of single generator operation.
- An LV distribution system which will enable comparison of both AC and DC ring mains to inform future system selection.
- A zonal power supply unit incorporating flywheel energy storage devices.

The aims of the ES TD are:

- To de-risk the IFEP concept and address system integration issues so that it becomes and attractive option for future warship propulsion systems without attracting an undue risk premium from the prime contractor.
- To provide technology pull-through by informing the baseline designs for future warship projects.
- To understand and demonstrate operation under normal, fault and extreme operating conditions.
- To validate equipment and system models and so reduce the requirement for shore testing of future ship-specific systems.
- To generate Integrated Logistic Support (ILS) data to inform future warship development.
- To understand and address signature issues.
- To support the production of technical requirements for future IFEP systems.

The ES TD is a co-operative programme with France. It will be sited at the Alstom Research Centre at Whetstone near Leicester. Testing is due to commence in Spring 2002 with final trials complete by the end of 2003. Testing is timed to meet the requirements of the FSC , CVF and FASM projects in the UK and the Composante Fregate in France.

13. Constraints and Pressures on Marine Engineering Development

The development and demonstration programmes already described, culminating in the Electric Ship Technology Demonstrator, provide a firm foundation for the incorporation of Electric Ship technologies in future warships. However, there remains a constant impetus to reduce ownership costs whilst boosting operational capabilities. We therefore need to look how the Electric Ship concept will evolve in the future. Before a strategy for further development can be formulated it is important to understand the constraints and pressures that impact on future marine engineering systems. These constraints and pressures fall into 3 broad categories:

- External Pressures. The external pressures are those that factors that are difficult to control or influence, such as industrial base capabilities.
- Management. The management issues are those pressures and constraints that the personnel managing the acquisition process can influence by means of adapting their business processes.
- Technical. Technical constraints can normally be overcome by the development of appropriate technical solutions

13.1 EXTERNAL CONSTRAINTS

The capabilities of the available industrial base impose the main external constraints on marine engineering development. The sectors of industry of most relevance are commercial shipping, power generation, controls, and transport (e.g. aero gas turbines, rail traction diesels). The Royal Navy on its own provides too small a market to influence industry's machinery development investment, and so attempts to move faster than industry, or in a different direction, would lead to large costs. It also becomes an increasingly expensive experience to be left supporting obsolescent technology. Therefore, it is essential that the Navy must keep pace with developments in industry. Furthermore, a strong industrial base that will support the new technology through its service life should underpin any changes to marine engineering practice.

13.2 MANAGEMENT PRESSURES

The purpose of the acquisition process is to deliver the required military capability on time and within budget. A fundamental activity in managing this process is the identification and reduction of the associated risks. Experience has shown that warship prime contractors will have to, of necessity, take significant risks with the warship combat systems and so have a natural tendency to be risk adverse for the marine engineering aspects of the project. This will potentially lead to stagnation in marine engineering development and, crucially, fail to take advantage of the performance and cost benefits that can be realised from technological advances.

The Acquisition Management System underpins the Ministry of Defences Smart Procurement Initiative and defines the new procurement cycle, known as CADMID:

- **C**oncept (leading to Initial Gate approval)
- **A**ssessment (leading to Main Gate approval)
- **D**evelopment
- **M**anufacture
- **I**n-Service
- **D**isposal

One of the objectives of the 'CADMID' cycle is:

To assist the reduction of risk during the Concept and Assessment stages so that, at Main Gate, there is a high level of confidence that project target time, whole-life cost, annual cost of ownership and performance will be achieved.

In practical terms, this means that marine engineering development needs to take place to deliver results progressively throughout the Concept and Assessment stages. Consequently, the warship prime contractor will have sufficient information to enable him to make wise choices that will meet the Users Requirements, minimise the subsequent whole-life costs and contain the risks that the MOD will bear to an acceptable level. Marine engineering development is therefore a de-risking process that demonstrates the capability of particular technologies rather than developing ship ready, production equipment. Technology Demonstration Programmes (TDP), as exemplified by the ESTD, normally carry out this de-risking process.

13.3 TECHNICAL CHALLENGES

The technical challenges in marine engineering that require appropriate technical solutions are:

- The requirement to identify and implement 'open architecture' systems that are flexible in concept, capable of utilising a variety of different equipment solutions and are adaptable for technology insertion.
- The development of system architectures and equipment solutions that will minimise the impact of marine engineering on warship design and operation.
- The development of system architectures that will support cost-effective incremental acquisition of additional equipment for combat systems in the future.
- The use of COTS equipment wherever possible with navalisation as necessary, for example to meet requirements of marine environment, shock and naval signatures.
- Commonality of system architectures and equipment solutions across all classes of major surface ships, submarines and minor war vessels wherever feasible.
- Compliance with the Royal Navy policy for environmentally sound warships.

14. Technology Drivers

14.1 The Defence Task and Operating Environment

Since the end of the Cold War the tasks that our ships can be expected to perform have become broader and more diverse in nature. However, power projection and the requirement to respond quickly to developing crises are common themes. This means that ships need to be able to deploy long distances at relatively high speeds to reach an area of operations and, when there, to operate long periods, perhaps at slow speed, with little or no support. Speed, economy, reliability and availability are therefore major attributes which are likely to be expressed as requirements in very demanding terms for all future major warships and auxiliaries

14.2 Manpower

The structure of the Navy remains under constant review and as a result long term trends on manpower levels, associated skills and training are difficult to predict with certainty. Manpower levels are almost certain to continue to fall and it is unlikely that automation of Marine Engineering systems will be a significant driver in determining manpower levels. Maintenance requirements will also continue to fall. Manpower levels will therefore be driven by external factors, such as retaining sufficient flexibility to support the myriad of tasks, like disaster relief, that a warship can be called upon to perform. The Damage Control and Firefighting requirement will also be a major driver, despite predicted technological advances in these areas.

14.3 Equipment and Technology

Many of the trends in technology have been discussed in the first part of this paper. These trends are, however, being driven by commercial forces and large industrial markets. Even the United States Navy, the World's largest, is too small a customer to influence these trends significantly. The Royal Navy will therefore be driven more and more by developments in commercial technology and the adaptation of these to meet the, often unique, naval requirement.

This does not mean that we can relax. The CADMID life-cycle can be very long for a major warship project, frequently exceeding 50 years from conception to disposal of the last ship of the class. A heightened awareness of commercially developed technologies is therefore required, combined with the good judgement needed to select successful technologies which will continue to be supported by industry throughout the life of the warship. To achieve this 'state-of-the-art' technologies will need to be selected for new projects and associated risks taken in order to avoid early obsolescence and un-supportable systems. This has to be balanced against the need to increase commonality and reduce diversification in order to control support costs.

Adaptation and development of commercial technologies will also be required to enable successful operation in the naval environment. Shock and signature aspects are prime examples where the naval requirement often exceeds the commercial requirement. Installation of commercially derived equipment may also necessitate increased system redundancy with its associated cost impact.

All this means that naval marine engineering development must be highly focused and needs to be managed by a technically competent and forward looking organisation, taking into account industrial trends and its applicability to the naval requirement. This requires significantly more effort than being simply an intelligent customer.

14.4 Operating Costs

The drive to reduce operating costs will continue. The introduction of the IFEP architecture and operating philosophy together with advanced cycle gas turbines gives a step reduction in operating costs. Further improvements will be much more difficult to achieve and will be incremental in nature, depending, once again, on evolution, rather than revolution, in marine engineering development. Critical to this evolution is the establishment of the Integrated Full Electric Propulsion system as the core 'open system' architecture into which new technologies can be introduced.

These new technologies will need to show continuing incremental improvements in efficiency whilst reducing the maintenance requirement. Improving availability is also important. Greater availability acts as a force multiplier enabling fewer ships to meet the operational requirement.

These requirements are not unique to Navies - they are also fully applicable throughout the commercial world. The Royal Navy will therefore benefit from following commercial trends in these areas.

14.5 Environmental

Current efforts are focused on reducing or eliminating the impact that a warship has on its environment during its operation. In simple terms this means controlling all its overboard emissions, whether solid, liquid or gaseous. In the future a warship will have to have minimal environmental impact during its full life-cycle, including build, operation, maintenance and disposal. This is far more difficult to achieve, involving a myriad a different organisations. However, legislation will mean that we have no choice but to address the issues.

14.6 Signatures

Warships emit a wide range of signatures, including acoustic, infra red, magnetic, electromagnetic, wake and atmospheric effects. Future efforts may not only try to minimise signatures but will also address control of signatures to the extent that a warship will be able to mimic faithfully the characteristics of another vessel. Future 'smart' weapon systems could be confused by the presence of a 'cruise liner' type target when the missile or mine was expecting a high-stealth target. The marine engineering systems largely dictate the signature of a warship and therefore significant investment will be required to be able to control as well as minimise their characteristics.

14.7 Fuels

Predicted trends for the availability and cost of fossil fuels are highly inconsistent and it is impossible to derive definitive figures. However, it can be said with reasonable confidence that ships being designed now for service between 2010 and 2040 are likely to experience increasing fuel costs through-out their life. Beyond 2040, fuel will become scarce, with prices increasing dramatically. This 'next-but-one' generation of ships will therefore need to find an alternative to traditional fossil fuels. No predictions are made here as to what this alternative could be. However, timescales are such that the problem needs to be addressed now, taking fully into account what is likely to happen commercially.

15. The Future Marine Engineering Development Strategy

The introduction of electric propulsion into LPD(R) and Type 45 Destroyer can be considered to be a major step change in marine engineering development. Although not all the benefits associated with electric propulsion will be realised in these classes these ships will see significant reductions in whole-life costs. Future warship systems will evolve from these ships so the scope for large reductions in operations and support costs are reduced. Nevertheless, further development of the electric ship concept has the potential to provide appreciable benefits and the following areas will probably need to be addressed through the next iteration of the Marine Engineering Development Strategy:

a. Military Effectiveness. To provide cost-effective marine engineering developments that will improve military effectiveness, particularly more adaptability, reduced signatures and increased survivability.

b. Optimal Design. To provide flexible system architectures thus reducing the constraints imposed on ship design and operation by marine engineering systems.

c. Technology Insertion. To identify and develop marine engineering equipment suitable for technology insertion into current and future classes of warship.

d. Incremental Acquisition. To identify and develop system architectures that are suitable for supporting cost-effective incremental acquisition of additional equipment for combat systems in the future.

e. Manpower. To provide reliable and efficient automated systems at a level appropriate to manning levels. Marine engineering technologies are an enabler to reduce the manpower required onboard Royal Navy ships. The limiting factor is now naval policy that will staff ships above the level necessary to operate and maintain marine engineering systems under all conditions.

f. Environmental Impact. Means of complying with environmental legislation will be identified and developed to ensure that Royal Navy policy on environmentally sound warship design is implemented.

World-wide industrial and commercial developments will be exploited to the maximum extent possible and only when these cannot meet naval requirements will the development of specific equipment or system concepts be funded. In some cases the requirement of the Navy may predate an anticipated commercial market prospect and participation in a joint or shared development will be the appropriate course of action.

Marine engineering development is to be undertaken in accordance with the Acquisition Management System. Further opportunities for collaboration and partnership will be sought whenever a common requirement is identified.

16. Conclusions

The concept of the Electric Ship, as envisaged over the last five years, is now here. IFEP architectures are now successfully in service in commercial ships and about to enter service in a number of Royal Navy vessels. The concept will be further refined in the T45, with another step forward taking place with the Future Surface Combatant.

The technologies supporting the Electric Ship concept continue to move forward and further incremental advances in efficiency and operational effectiveness are expected.

The challenges facing navies during the next century are developing. Whole life costs and manpower levels will continue to be driven down whilst operational capabilities must improve to meet the new defence tasks. Environmental legislation will become ever more stringent and commercial trends will dictate the equipment that navies procure to a greater extent than ever before. Finally, and perhaps most significantly, we are starting to see the end of fossil fuels.

The outline strategy proposed in this paper builds on what has already been achieved and forms a firm foundation for meeting the many challenges which we are now facing.

References

Energy Storage Requirements for Integrated Full Electric Propulsion (IFEP) Warships - RRA 18809 Issue 02 dated March 1999.