TECHNOLOGY INSERTION INTO AN ALL ELECTRIC SHIP

CAN IT BE DONE?

BY

LIEUTENANT COMMANDER T. DRYWOOD, MSC, CENG, MIMAREST, RN
(MoD WSA – FSC ESPO4)

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ABSTRACT

The Electric Ship Concept and architecture has been pushed for many years as the key building block on the way to the All Electric Ship (AES). The selection of an Integrated Electric Propulsion system for the UK's T45 Destroyer Project shows the UK's commitment and belief in the technology and concept, but doesn't fulfil the final goal. Since the inception of the Electric Ship Concept in the early 1990s the environment that it has progressed in has changed. The Strategic Defence Review of 1998 and the introduction of SMART Procurement, now SMART Acquisition, has introduced new challenges to the technology, systems and platform designs that make up the AES. One of these challenges is flexibility of the platform (warship swing). In SMART Acquisition this is facilitated by incremental acquisition and technology insertion. This article looks at whether the AES Concept, and T45 in particular, can adapt to the new challenge of Technology Insertion, or is fatally flawed by it.

INTRODUCTION

Background

The Marine Engineering Development Strategy[1] was endorsed by Ministers in 1996 and set out a path from the T23 hybrid propulsion and distribution system to an All Electric Ship (AES) in the target platforms of the Future Surface Combatant, Future Carrier and Future Attack Submarine. The programme was based on an Integrated Full Electric Propulsion (IFEP) power station concept enabled primarily by advanced cycle gas turbines, power dense propulsion motors and modern power electronics. Since 1996 all major vessels ordered for the UK MoD have had versions of Integrated Electric Propulsion (IEP). These include the:

- Landing Platform Docks, HMS *Albion* and *Bulwark*.
- Hydrographic survey vessels HMS *Enterprise* and *Echo*.
- Auxiliary oilers RFA *Wave Knight* and *Wave Ruler*.
- Research vessel RV *Triton*.
- 4 landing ship logistics for the RFA.

For all these vessels a commercial solution met the requirement, using IEP architecture, and not a full IFEP or AES solution.[2] The selection of IEP for the T45 destroyer, a front line combatant, is another strong step forward towards the Royal Navy's final AES goal. The T45 has not selected an all gas turbine solution, utilizes transformers and hasn't fully electrified it's auxiliaries, but takes a good step towards the AES concept.

Midway through the current Electric Ship Programme SMART Procurement/Acquisition was introduced. This changed the acquisition process, it's terminology, reference points and approvals process. The main items to impact on the Electric Ship Programme were Technology Insertion (TI) and Incremental Acquisition (IA). IA allows for capability to be added to the platform in a planned incremental way. This means design margins, funding and programmes are in place to allow capability, be it weapons, sensors, personnel or marine engineering equipment, to be grown into the warship. TI is complementary to IA, but is aimed at overcoming obsolescence, upgrading, updating, meeting new legislation and reducing whole life costs by using newer technologies to carry out the tasks already being carried out on board. The move towards the use of more COTS based equipment on warships, which may require more frequent replacement, further endorses the adoption of TI. It is also recognized in the SMART literature that TI will bring increased operational capability in many areas when applied. It is the newly formalized TI role that this paper will concentrate on, with T45 as the baseline IEP system for discussion.

An All Electric Ship Architecture

Several terms have been used to describe AESs in the past, but the definitions[3] below are used throughout this article:

- *Hybrid*

  Similar to the T23 frigate, where mechanical drive and electric drive systems are combined.

- *IEP*

  Where a common power source is utilized for both ship services and propulsion system, with the propulsion being purely electric. T45, AO and LPD(R) are examples.

- *IFEP*

  Takes the IEP concept further by incorporating advanced power electronics and energy storage into the architecture to give further cost and operational benefits.

- *Electric Ship*

  Incorporates advanced prime movers and widespread electrification of auxiliaries into the IFEP architecture.

- *Electric Warship*

  Where novel high power weapons and sensors are incorporated to take advantage of the high system powers available.

The propulsion and power distribution system selected for the T45 DARING class destroyer follows the power station concept with four prime movers feeding an High Voltage (HV) switchboard, which in turn supplies the electric propulsion motors and the ship's Low Voltage (LV) distribution system. An IEP system by the definitions above. The single line diagram shown in (FIG.1) gives the complete system.

The system in FIG.1 gives the platform, and it's commanders, great flexibility in operating mode, considerable redundancy, good economy (with single generator running possible for much of the ship's operating profile, with resulting low through life costs), resilience and reduced vulnerability. The system of T45 does not set out to be an AES solution, rather it is the system that, at the time of selection, met the requirement with an acceptable level of risk. Development continues and the potential to realise the benefits of AES technologies may be possible by TI. This article explores the potential.

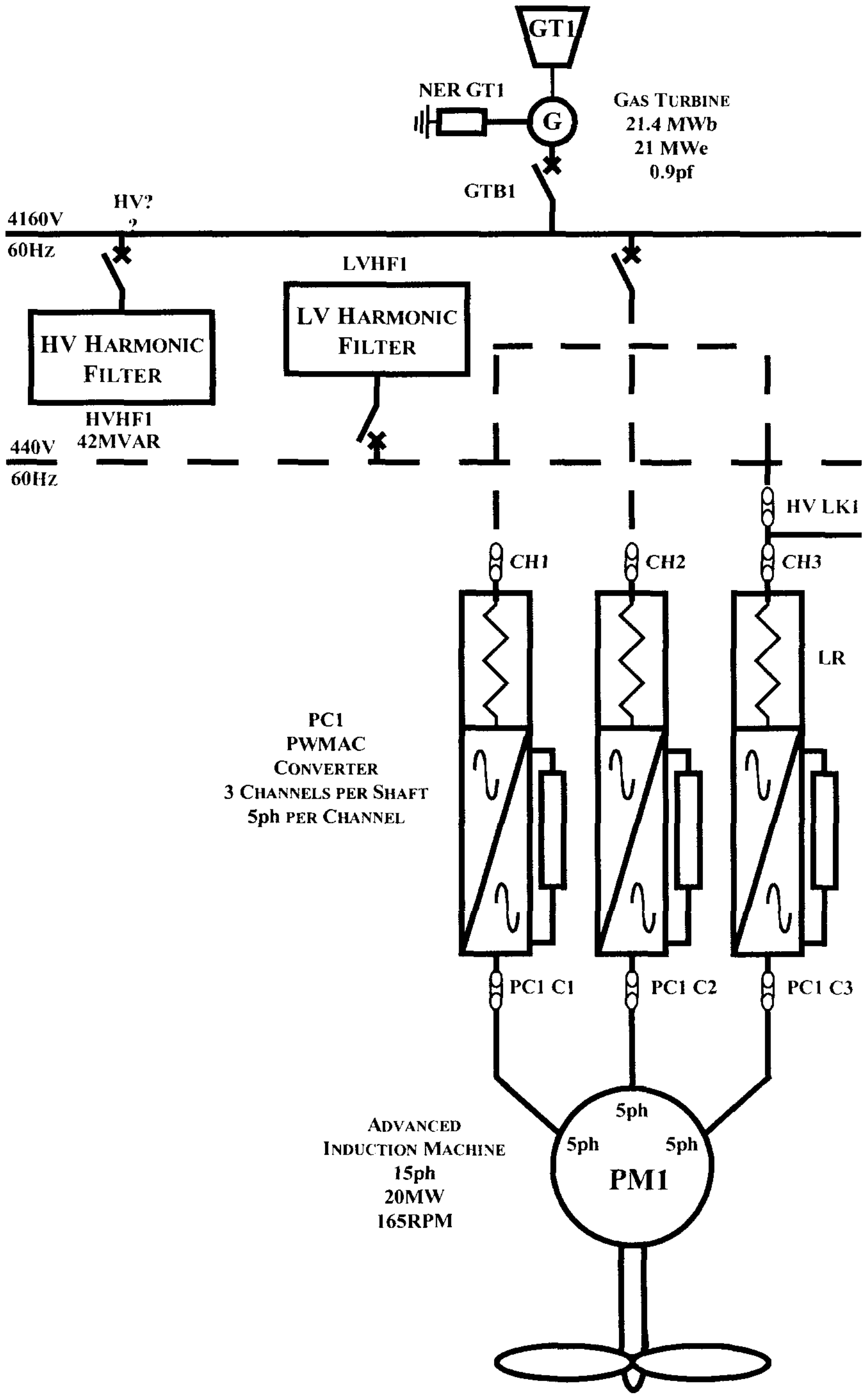
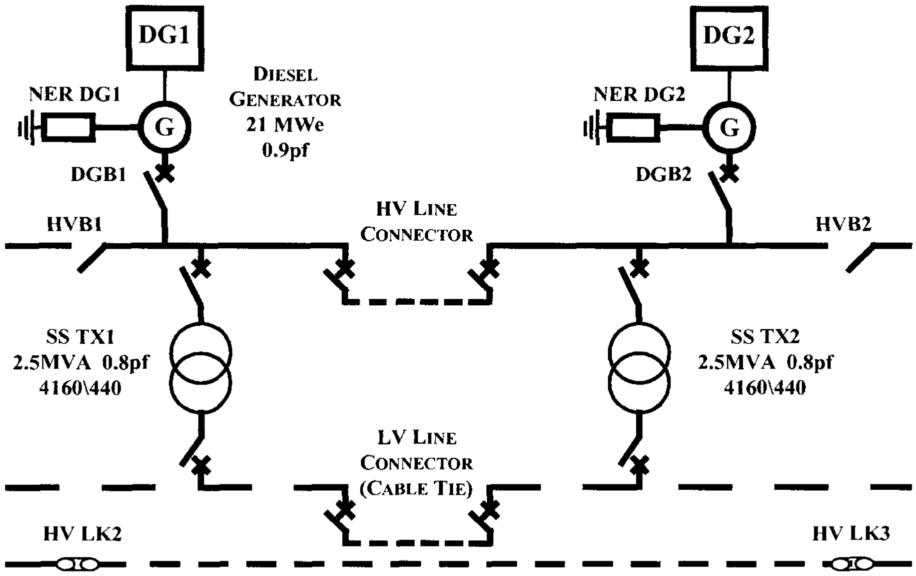


FIG.1 -- SINGLE LINE ELECTRICAL SYSTEM FOR UK T45 DESTROYER



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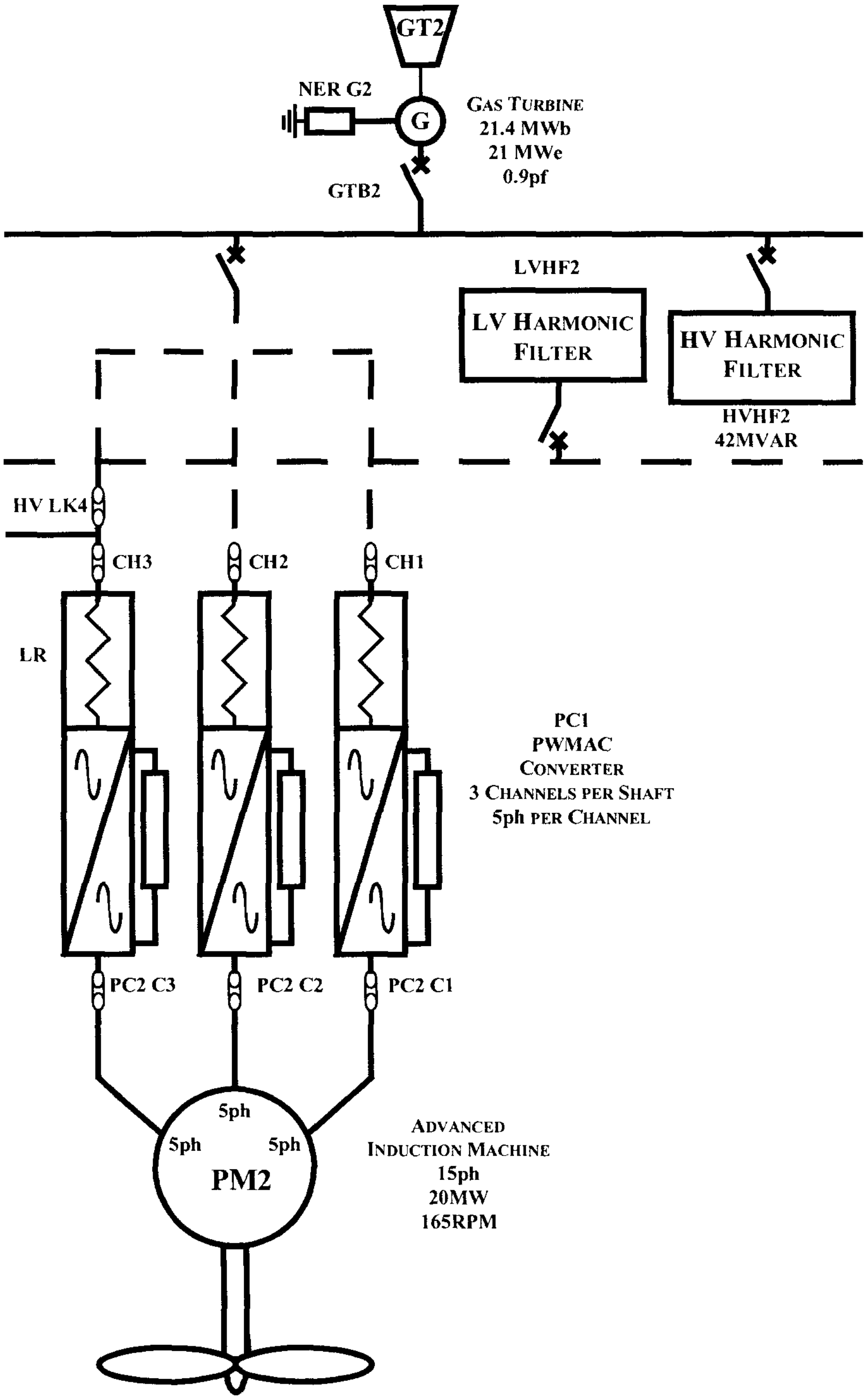

FIG.1 -- SINGLE LINE ELECTRICAL SYSTEM FOR UK T45 DESTROYER

Technology Insertion

The T45 system will be considered in four separate, but interlinked, areas and the TI opportunities or needs considered for each. The four areas are;

- Power Generation.
- Power Distribution (HV).
- Power Distribution (LV).
- Auxiliaries and Weapons/Sensors Support.

Power Generation

TI, or indeed IA, for the prime movers of any platform is severely constrained by the ship's structure, investment considerations and the long lead times typical of naval projects. So upgrade work for T45 in the 5-10 year time scale are unlikely to include re-engineering the WR21's, (FIG.2), or the diesels. Significant investment has been placed in the WR21 alternator set and it is the solution of the here and now, and for the foreseeable future. Only the Japanese ICR engine currently under development is a candidate competitor. Through life growth in power demand, for which there is an increasing trend, could drive the need to upgrade the installed diesels on T45. At the time of the investment decision in the future the best solution may be to TI a new engine, maybe a gas turbine, but ship fit and installation issues would have to be considered carefully.

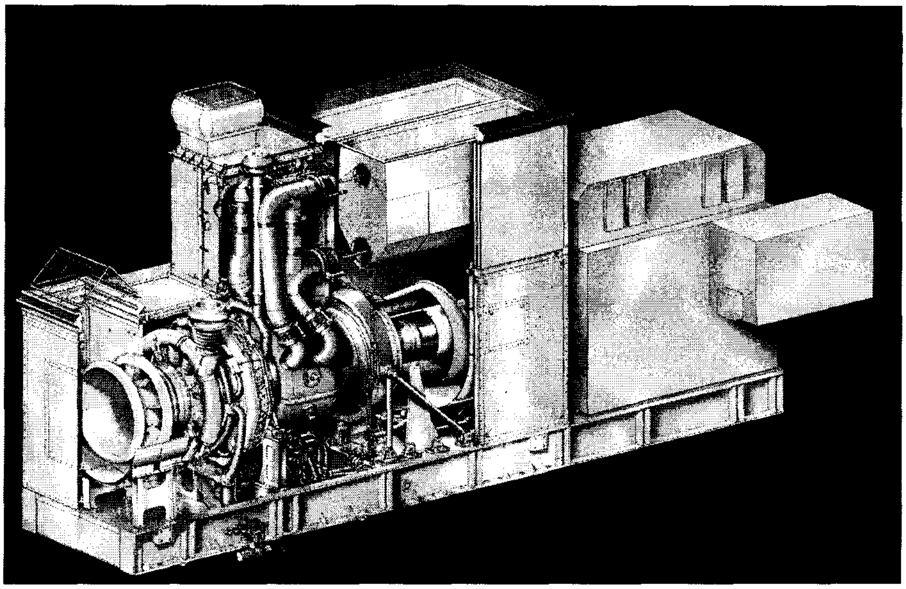

FIG.2 – WR21 GAS TURBINE ALTERNATOR SET FOR THE T45

Whilst complete engine replacement is unlikely, due to other factors than the selection of an AES architecture, sub-system and component TI is possible. Performance increases and reductions in support costs will be possible by TI. Examples of this include electric start for the WR21's, improved engine control algorithms, better turbo-charging for the diesels, dry low emission combustors for the WR21, and auxiliary skid consolidation of the WR21 auxiliaries. These would all fulfil the requirements of TI.

Replacement or upgrade of the emergency generator for T45 is a more realisable opportunity for TI. Other more powerful and power dense diesels are available now, small marinized micro GTA's will be mature before 2005, with fuel cells a possibility for ship fitting from 2015. In 2015 the first T45, HMS *Daring*, will have been in commission for 8 years, and the last of the current build contract, HMS *Duncan*, will have been in service for only 3 years.

The move to an AES does not seem to have either closed off or opened up more TI or indeed IA options in this area. However, the move to a power station concept has allowed the much increased chance of changing prime movers in the future as the output required is electricity. No shaft alignment or gearbox matching would be required if the cruise diesels were to be upgraded or replaced for example.

Power Distribution (HV)

Technologies being considered for insertion in this section include;

- Cabling.
- Switchboard.
- Breakers.
- Propulsion Motors and converters.
- Energy storage.
- Filters.
- HV-LV link.

The move to an IEP solution for T45 has driven the system ratings higher, into the HV range. This has meant the incorporation of 1000V+ cable, switchgear and switchboards into the modern naval platform. This has been achieved with the T45's 4.16KV solution, with only minor difficulties with cable bend radius, EMC considerations and ship design constraints due to regulations concerning HV. Having incorporated this solution, FIG.1, into the T45 hull form, there will be very little chance of the cabling being upgraded or renewed throughout the life of the ship. Care has been taken to ensure the cable selected meets all current, and future predicted loading conditions safely. All other technologies in this area are possibilities for TI in some shape or form.

The Propulsion Motors selected for the T45 are Advanced Induction Machines, (FIG.3), and represent the best the market can offer early in the 21st Century. Improvements are already in development for these machines, most of which cannot be incorporated into the T45's motors. Step changes in technology to permanent magnet or super-conducting machines will occur in the lifetime of the T45's, but significant operational capability increase or through-life cost reductions must be possible if a costly complete motor TI option is to be considered.

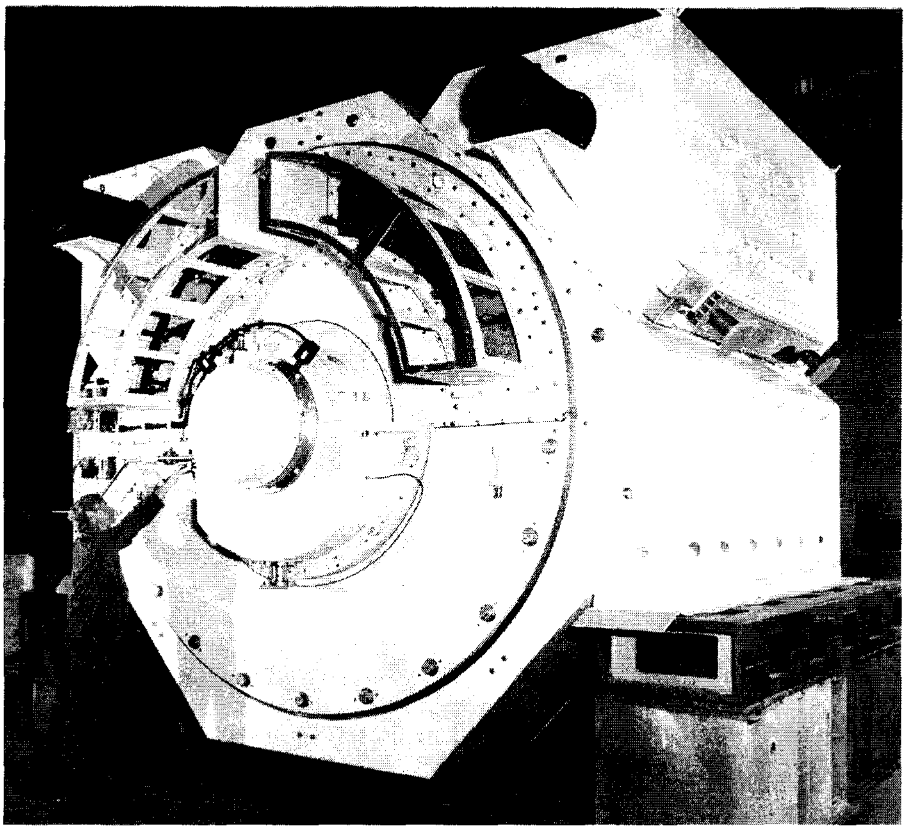

FIG.3 – ADVANCED INDUCTION MOTOR FOR THE T45 DESTROYER

The only likely TI options in the Propulsion Motor area is improved control algorithms and auxiliary systems (cooling, lubrication). These can be implemented without undue disruption or impact on the ship. These forms of TI are a demonstration of the flexibility an AES solution can give.

The Propulsion Motor drives of the future give greater opportunity for TI. The rating of power electronic devices has increased rapidly over the last 10 years, and indeed the move to a naval AES concept would not have been possible without this progression. Individual components, device bridges, cooling sub-systems, firing circuits, control software and whole system architectures can be changed in the future. All the triggers for TI (overcoming obsolescence, upgrading, updating, meeting new legislation and reducing whole life costs by using newer technologies) could cause a change in this area. The introduction of motor drives technology by the AES concept has improved the chances of TI in the future. The only comparative item of equipment in the traditional conventionally shafted warship is the gearbox, and historically little TI or IA has been carried out on this equipment once fitted. The adoption of AES allows for updated drive control algorithms to be implemented that could optimize the efficiency of the motor during the majority of its operating profile, whilst allowing quieter operation when the environment requires it (minefield transit, future legislation). No gearbox design allows this.

The incorporation of a podded drives solution for the first batch of 6 T45's has been ruled out due to the immaturity of a naval podded drives and structural hydrodynamic issues, but is fully compatible with the wider AES concept. If podded drives were incorporated from the design stage, the TI of podded technology into future ships is very realisable. Lower specification podded drives could be fitted from build and replaced through life as higher capability podded drives are made available. This action is more likely to be part of an IA plan than true TI, but complete propulsor changes could be incorporated to overcome obsolescence, signature issues and design shortfalls. Higher specification, 'warshot' podded drives could be TI to platforms going to areas of conflict, or propulsors more suited to shallow or warm water environments could be TI to future platforms to give best operational capability for as little investment as possible.

Other propulsor technologies that could be considered for TI include waterjets, magneto-hydro-dynamic and rim drives. However, due to the large ship fit and hydrodynamic considerations these technologies are unlikely to be TI candidates. Their incorporation in to future AESs is possible due to common theme of electrical power being the driver for these types of propulsor.

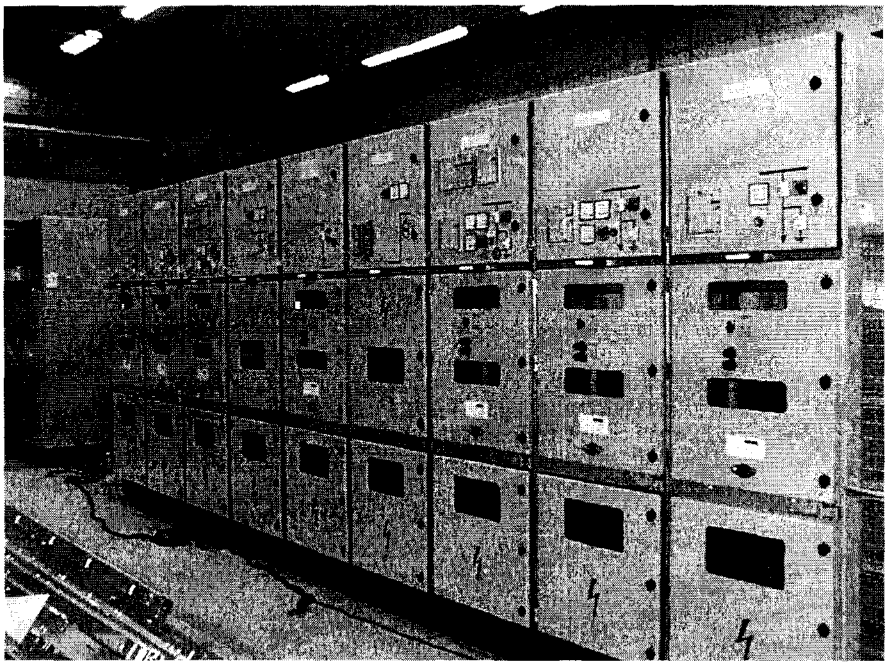

FIG. 4 – 4.16KV SWITCHBOARD

The HV switchboards and breakers (Fig.4) have a similar potential to propulsion motor drives for sub-system and component TI. Hybrid and solid state breakers currently under development could present sufficient safety and efficiency improvements in the future to be TI candidates for the T45's system. Ship fit implications would be minimal, and if the need for cooling could be reduced or even removed (by adopting hybrid switchgear) with TI, this would make the new technology very attractive. Heat management and cooling system loads have the potential to be an issue for the T45.

The T45's IEP system includes two filters on the HV system to ensure system parameters remain within manageable levels. These pieces of equipment offer more TI options. The current T45 design includes a passive 3 phase, star connected set of series connected reactors and capacitors, tuned to just below the

5th harmonic. It provides 4.2 MVAR of power factor correction at 60Hz. However, this capability comes with a penalty. Each HV filter's dimensions are 3.2 x 1.4 x 2.2m and weighs 6.4 tonnes. When interfaces, cooling, shock mounting and drains issues are added to the picture these items of equipment are not insignificant. TI to remove some of the cooling load would improve the situation, as too would the move to active filtration. As more systems, particularly weapons and sensor loads, are added to the platform, via IA or TI, the need to clean up the HV system will increase. The only way to achieve this is to TI into the filter. Again complete system change is unlikely due to ship fit constraints, but major sub-systems and components could be changed. It is entirely possible that in 15-20 years time the only remaining part of the originally fitted filter is it's cabinet.

The AES concept includes bulk energy storage to provide power ride through if the single running generator were to fail, and to give near silent short term transit speed. This option has not been included in the T45's IEP solution. Candidate technologies include:

- Batteries.
- Flywheels.
- Spinning generators.
- Regenerative fuel cells.

Maturity levels for all of these technologies differ widely, but all will be capable of TI with suitable development. TI of a bulk energy storage device into the current T45 design is unlikely due to the unbalanced level of effort required to incorporate them compared to the benefits that could be realized at this stage of the design. If bulk energy storage were to be incorporated into future AES designs it would be a prime area for TI, facilitated by the full adoption of the AES concept.

The final element of the AES being considered in this section is the HV-LV link. In the T45 this is carried out by two transformers rated at 2.5 MVA each. At the time of specification no other candidate technology was mature enough for the T45 application, but solid state 4160/440V, 1 MVA link converters are under construction and will be tested in the near future at the UK/FR Electric Ship Test Demonstrator (ESTD) site near Leicester[4]. The developed solid state link converters could fit within the space (2.8 x 1.6 x 2.1m) and weight (5.8 tonnes) envelopes of the current transformer solution. The solid state link converters are a T45 TI option if ESTD shows that they can withstand high levels of HV distortion and hence remove the need for HV filtration, and through improved isolation reduce the LV filtration duty. The adoption of link converters could improve performance and resilience, reduce vulnerability and simplify systems. Other factors like under capacity, loss in fighting capability if one transformer fails and unreliability of auxiliary systems for the transformers may force this to be a TI option for T45.

This section has considered all equipment related to HV power distribution, all of which have been introduced by the move to an AES based architecture. The T45 system has some in-built shortcomings in it's IEP design, primarily due to immaturity of better technologies at time of specification, and the inevitable build budget constraints. But as described in the section above, all technologies except cabling are open to TI. The level, economic basis, driver and potential vary in all cases, but TI is made possible by adopting the AES concept.

Power distribution – LV

The areas covered in this section include:

- Cabling.
- Switchboards.
- Electrical Distribution Centres.
- Local energy storage.
- Fan/motor starters and filters.

Similar to the HV distribution section, cabling is unlikely to be changed or upgraded during the life of the platform. The remaining technologies are all candidates for TI.

LV switchboards, breakers and Electrical Distribution Centres are all potential TI options. Advances in breakers, solid state technology, switch safety and materials and the possibility of future legislation will all drive TI in these areas. The potential of TI into T45 exists if the strong drivers for TI are presented during the service life of the T45 platform. One area where TI is more likely on the T45 is motor starters. Simple, low risk motor starters have been selected for the T45 which have very little intelligence, are not capable of outputting condition based maintenance data to the Platform Management System and have a poor upgrade path. In this area complete TI of a starter is possible, and fully achievable with the AES architecture. The introduction of Variable Speed Drives (VSD) for motors and fans is possible with the AES concept, and with the increased intelligence of starters their incorporation (TI) into the platform would be a relatively easy and low cost option.

Energy storage at a zonal LV level was also a major feature of the AES concept. The advantages cited include better fight through capability after damage, fewer UPS's and Transformer Rectifier Units (TRU) and greater system flexibility. The T45 has not chosen a zonal LV distribution system with energy storage placed at this level. Consequently a large number of TRU's and UPS's have been necessary to give the availability and reliability figures set in the requirements, causing a space, weight and cooling issues. The candidate technologies for energy storage are the same as for the HV bulk energy storage; batteries, flywheels, spinning generators and Regenerative Fuel Cells, (FIG.5), and have the same TI implications as the HV section. Smaller scale energy storage would however be a more viable TI route due to the lower ship fit and interference issues.

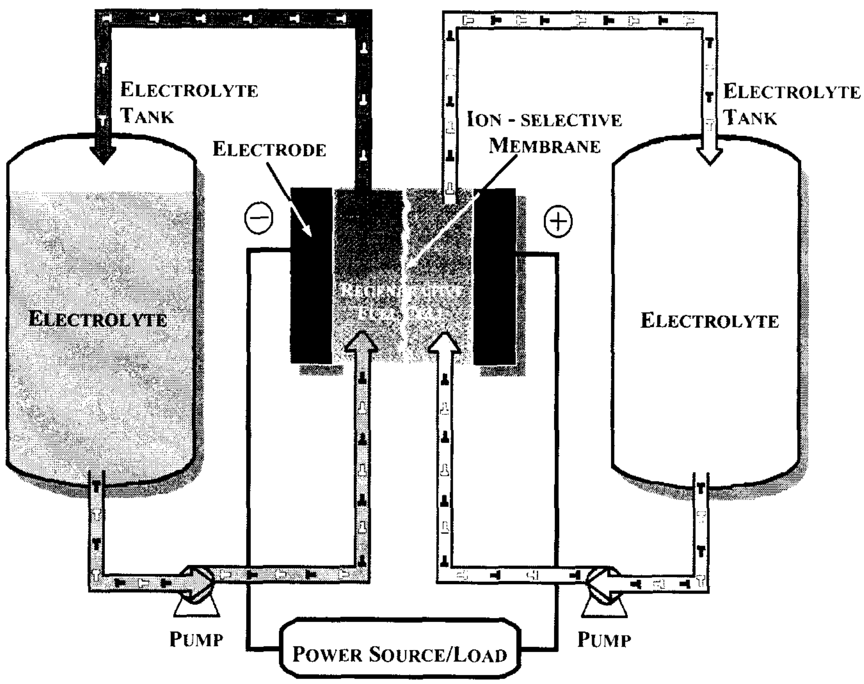

FIG.5 – REGENERATIVE FUEL CELL ENERGY STORAGE

The final technology in this section is LV filters. Again the move to AES have necessitated the incorporation of a filter, and in T45's case, active filters. TI of the filter or its component parts will be possible when driven by any of the TI triggers. The T45's filters, sets of power factor correction capacitors connected directly to the LV busbars and a 2 level PWM, IGBT converter connected to the LV busbar via a series reactor, are again large items of equipment, 3.4 x 1.4 x x2.2m and 5 tonnes. Any TI that could be done will reduce the impact these items have on the platform; size, weight, cooling etc. The move to an AES again facilitates TI, and indeed it may be required to maintain the quality of power supply throughout the ships life due to TI of other loads onto the LV system.

As for the HV distribution section the adoption of an AES concept has increased the potential for TI, and greatly improved the possibility of it happening. A certain amount of blame could be levelled at the AES system for introducing items of equipment that consequently require TI, filters and energy storage for example, but the benefits of AES far out-way the disadvantages introduced.

Auxiliaries and Weapons/Sensors Support

The electrification of auxiliaries is one of the final steps from IFEP to the AES. Areas of application in this section include:

- Pumps.
- Steering gear and stabilisers.
- HP air.
- Hydraulics.
- Chilled water.

Some steps towards electrification of these systems and equipment have been taken on the T45, but de-risked power dense motors to replace hydraulic systems have not matured sufficiently to be incorporated in the T45 design. Hydraulic start for the WR21's has been chosen over air start, with progression to electric start a possibility in the future. Areas where TI of VSD's is possible are fan motors, cooling water and lubrication system pumps. The opportunity and potential for TI in these auxiliary areas has been increased by the move to an AES as the common theme is power transmission/conversion being all electrical. This makes ship integration issues less, and compatibility easier to manage.

The development of pulsed and burst energy weapons and sensors has accelerated greatly in the last 10 years, again greatly facilitated by the rapid advances in power electronics and power systems. Technology demonstrators are now in place (FIG.6) for:

- Electro-thermal guns.
- Electro-chemical guns.
- Rail guns.
- Lasers.
- Pulsed radars and sonars.
- Burst communication systems.

Many of these have maturity dates in the next 5-10 years, and will be TI and IA options for future ships, including the T45. The adoption of the power station AES concept greatly improves the chance of these types of weapons and sensors being TI'd into ships, and indeed may be the greatest benefit in the future of adopting AES fleetwide.

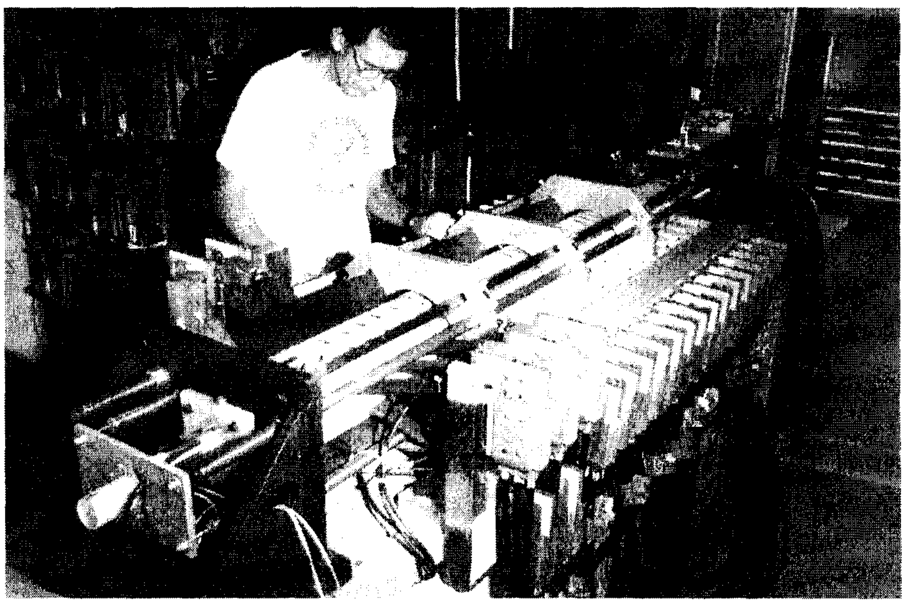

FIG..6 – COIL GUN TECHNOLOGY DEVELOPMENT.

The other great benefit of AES is the increased level of integration at the platform management level. This allows links to be formed between the traditional combat and the platform systems. This will enable pre-emptive action to be taken by the platform systems based on information from the combat system. This possibility, termed 'Flinch', will allow fluid systems and the electrical distribution system to reconfigure itself to reduce the impact of a missile hit, and then to recover as much of the system and capability as quickly as possible automatically. This will greatly improve the warships survivability and operability. This capability increase can only be implemented if a platform embraces platform management and the AES concept.

The move to an AES solution has not impacted greatly on the auxiliaries of a warship, other than to make TI of motor starters, SMART system intelligence and VSD's easier. The area where AES will have a much greater impact for TI in the 10 year plus timescale is in the weapons and sensors arena. The bolting on of pulsed energy weapons to T45 and other future platforms is made very feasible by the adoption of a power station concept.

Conclusions

The four sections above covered the different areas of the AES solution, with the T45, (FIG.7), as a focus. With the exception of the majority of power generation technologies the opportunity for TI has either remained the same or improved greatly with the move to an AES concept.

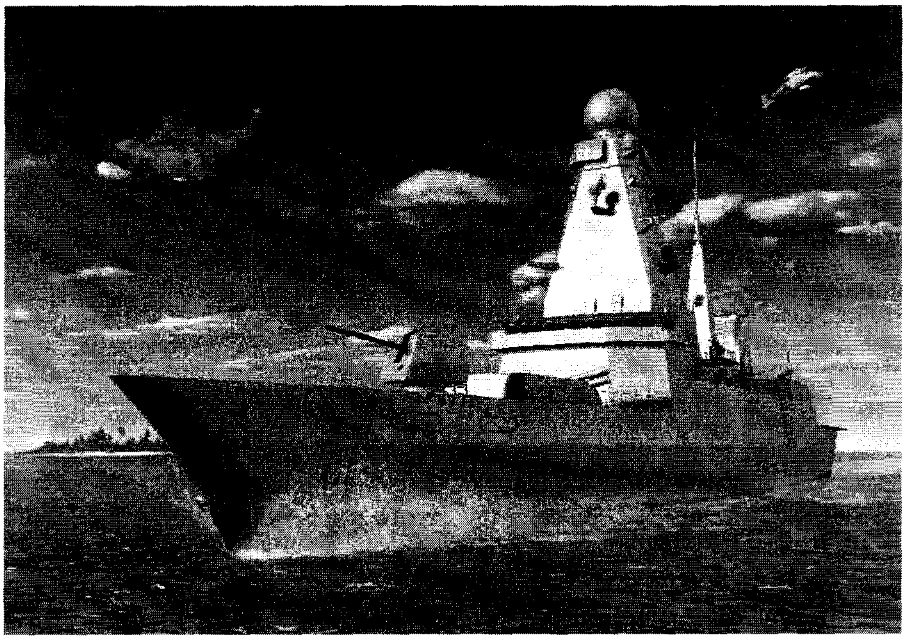

FIG.7. – ARTIST'S IMPRESSION OF THE T45 DARING CLASS DESTROYER

Component and sub-system TI is possible with all the electrical equipments that make up the IEP solution for the T45, and this will only increase in future platforms as the fully AES ideal is realized. The only exception to this being the cabling, GTAs and possibly the Propuksion Motor. Of greater significance is the potential to improve operational capability by weapon, sensor and platform management improvements that can only be entertained if the AES concept is embraced. The T45 solution has gone a long way to reaping the benefits of the AES concept, but due to time and cost constraints will not fully utilize the potential that an AES can give. Some TI opportunities have been severely restricted by the design of the T45, and it's processes, and every effort must be made to ensure that the very solid baseline of the T45 is taken forward for later batches and other future surface combatants.

The move towards an AES navy is compatible with one of the key mantras of SMART Acquisition – Technology Insertion.

Acknowledgements

The support of the T45 IPT is greatly appreciated by the Author.

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