HIGH VOLTAGE SYSTEMS IN WARSHIPS

THE REALITY
A PRACTITIONER'S PERSPECTIVE

BY

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ABSTRACT

HMS *Albion*, one of two LPD(R)s currently in build in Barrow-in-Furness, is the first RN warship to adopt Integrated Electrical Propulsion. Based on a commercial solution, the power distribution and propulsion system utilizes a 6.6kV distribution system, 4 Diesel Generator prime movers and a 6MVA synchroconverter propulsion drive to each of 2 shafts. Low Voltage supplies are transformer fed from the 6.6kV system. Bounded by legislative requirements, Health and Safety and the exacting 'owners' requirements of the naval environment – the introduction and operation of High Voltage (HV) equipment and systems has required the Royal Navy to establish new procedures, policy and 'best practice'. In reviewing the reality of HV the article will assess a range of related issues, including: Training, System Operation, Equipment and System Specification, Integration, Safety and Damage Control and Fire Fighting.

The issues will be discussed from the perspective of LPD(R) to demonstrate how the Royal Navy is managing the introduction of HV; raising issues of design, integration, operation and support. It will be shown that whilst the implications of HV in a warship are very different, the issues are not insurmountable and a Safe, Survivable system is clearly achievable with the correct focus.

Introduction

Integrated Electric Propulsion (IEP) is now a reality in the Naval Service. It has been discussed in a plethora of papers and seminars, the reality however brings to the fore a number of issues, for the design, support, operations and training communities; the main focus of which is the implication of High Voltage (HV) equipment and systems. In facing these challenges, the naval community have sought to embrace the requirements of classification societies, operating experience, legislative bodies and best practice from the commercial sector. In doing so a HV document has been produced which aims to capture a set of Naval 'Owner's Requirements'. The reality of IEP is the Landing Platform Dock Replacement (LPD(R)) and the Auxiliary Oiler (AO) both of which embody commercial power and propulsion solutions, but the article will look to the LPD(R) to capture and illustrate the issues.

This article will introduce the LPD(R) power and propulsion system, reviewing aspects of the equipment and system design whilst focussing on HV and the impact on the operational community. The aim of the article is to promote discussion within the wider community and to inform system designers, integrators and the operating and support communities of the constraints and suggested 'best practice' for IEP.

Background

The use of a common power system for both propulsion and ship's services is now an accepted norm for the commercial marine and offshore markets. Electric Propulsion brings together efficiency, flexibility, survivability and, perhaps most importantly, reductions in cost of ownership. Captured simply – reduced numbers of prime movers, integrated systems, flexibility in layout and proven commercial precedent make it a credible solution to the requirement. Whilst successful in the commercial sector, the exacting demands of the naval environment mean that systems need to be survivable and have flexibility to operate in both peacetime and wartime scenarios. It is this framework of commercial solution, the naval environment and legislative requirement, which bounds the successful introduction of IEP.

LPD(R) exposed

Originally designed as a direct drive mechanical propulsion system, IEP was introduced as the most effective power and propulsion design solution during the final stages of design; premised on the inability of the mechanical solution to meet the performance requirements of the vessel, notably the loiter requirement and the cost of ownership benefits of the IEP configuration. As a result of the design studies and investment appraisal, the diesel electric IEP option was adopted for LPD(R), HMS *Albion* and *Bulwark*.

The LPD(R) power system configuration (FIG.1) is a basic Diesel Generator powered commercial IEP architecture system with interconnected electrical propulsion and ship service systems. The propulsion motors are each variable speed AC synchronous machines, each controlled through a synchrodrive converter. The electric power for the system is derived from three 6.6 kV switchboards, located aft, mid and forward. The aft and mid 6.6 kV switchboards are fed from nominally rated 6.25 MW diesel generator sets and each has a propulsion motor and its associated drive control unit connected to it. The forward switchboard is fed by two nominally rated 1.56 MW diesel generator sets and has the bow thruster connected to it through a direct on line starter. Ship's service supply transformers are positioned on the forward and aft switchboards. The ship's service transformers are three phase 6.6kV to 450 V rated at 3.75 MVA with normal air cooling. The transformers are also rated for 5 MVA with the use of forced air cooling. Under normal operating conditions, all three of the 6.6 kV switchboards are connected through their busbar tie circuit breakers. The AO includes similar equipments but in a tandem motor, single shaft configuration.

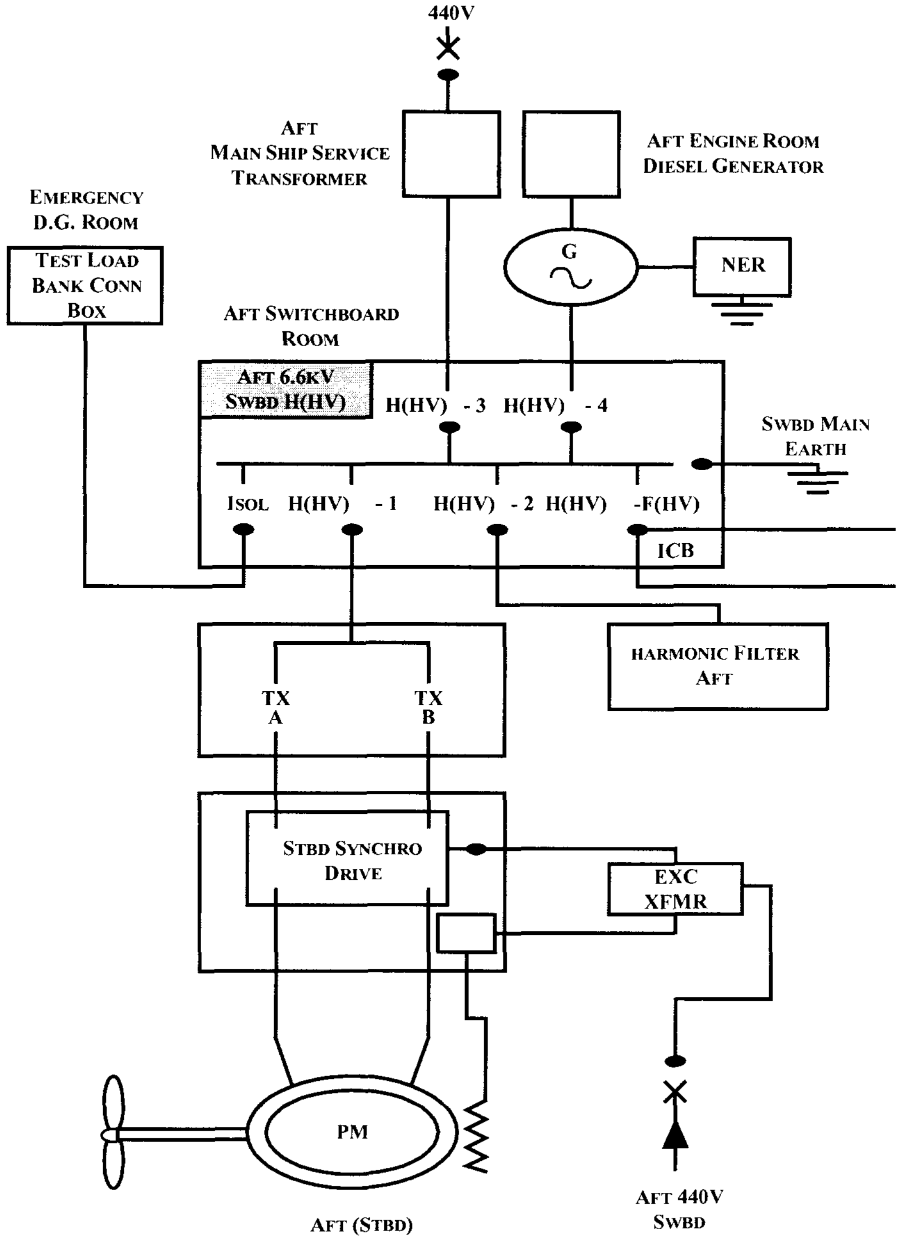

FIG.1 – LPD(R) SINGLE LINE DIAGRAM

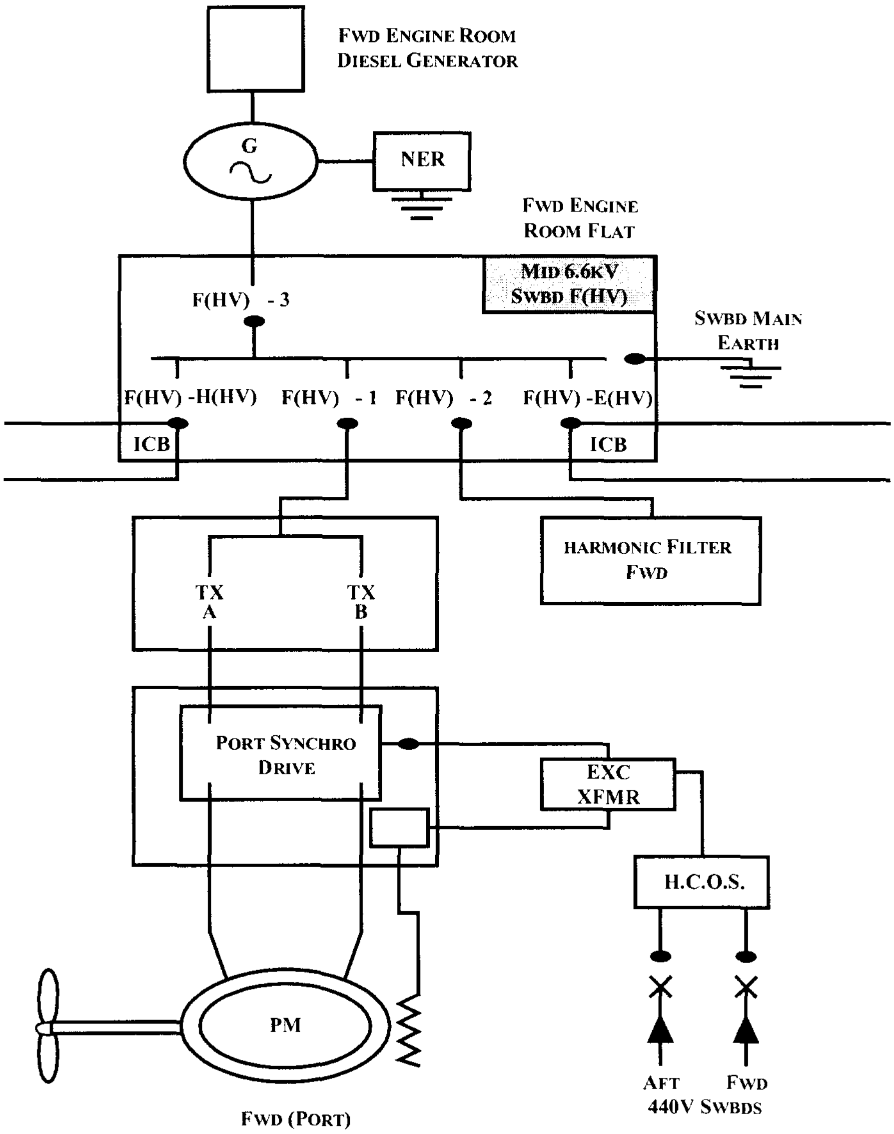

FIG.1 – LPD(R) SINGLE LINE DIAGRAM

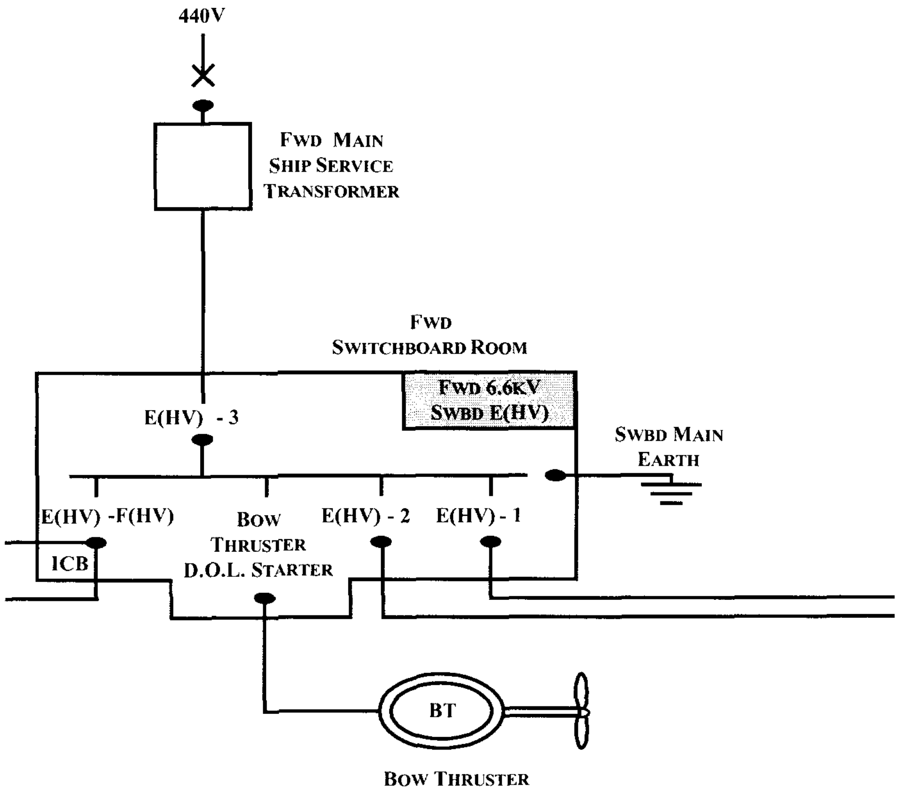

FIG.1 – LPD(R) SINGLE LINE DIAGRAM

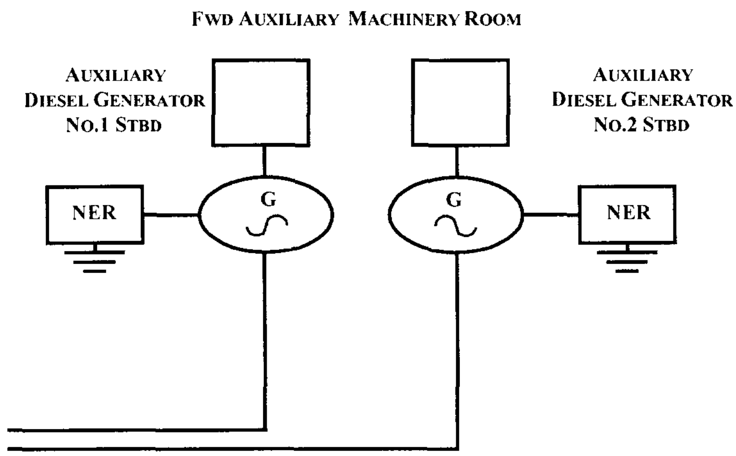

FIG.1 – LPD(R) SINGLE LINE DIAGRAM

Noting that the LPD(R) power system design was re-designed from a diesel mechanical solution it was subject to a number of critical design constraints. Key aspects of which included:

- The general arrangements were fixed putting considerable spatial constraints on the IEP architecture; notably extended shaft lines and non-optimized system survivability.
- The timescales meant that only commercially available equipment and systems could be utilized.
- Auxiliary system designs were not optimized for IEP and time precluded wider electrification of systems to maximize the benefits of IEP.

Commercial solutions – naval environment

The application of a commercial solution to the naval environment provides a number of challenges; basically how to design, build and operate a commercial system so that it is robust enough to withstand the warship operating environment. In achieving this, the overriding factors are Safety and Operability of HV systems. It is these factors which will form the basis of the review of IEP.

In looking to capture the issues a working group was established, comprising representatives from the technical, platform, support, scientific and operating communities, supported by the wider Naval Service and Classification Societies. It is the involvement of the Royal Fleet Auxiliary and Lloyds Register that has informed the group and established baseline criteria and accepted 'best practice' for such systems. To translate this into requirements for the Naval Service the working group has undertaken a review of the risks associated with the top level risks identified in Table 1.

TABLE I – *Top 'X' Review - The Associated Risks*

Risk No	Risk Type	Description of RISK Concern	Description of Potential IMPACT	Description of LIKELIHOOD
1.	Safety	Branch Structure and Training.	Shortfall in suitably qualified/experienced Electrical Engineers at all levels leading to reduction in availability and safety. No suitable PJT/Type/HV specific training leading to safety issues and danger of severe injury or loss of life.	Commercial courses and 'ad hoc' training focus will manage early introduction but not sustainable for IEP in longer term.
2.	Safety	Safe System of Work.	Danger of severe injury or death.	Unfamiliarity with procedural and legislative procedures will increase likelihood of incident.
3.	Safety	Certification.	Lack of certification/Naval Authority leading to lack of common practice between Platforms and wider Stakeholding Communities and inability to audit power and propulsion systems resulting in equipment failures, severe injury or death and loss of ship.	Unable to maintain common 'best practice' to maintain standards across Naval Service.
4.	Safety	Classification Society Rules Owners' Requirements.	Installation not optimized for naval environment with reduced operability, survivability and safety.	Naval environment will expose problems during STW, trials and normal operation.
5.	Safety	Effective FF/DC Policy.	Unable to fight fires or undertake effective damage control without endangering personnel or ship.	Likely that minor incidents will not be contained and escalate.
6.	Cost	Infrastructure.	Unable to provide support or services alongside with commensurate demands on ship's equipment and resource.	Investment and IYM pressures will undermine Naval Base provision of services.
7.	Safety	Electromagnetic Fields.	Risk to personnel (to be quantified) and increased signature.	No coherent MoD/Industry focus with no palliatives identified.

IMPACT Rating	LIKELIHOOD Rating	RISK Rating	Mitigating Actions and Time Frames
3	3	9	Electrical Training Review supported with Facilities Review.
3	3	9	HV Policy Document translated into Naval Service Standard Operating Procedures.
3	3	9	Establish a Power and Propulsion Naval Authority.
3	2	6	HV Policy Document. Translate Owners' Requirements to Platform Requirements.
3	2	6	HV FF and DC strategy supported by Trials Programme.
2	2	4	Early identification of jetty requirements and shore power requirements.
2	2	4	EMF trials supported by analysis and modelling to manage problems and inform future platforms.

Classification Society Rules and Owners' Requirements

The classification society rules of DNV and Lloyds Register and the standards in IEC 928 have established design criteria for HV electrical systems, including a range of design standards and constraints. The owners' requirements are captured in the MoD's HV Policy Document. The commercial rules, whilst extremely taught in places are open to interpretation in a number of areas and it is those areas that have led to early problems in the LPD(R). It is therefore essential that the Naval requirements are brought to bear at an early stage if the system is to be safe. In broad terms the issues centre on the architecture and physical layout and it is imperative that design effort is focussed to ensure:

- Ingress Protection (IP) Ratings are to be suitable for the physical location of equipment to prevent water and dust contamination and ensure the safe operation, fire and flood protection and survivability of HV equipment. The following minimum IP ratings must be adhered to:
  - IP33 protection in dry compartments with no fluid systems (protection from 1mm probe and sprays up to 60 deg from the vertical).
  - IP56 protection in wet compartments containing fluid systems (protection from limited dust and strong jets of water).
  - IP68 protection in machinery spaces below the propeller shaft line (protection from full immersion).
- Within the constraints of survivability and operability, HV equipment is to be co-located to minimize problems of access, excessive cable runs. Also limit as far as possible, the siting of other equipment within the same compartment and avoid, as far as practically possible, locating HV equipment in main machinery spaces.
- Platform Management System (PMS) and Electrical Power Control and Management (EPCAM) functionality is to allow for remote and reversionary remote control of the HV system and whilst hand switching is to be provided it is only to be used for reversionary control as authorized by an Authorized Person (AP).
- All fluid systems within 5 meters of HV equipment with less than IP56 protection must have welded joints. Where this is not practical flanged joints must be shielded and kept as far from the HV equipment as reasonably practical.
- Compartments containing HV electrical equipment are to have restricted access and physical barriers are to be fitted to enclosures, chambers, cubicles or cells containing Live HV conductors. Unique locking arrangements are to be provided to restrict access to all HV equipments.
- Cable installation is to take full account of minimum separation, bend radii constraints, impact of terminations, securing mechanisms and radiated fields.
- Switchboards are to be a proven type tested design to manage overpressures due to internal arcing faults and to contain internal arcing faults within switchboard sections.
- All HV compartments are to be fitted with remote CCTV surveillance.

- The use of electrical safety devices, remote monitoring and arc fault detection should be considered as standard.
- Maximize the use of fire retardant material for all fittings and systems in HV compartments and cabinets. Ensure auxiliary low voltage systems collocated in HV cabinets are correctly secured/segregated and of a low fire risk.
- Provide compartment thermal boundary protection (A60 boundary) to prevent risk of fire from adjacent compartments and remove requirement for boundary cooling.
- Provide collective, grouped, disconnections for all HV equipment from dedicated points outside the compartment.
- Fit a fixed fire suppression system to all HV compartments with remote operation and supported by an appropriate fire detection system.
- Provision of dedicated ventilation to HV compartments.

System integration

The integration of the IEP systems is a significant challenge to system and equipment designers and an area, which needs the requisite focus at all stages of the design process; this has been very true for LPD(R). Integration issues include system stability, operability, compatibility – notably EMC, physical issues and cross system issues.

Existing power system standards are not sufficiently robust to support IEP architectures. Fundamentally standards reflect conventional systems and architectures and are not sufficiently flexible to be adapted to suit IEP systems. In support of this a review is being undertaken to propose a policy for IEP systems covering issues as diverse as Power System Standards, Safety, Design Constraints and Working Practices. This is even more relevant in view of the HV implications. The balance must therefore be to take 'best practice' from Defence and Commercial Standards to produce a definitive guide for IEP and HV installations.

Training implications

The trend towards IEP and HV requires a new focus and emphasis and whilst the requirement for LPD(R) can be met with commercial and local training courses the longer term case must be made to provide adequate training 'in house'. Training takes the form of specialist HV training, equipment training and technology training. It is the synergy between these requirements and across platforms which must be exploited if the introduction of such systems is to be achieved safely. Turning to each of the training requirements in turn:

- *HV training*

  The Naval Service has no 'in house' training facility for HV training with training undertaken at the Faraday Centre in Middlesborough. The training provides generic HV training with a marine perspective and as experience improves, the naval relevance is increasing. In the longer term, throughput and experience will support establishing an 'in house' facility. If a facility is to provide the necessary level of accredited training, it must use representative equipment and the training resource must be experienced. The provision of such training is a key Risk to the safe implementation and needs to attract the necessary resource funding.

- *Equipment training*

  Similarly, specific to type equipment training needs to be managed. Currently delivered commercially, the diverse range of equipment and suppliers presents a problem which the MoD and Prime Contracts Offices need to resolve by producing a coherent focus on the provision of training for IEP and HV platforms.

- *Technology training*

  More a fundamental change in technology focus, than specific to type training, IEP brings with it a complete range of technologies as diverse as propulsion converters and HV switchgear. Current courses do little to address the enabling technology groups and it is therefore essential that core syllabi look to introduce the concepts

Slightly out with the direct focus of training is that of Branch focus and the importance of a coherent focus on suitably qualified Electrical Engineers in the Marine Engineering operating community. At all levels the lack of experience and electrical background do not bode well for IEP and the safe operation of HV systems.

Onboard organization and qualifications

The structure to be implemented for the operation/maintenance of HV Systems is outlined below and summarized at Table.2.

TABLE.2 – *Onboard Organization*

Personnel	Training
Authorizing Authority (CinCFleet CSO(E) (SS))	HV Awareness
Authorizing Engineer (MEO - May have nominated deputies)	MCQ + AP + local assessment
APs	AP + local assessment
Competent Persons (CP)	Video + detailed briefing
HV Aware (Remainder of ship's company)	Video + briefing
MEOOW1	As CP

- *Authorizing Engineer*

  A technically trained and suitably qualified Engineer, usually the Marine Engineer Officer, fully conversant with the HV Systems and possessing in-depth knowledge of Electrical Safety Rules and Statutory Requirements. In the absence of the Marine Engineer Officer, one or more Charge qualified Officers or Senior Rates may deputize for him. The Authorising Engineer should be appointed in writing from CinCFleet CSO(E) (SS).

- *AP*

  A Competent Person (CP), normally of Officer or Senior Rate status, who has been Approved by the Authorizing Engineer to issue and cancel Permits to Work, Sanctions for Test and Limitations of Access. The Switchboard Register shall state the class of operation and/or work the person is authorized to carry out and the section of the Switching to which it applies. AP qualifications are Ship type specific.

- *Authorised Person in Control (APC)*

  An AP specifically deputed to exercise the function of control of the System. Normally at sea the nominated HV Section CPOMEA will be the APC in charge of any work on the System and will maintain the Switchboard Register.

- *CP*

  A person who has sufficient technical knowledge or experience to enable the person to avoid danger from electrical hazards. All members of the Marine Engineering Department, or a person Approved by the Authorizing Engineer in the Switchboard Register, who have been adequately trained and possesses sufficient technical knowledge to carry out specific operations and/or work on the systems or apparatus. The Switchboard Register shall state the class of operation and/or work the person is authorised to carry out and the section of the System to which it applies and may include authority to issue and cancel Limitations of Access.

- *HV Aware Personnel (HVAP)*

  All other members of the Ship's Company who have been adequately trained. They may not enter compartments or enclosures containing HV Apparatus unless accompanied by an AP or a CP. To receive full safety brief (including video) regarding HV hazards.

- *Certification*

  Formal certification will only be awarded on completion of the AP course where, upon successful completion, a Certificate of Competence will be awarded. Course completion will be recorded by C173 and the qualification will subsequently appear on Draft Orders for ratings and on biographical appointing data for officers. Persons holding a certificate will only become Authorized once they have completed a local assessment, conducted by the Authorising Engineer or his delegated representative. Successful completion of this assessment will be entered into the Switchboard Register at which point that person will be deemed Authorized (on that platform only).

There is a requirement for the provision of a training/joining video for the education of the Ships Company not involved in the 'day to day' working of HV equipment. This video may also have to be made available to potential contractors to also make them aware of the potential hazards. Other training issues include those provision of training and awareness for organizations such as Flag Officer Sea Training (FOST), contractors and trials teams.

Fire Fighting

Fire fighting in a HV environment can expose personnel to a number of dangers including:

- Massive electric shock from live equipment.
- Blast effects resulting from an internal arc caused by either the fire fighting activity or the subsequent development of the initial electrical fault.
- Exposure to hazardous electric arc products.
- Increase exposure to the fire hazard due to the restrictions placed on fire fighting.
- Increased fire propagation resulting from the initial delay in using more effective fire fighting equipment until such time that HV equipment is made safe.

The fire fighting procedures adopted will depend on the design of the installed HV system as well as the operational state of the vessel and nature of the incident. Clear guidance must be provided in local standing orders and the ship's fire fighting teams should be both familiar with the procedures and the layout and hazards within all HV compartments. A decision process flow chart is at (FIG.2), and is discussed below:

- *Small fires within a HV compartment*

  Small fires should be attacked, without waiting for electrical isolations, using the most appropriate first aid fire fighting equipment certified as inherently safe for use in a HV environment. Where the ingress protection of the electrical equipment is IP56 or above and the fire can be clearly identified as being remote to any HV equipment, then more appropriate water based first aid fire fighting equipment may be used. Once HV power has been confirmed as removed then standard RN fire fighting procedures may be applied noting that the excessive use of water may cause significant damage to the HV equipment and put it beyond use. If the fire is not easily contained then early evacuation of the compartment should be considered (note: both CO_2 and dry powder will cause significant obscuration).

- *Small low voltage fires within a HV compartment*

  Standard RN fire fighting procedures apply and a CO_2 extinguisher should be used either with a discharge horn or a bayonet connection for electrical cabinets. Electrical power should be removed as soon as reasonably practicable.

- *Major fires within a HV compartment*

  The compartment should be evacuated and the fixed fire suppression system deployed in accordance with the local procedures. The method of compartment re-entry and recovery will depend on the individual circumstances of the incident and operational state of the vessel. The excessive use of water in recovering the compartment could cause significant damage to the HV equipment and put it beyond use.

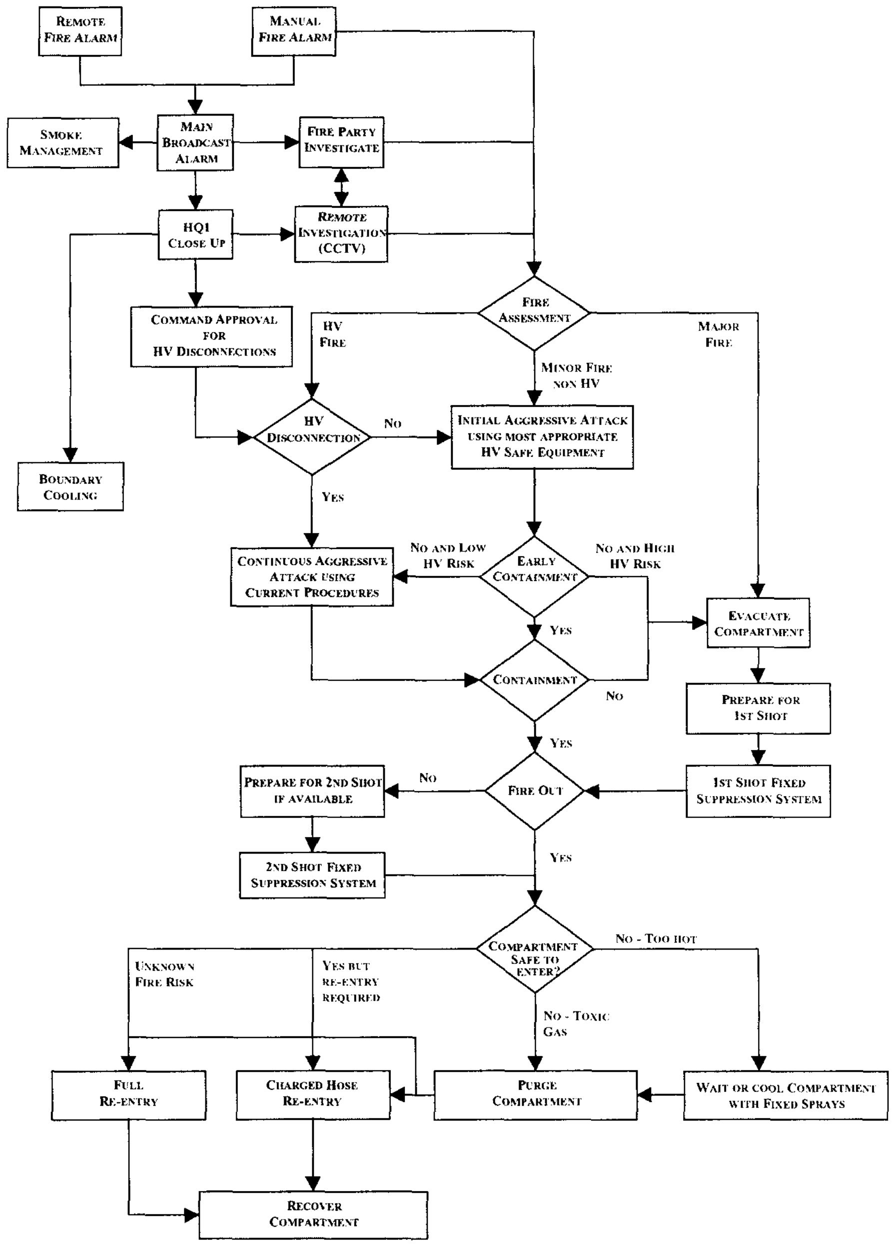

FIG.2 – PROCEDURE FOR FIREFIGHTING IN A HV ENVIRONMENT

- *HV fires*

  HV power should be removed as soon as operationally possible and the fixed fire suppression systems deployed in accordance with local operating procedures. Where there is no fixed system, a controlled re-entry should be made once all HV equipment has been made safe.

- *Fire Danger within a HV compartment*

  HV power should be removed as soon as operationally possible as a fire precautionary measure and before applying any form of foam blanket. Where immediate action is required or power can not be removed, a localized fire danger may be made safe where the risk of not taking action out-weighs the risk of exposure to HV and will depend on the location and ingress protection of the installed HV equipment.

In maintaining an aggressive attack on a fire the following issues should be recognized:

- *Kill Cards*

  Kill cards must identify the HV risks adjacent to and within compartments with details of how to isolate the equipment as well as the ingress protection rating and drain down times associated with each equipment.

- *Electrical disconnections*

  The ability to collectively isolate all HV equipment from dedicated points from outside the compartment is essential. There should also be clear indication both from outside the compartment and on individual equipment as to whether the equipment is live or at zero charge.

- *Decay times*

  The decay times for HV equipment should be established during set to work or following any major modifications and be clearly identified below the HV warning sign and be visible from the direction of the main access point. The system designer is to ensure that every reasonable measure is taken to ensure that decay times are kept as low as reasonably practicable.

- *Boundary Cooling*

  Boundary cooling within HV compartments should whereever possible be carried out with the HV equipment de-energized. Where operational requirements preclude this, boundary cooling may only be carried out by a competent person whilst the HV equipment remains live, with due regard to the ingress protection of that equipment. In both cases all electrical equipment should be protected by plastic sheet.

The following paragraphs raise a number of issues, which are pertinent to fire fighting in a HV compartment. They reflect the current thinking but are subject to completion of trials:

- The selection of an appropriate fixed fire suppression system must be consistent with the risks identified within the compartment and cannot be mandated as policy, however the following additional factors must be considered for HV compartments:

- Ability to operate the suppression system whilst the HV system is live given that the fire may not be on the HV equipment and maintenance of power supply is operationally desirable.
- Minimize secondary damage to HV equipment in order that the equipment can be recovered and re-energized once the fire has been extinguished.
- Remote operation from outside the compartment.
- Provision for compartment over-pressurization both from the effects of arc products and the use of the fire suppression system.
- If the fixed fire protection is limited to cabinet level then it must be combined with a dedicated cabinet based fire detection system and the cabinet must be designed to contain any internal blast.
- Centre feed hose reels and hydrants should be installed where appropriate and in accordance with the fire hazard analysis; but where HV equipment has inadequate ingress protection (less than IP56), these systems should be inhibited until such time as it is confirmed safe for their deployment.
- Manual CO_2 injection ports must not be fitted to HV equipment due to the inherent dangers associated with HV faults. A remotely operated CO_2 cabinet drench system is therefore recommended. Low Voltage equipment within the HV compartments should still be protected with injection ports.

* Only portable fire fighting equipment certified by the MOD as inherently safe for use in HV environment may be deployed for first aid fire fighting on live HV equipment. The following portable extinguishers are MoD endorsed for use in a live HV environment:

    - *Dry Powder*

      Initial trials results indicate that Dry Powder is safe for use on live equipment up to 27 KV with a minimum air gap of 35mm (fault current of 3mA), however high humidity above (50%) will reduce this safe working voltage. The residue powder has not proved to be conductive but will absorb moisture and should be removed from electrical equipment as soon as reasonably practicable.

    - *Carbon Dioxide*

      Initial trials results indicate that Carbon Dioxide is safe for use on live equipment up to 30 KV with a minimum air gap of 35mm (fault current of 3mA), however high humidity above (50%) will reduce this safe working voltage.

    - *Pyrotechnically Generated Aerosols*

      Not yet in service but aerosol grenades may provide a safe stand off approach to first aid fire fighting and are currently under trial with the MoD and QinetiQ. Reputed to be as effective as Halon, it is suitable for use in a confined space where sufficiently high volume concentrations can be achieved.

- *De-ionized Water Lance*

  Not yet in service in the Royal Navy, similar equipment is stipulated by SOLAS and widely used on RFAs; again currently under trial by the MoD and QinetiQ.

- *AFFF Fire Extinguishers and Centre Feed Hose Reels*

  May only be used in a live HV environment if all the HV equipment within that compartment is protected by an ingress rating of IP56 or higher and only then if the fire is clearly identifiable and is remote from all HV equipment. High pressure water should not intentionally be sprayed directly at HV equipment regardless of the factory tested ingress rating.

Damage Repair

Where there is an increased HV risk to personnel following peace or war-time damage to HV equipment then power should be removed as soon as operationally practical and before personnel enter the compartment. Once power has been removed standard Damage Control procedures should be followed. Where the operational tempo and command priorities override this approach the following generalized guidance is provided:

- *Pumping and Flooding*

  Small floods remote from HV equipment may be contained without removing power. Major flooding is likely to cause significant damage to HV equipment and power should be removed both to safeguard the equipment and personnel before any attempt is made to contain the flooding.

  System Repair

  The repair of minor fluid leeks on low pressure systems remote to HV equipment may be carried out following standard procedures without removing power. Where appropriate, consideration should be given to covering HV electrical equipment with plastic sheet to minimize risk to equipment and personnel. Major leeks from high pressure systems represent a serious risk. The fluid systems must be isolated and the HV system must be disconnected immediately even when remote from each other.

- *Shoring*

  Shoring may be carried out in a live HV environment however the risk of man-handled timber and steel shores adjacent to live HV equipment must be assessed and where possible power should always be removed.

Access to compartments containing live HV equipment for fire fighting and damage control is to be restricted to CPs only and therefore provision must be made to ensure that there are sufficient personnel within the DC&FF organization with adequate electrical training. HV systems must not be re-energized following repair from action damage until such time that a full integrity check has been conducted and authorization is given by the Authorizing Engineer.

Safe System of Work

A safe system of work to include Health & Safety and other statutory requirements is essential if the system is to be operated safely, noting the requirement to have established procedures for maintenance and operation by naval and civilian personnel. Wherever possible standard Royal Navy practice has been adopted but HV requires additional precautions including hazard markings for compartments, hazard signage, restricted access procedures and CCTV monitoring of all compartments designated 'High Voltage'. Both contractors and visitors require routines with restricted access regulations controlled by either a 'Day Pass' or 'Contractors Pass'. Contractors requiring access to HV compartments will need to be briefed on the hazards and will require a Limitation of Access prior to unescorted access/work in these spaces. None of these issues are insurmountable but they need to feature in the baseline design for an IEP solution as the presence of HV will limit access and require control procedures.

The following safety procedures and requirements form the framework for operation of HV systems:

- *Access to HV Enclosures and Equipment*

  Compartments containing live HV electrical equipment are to have restricted access and subject to the 'Man Below' procedures. Physical barriers are to be provided to prevent access to live HV conductors.

- *Switching*

  PMS is to control all switching operations. Manual initiated HV switching is to be sanctioned by the appropriate AP in Control, except for agreed routine switching or in cases of emergency switching to isolate supplies.

- *Safety Locks and Key Arrangements*

  Procedures are to be in place for the control of access using a system of Safety Locks, all of which are to be provided with unique keys. Keys are to be kept in Key Safes with Master Keys to the safes held in the Master High Voltage Key Safe.

- *Precautions to be taken before working on HV systems*

  No repairs, maintenance, cleaning, alteration or similar work is to take place on HV apparatus unless it is:

  - ❑ Proved dead, Isolated and all practicable steps taken to lock off from live conductors.
  - ❑ Efficiently connected to Earth at all points of disconnection.

or

  - ❑ Released for work by the issue of a Permit to Work or Sanction for Test.

- *Circuit Main Earths*

  When HV equipment is to be discharged and Earthed it is to be done by the use of a circuit breaker or specially provided earthing switch to make the Earth connection. Alternatively, earthing leads may be used, once equipment has been proved dead.

APC CHECKS FOR ANY EXTANT PTW/SFTS IN FORCE. IF THERE ARE CONFLICTING PERMITS IN FORCE CONSIDER THE FOLLOWING:

- **DE-CONFLICT.**
- **ISSUING SINGLE PERMIT TO WORK TO COVER BOTH TASK.**
- **DEFERRING THE TASK.**
- **USING MULTIPLE LOCKING DEVICES**

ANY CONFLICTING LIMITATION OF ACCESS (LOA) TO BE CANCELLED.

APC OR DELEGATED AP PRODUCES SS. COPY TO SR

IDENTIFY THE AP/CP WHO WILL BECOME THE PERSON IN CHARGE

INFORM/OBTAIN APPROVAL FROM COMMAND/OPERATORS

VIEW EQUIPMENT AND EXPLAIN THE TASK TO BE DONE/RELATE TO SS SKETCH

APC ISSUES SWITCHBOARD KEY SAFE KEY TO AP FROM MASTER HIGH VOLTAGE KEY SAFE. LOGGED IN SR. CARRY OUT SS

DEMONSTRATE EQUIPMENT IS DEAD

APC/AP ISSUES THE PTW/SFT AT POINT OF WORK. AP/CP THEN BECOMES PERSON IN CHARGE (PIC). PTW/SFT GOES TO:

- **COPY TO PIC**
- **COPY TO SR**
- **COPY TO PTW SAFE IN SCC**
- **ORIGINAL SS TO SR. DUPLICATE MAY BE DESTROYED**

LOCK PTW SAFE IN SCC:

- **1 KEY TO PIC**
- **1 KEY TO AP**

CARRY OUT WORK/TEST

Notes:

1. PTW and SFT may not be issued by an AP to himself.
2. During any temporary absence of the Person in Charge from the place where the work is being carried out, the work is to be suspended and adequate safety precautions taken until work is resumed on the return of the Person in Charge.
3. On completion of work, with all personnel, tools and instruments removed, and after advising all personnel associated with the work that it is no longer safe to work on the equipment, the issuing AP and the PIC are to cancel the PTW/SFT. The cancelled PTW/SFT is to be retained in the SR and the return of Master HV keys logged in the SR.

FIG.3 –PTW FLOW DIAGRAM

- *Testing of HV apparatus*

  When any HV equipment is to be subjected to test voltage before being connected to the HV System, the apparatus is to be adequately guarded. All cables shall be discharged before and after the application of test voltage

- *Permits To Work (PTW)*

  A PTW is to be issued by the AP to a prospective Person in Charge before any work on defined items of Equipment is commenced. An AP may not issue a PTW to himself. A flow chart for PTW is at (FIG.3):

Infrastructure

The introduction of HV and IEP will require a number of changes to the wider infrastructure. This will cover issues as diverse as the ability for the Naval Bases to undertake work, notably the experience of the workforce, availability of load trial facilities, the provision of test equipment and the capacity of shore supplies.

MoD's High Voltage Design and Operators Guidance

The preceding paragraphs highlight a number of themes for HV systems, all of which are captured in the MoD's *High Voltage Design and Operators Guidance.* The document looks to provide the wider Naval Marine Power System Community with guidance on the specification, design, installation, test and operation of HV Power Systems in warships together with the wider issues of training and infrastructure. The two volumes will in broad terms capture esign issues and owner's requirements (pseudo Def Standards) and operating standards (pseudo BRs). In the longer term it is hoped to incorporate the policy guidelines within the requirements documentation for future platforms, notably on all safety related issues but in the near term the plan is to issue the document for 'buy in' from the wider naval power system community.

Conclusions

IEP and HV provide the Royal Navy and the wider naval community with a number of challenges, notably in terms of Training, System Operation, Equipment and System Specification, Integration, Safety and Damage Control and Fire Fighting. The Royal Navy is using the experience of Classification Societies, commercial systems and the wider naval service to produce the 'owners requirements' and safe systems of work to ensure that IEP, HV systems are survivable and able to meet the demands of the naval environment. In support of this, the MoD's *High Voltage Policy Design and Operators Guidance* looks to capture 'best practice' and promote discussion, information transfer and 'buy in' from all stakeholders including industry.

LPD(R) has faced many of the challenges mentioned in this article and is now a system able to meet the demands of the naval environment, reinforcing the importance of correct equipment and system specification, design integration, operation and support. It has been shown that, whilst the implications of HV in a warship are very different to those of commercial or previous naval systems, the issues are not insurmountable and a safe, survivable system is clearly achievable with the correct focus.