Electric Propulsion - Implementation and Way Ahead

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***Abstract**: Increasing need to reduce cost, save space, provide more and more Electric power for modern power-intensive weapon & radar systems and simultaneous need to comply with the stringent environment conservation norms is driving the world navies to opt for power dense and energy efficient technology in warships. Electric Propulsion is one such technology that has the potential to augment the overall electric power availability and optimise the overall life cycle cost & energy efficiency besides reducing the overall carbon footprints of a ship. Due to these distinct advantages, introduction of Electric Propulsion in future Warships is one of the key thrust areas for Indian Navy in general and Design and Production directorates, in particular. This is also reflected in recently formulated Indian Navy's Roadmap for Energy & Environmental Conservation which lays utmost emphasis on implementation of energy efficient propulsion systems for future warship projects of the Indian Navy. Induction of any new technology into present system represent a paradigm shift that requires a special focus on updating the knowledge level and training the individual on operational requirements, maintenance activities and safety procedures related to the new system. This Paper primarily focuses on the IFEP system requirements and the associated training requirements for successful implementation of the technology for future implementation.*

1. Introduction: Awareness towards environment due to greenhouse gas (GHG) emissions became a forefront consideration for power plant selection. Accordingly, many stringent guidelines were drafted and accepted globally, this drive towards clearer power sources, burning better fuel and getting more out of the energy spent by working on efficiency, began. The coal burning boilers were replaced by FFO and thereafter diesel (LSHSD) and Internal Combustion Engines (ICE) emerged as suitable successors for merchant fleet and naval application as a more robust, reliable and far more efficient propulsion option. However, it is important to mention 'the necessity is mother of all invention', and on these lines the warring factions globally with the aim to gain supremacy over his rival, and today the focus is on cost-effective, energy-efficient and sustainable solutions which can provide high power density to meet the modern power intensive weapon systems, occupy lesser space and require least maintenance & manpower besides optimizing longevity, flexibility, modularity and scalability to meet future roles with diversified operating profiles. With the recent advancement of research and development in the field of power electronics, power generation and power distribution, marine propulsion system technology for surface ships has witnessed significant amount of improvisation and innovation in the recent decade. In this regard, integrated fully electric propulsion (IFEP) is one such core technology that has been adopted worldwide with various degrees of success, and hence is being considered as a promising option for future induction into Indian Navy platforms as well.

Today, Indian Navy is a rapidly growing force and has been constantly upgrading and adapting to reliable, proven, efficient, effective, economical and environmental friendly state of the art technologies. The paradigm shift from conventional steam propelled warships of 1950's to waterjet based fast attack crafts (FAC's) in 2000's and the parallel induction of high power density gas turbines to propel its fleet or the introduction of state of the art combined propulsion system configurations such as COGAG, CODAD, CODOG since 1980's has been a testimony to the rapid speed at which the Navy is embracing modern, modular, flexible and efficient propulsion system technologies.

Today's wars at sea will be determined by navies which can use stealth effectively, endure longer and be more resilient. The navy's pressing demands for dynamic response in speed, torque, quite operation, and minimum mechanical vibrations has resulted in considering electric propulsion as the future at sea. The inception and growth of the Electric Propulsion Technology in surface combatants necessitates its evaluation and a road map for its induction into the country simultaneously paving the path of self reliance through Make in India. In past, the ships that used electric propulsion were mostly non-combatant vessels that included icebreakers, research vessels, ocean survey ships, oil tankers and numerous passenger liners. However, with the technology maturing and becoming more and more reliable, cost effective and energy efficient, today, combatant warships such as Queen Elizabeth Class Aircraft Carriers, LPDs as well as front line warships such as F-125, Type 45 frigates, USS Zumwalt are installed with state of the art electric propulsion systems to leverage the distinct benefits of electric drives.

The journey towards development and maturing of electric propulsion systems has not been without impediments and a fair share of failure. Thus, it is prudent that a systematic approach with lesson learnt from experience of other navies be undertaken for induction in future warship projects. One of the key for successful implementation of emerging technology in present day war ships is to train the personnel on usage, maintenance and repair.

2. Electric Propulsion Systems. The electric propulsion concept is primarily based on principle of employing either a partially or fully integrated Electric power system for both propulsion and ship's auxiliary & weapons services. This is achieved through first generating much larger capacity Electric power using parallel connected prime movers such as diesel/gas/steam engines coupled with diesel generating (DG) sets and then employing this integrated pool of Electric power to meet various power requirements of the ship. These requirements include shaft power for ship's propulsion (through an electric motor), power for weapons and radar systems, power for auxiliary and other support systems & services. The surplus Electric power in any of the system can be diverted to other systems as and when required. This concept ensures that the prime movers are always optimally loaded at their most energy efficient operating regimes. The reduction gearbox as well as substantial part of mechanical shaftlines employed in conventional or mechanical propulsion system is no longer required. A schematic of a typical electric propulsion system indicating main components is shown in Fig 1. As can be seen, in electric propulsion, ship designers have a greater flexibility in laying out of prime movers and the associated support systems on the ship's general arrangement (GA) to improve habitability and onboard space management.

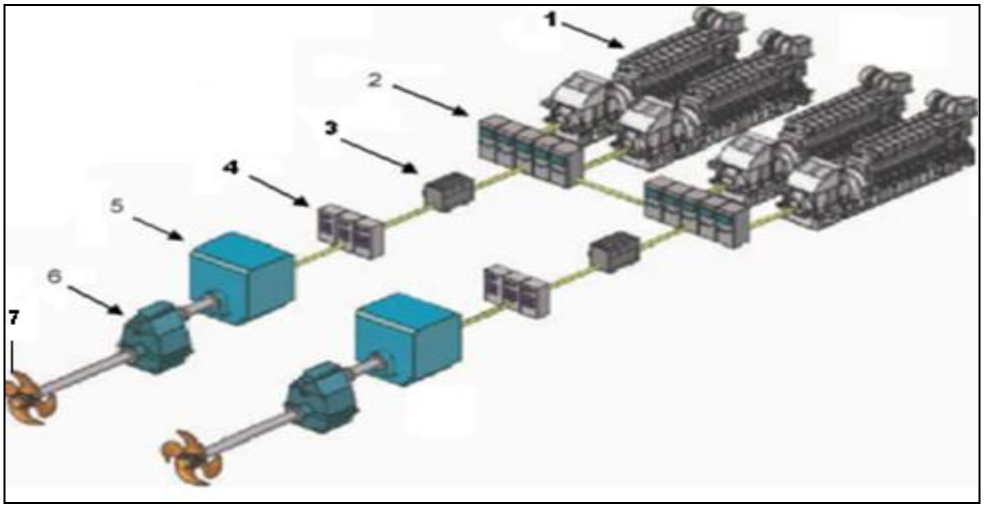

Fig 1. A typical Schematic Layout of an Electric Propulsion System: (1) Prime Mover (2) Switchboards (3) Convertors (4) Harmonic Filters (5) Pulse Frequency modulators (6) Electric Propulsion Motors (EPMs) (7) Propulsors (Pods/ Shaftless-Rim-Driven Propellers)

3. Types of Electric Propulsion Systems: Based on the design philosophy, Electric Propulsion Systems are broadly classified into three broad categories as described below: -

(a) **Hybrid Electric Propulsion (viz., CODLAG)**. A hybrid-electric propulsion system architecture comprises of a combination of electric drive with conventional/mechanical or waterjet propulsion drives. For example, Royal Navy Type 23 ASW frigates have CODLAG type of arrangement comprising of twin shaft and each shaft driven by gas turbine (for boost mode) and an electric motor (for silent and cruise mode) which have been operating successfully since 1991. In hybrid electric propulsion, the Electric drive operated on economical primemovers such as DGs or low power (LP) GTGs, are normally employed to optimize overall energy efficiency and radiated noise levels (RNLs) and cost of operation of the propulsion plant during slow and quiet operations whereas the conventional (mechanical) drive operated on high speed diesels (HSDs) or high power (HP) GTGs, is used to get boost speeds with fuel economy at higher speed operations. Thus, such an arrangement accrues benefits of both types of propulsion system to suit modern ship's diversified operating profile. A general arrangement of a Hybrid type of electric propulsion system is shown in Fig. 2.

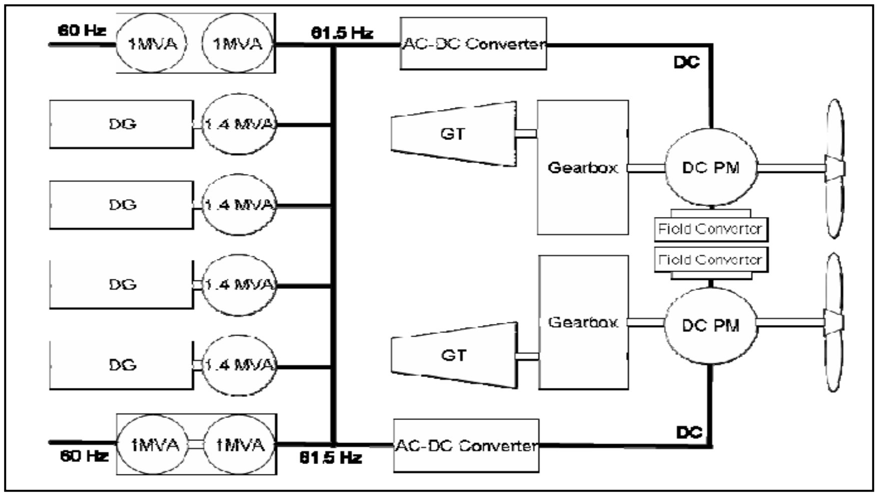

Fig 2. An example of Hybrid Electric Propulsion viz., CODLAG Configuration

(b) **<u>All-Electric-Propulsion (AEP)</u>**. In an All-Electric-Propulsion system or AEP architecture, a set of generators (called as Propulsion Power generators) produce power for the propulsion and feed <u>dedicated propulsion buses</u> which in turn transmit propulsive power to the components of propulsion segment, while another set of ship's auxiliary services generators (called as ship's services or auxiliary generators) produce power for the ship's auxiliaries and feed <u>dedicated ship service buses</u> which in turn transmit power to ship services including electrical weapon systems. Both dedicated buses are indirectly connected through link converters. In a typical AEP configuration, for example, a high-speed gas-turbine generator (GTGs) will produce only propulsive power and another set of diesel-engine generators (DGs) will produce power for only ship's services & electrical weapon systems. Although this feature partly facilitates sharing of power between propulsive power and ship services power buses, however, there are some limitations involved. A schematic layout of a typical AEP system is shown in Fig. 3.

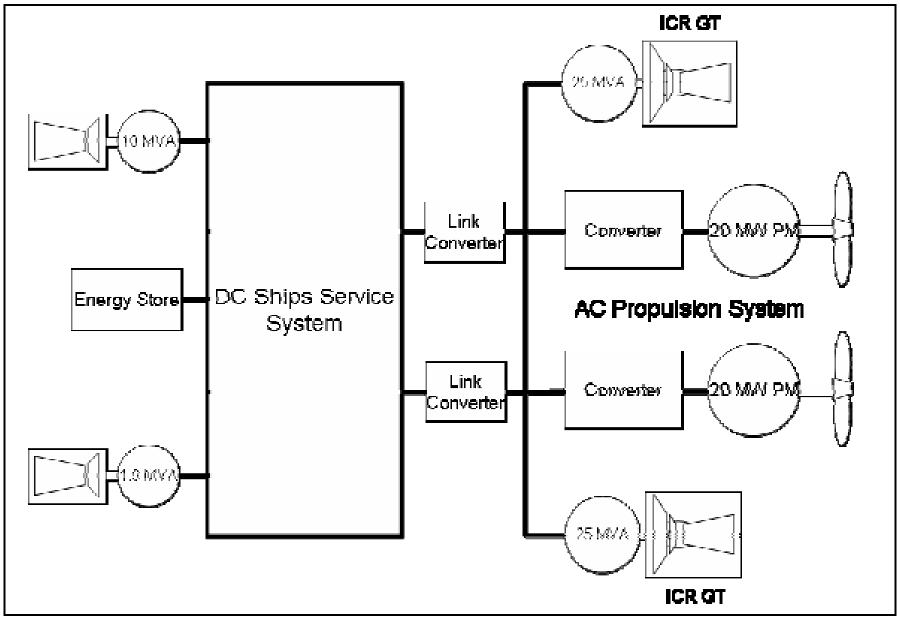

Fig 3. All-Electric-Propulsion (AEP) System Configuration

(c) **<u>Integrated Electric Propulsion (IEP/ IFEP)</u>**. An integrated electric propulsion system or IEP architecture is the latest technology based on complete integration of electrical power generated onboard i.e., both the propulsive power and ship's services and electrical weapon system power are integrated and then utilised. This concept uses one or more power buses that are electrically interconnected and then the power is distributed among both the propulsion and the ship service loads consumers. The power quality (frequency and voltage) are maintained within tolerances that permit the bulk of the ship services loads (which includes weapons) to be served directly or through step-down transformers. This type of configuration is popularly known as Integrated Electric Propulsion (IEP) or Integrated Full Electric Propulsion IFEP and shown at Fig. 4.

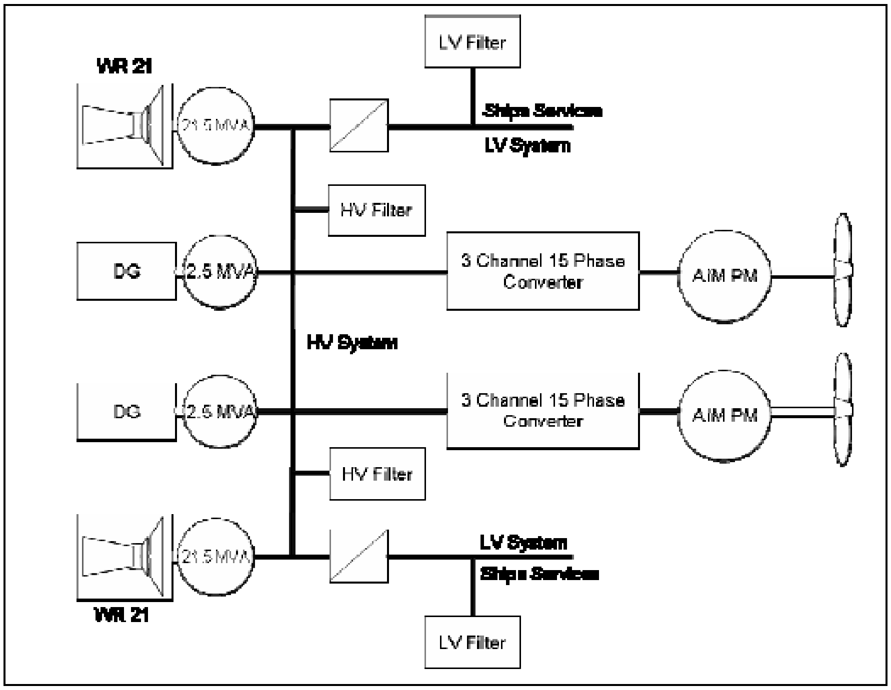

Fig 4. Integrated Electric Propulsion (viz., IEP/ IFEP) Configuration

4. SWOT Analysis of Electric Propulsion System for *IN*

Strength	**Weakness**
• Higher power density • Lesser frictional parts; Low Maintenance • Flexibility on distribution of power as required; Unlocking of propulsion power. • Induction of modern power hungry weapon systems • Lower SBN/ABN	• Power Conversion Module • Adaptability to Marine Environment • Lack of Specifications (SOTRs)/ Standards • Thermal management • Lower Recyclability (Battery/ Electronics) • Maturity of Technology
Opportunities	**Threats**
• Adaptability; Modularity • Better fuel utilisation • New Market exploitation • Emission control • Newer Job opportunities • Green Initiatives • Lean and Mean Systems	• Higher Initial Cost • Standardisation of Design and Technology • Spare Parts Production • New Training modules • Organisation Restructuring • Safety Precautions; Fire Fighting • Isolation from Magnetic Signature.

Implementation and Training

5. The existing concept in the *IN* ships is based on clear demarcation of responsibility between operators and maintainers of a system. Accordingly, the crew is primarily distributed into Engineering, Electrical and Executive departments respectively. This is unlike the concept of operations in most western/ foreign navies, which have a single Marine Engineering branch looking after all aspects related to the power generation, propulsion and ship's auxiliary or services machinery. The integrated electric propulsion (IEP/ IFEP) architecture leads to a unique scenario wherein, while the integrated power generation is mechanical in nature while a significant segment of the propulsion system viz., power conversion and distribution including propulsion drive (EPMs) is electrical in nature. As a result, it is likely to result in ambiguity in demarcation of areas of responsibility of operation and maintenance, thereby affecting the smooth function of the ship's organisation. The current study would also endeavor to address this issue and propose actionable alternatives in order to facilitate seamless transition to the IFEP technology.

6. **Exploitation & Maintenance Philosophy**. The introduction of Electric Propulsion along with HV/ MV power generation equipment will necessitate formulation of new exploitation and maintenance procedures. The exploitation procedure would have to factor optimal loading of prime-mover for best life-cycle performance. The development of platform level exploitation procedures can be best addressed through Information Exchange Agreements with Navies who have already inducted this technology. This will include manning philosophy of HV compartments in various states of alertness and the related anthropodics while manning it, attires for watchkeepers and their Personal Protective Equipment, RADHAZ marking of compartments, entry/exit authentication and monitoring procedures, extraction procedures in case of emergencies or accidents, use of Support A and Support B Fire-Fighting teams and finally an individual's medical condition would need to be factored. INSMA would have to lead the efforts wrt generation of Maintops and keeping them updated, Job Information cards and conduct of reliability assessments.

7. **Training**. Training on exploitation procedures and Level I, II and III maintenance for onboard and ashore personnel is mostly catered in the acquisition contracts. However, base specialisation and qualifying criteria for this level of training would have to be worked out by *IN*. While the commissioning ship's crews will be trained by the OEMs, training the trainers to meet future requirements would have to be catered in the acquisition contracts. These trainers would then lay the foundation of PCT syllabi for various specialisation-vise courses, and requirement of simulators and virtual labs. Shivaji on its part can look at development of HV Lab or use of MV Lab at Valsura and take up fabrication of instrumented scaled models of entire propulsion plant already in use by Navies. Besides being excellent training aids and a technology demonstrator-cum-simulator, they can also be used to generate performance data for better decision making. In collaboration with the lead integrator, they can then be mated with a hull to give the young student officers and sailors valuable insights into the integration aspects. The net focus should remain on the practical aspects of exploiting Electrical Propulsion. The more the generation of tomorrow dabbles in this technology in the very crucible of Marine Engineering the more proficient, confident and comfortable they will be onboard. Additional requirements as may emerge with experience would have to be factored into separate contracts with the vendor.

8. **Infrastructure**. Infrastructure development would need to be progressed to address training and repair requirements. The Royal Navy and French Navy have invested in an Electric Ship Technology Demonstrator ashore as a part of technology development and for conduct of validation studies. This facility is now, in addition, catering to training requirements. Ashore training facilities in the form of an IFEP emulator has already been initiated as a part of ATWP. While major components of Electric Propulsion such as Alternators and Motors are being inducted for the ship's life, smaller equipment like switchgear, converters, power storage devices etc would require skill based training and setting up pf certain degree of repair infrastructure. Reference Systems, special testing, tuning and calibration equipment will also be required to address repair requirements as may arise.

9. **Knowledge Management**. A nodal agency would need to be nominated as Repository of Knowledge to manage all data pertaining to Electric Propulsion as will be generated as part of the LPD Project. This needs to include real-time Product Data Model (PDM) and Ship Work Breakdown Structure (SWBS) from the Shipyard. Further, all technology management decisions till now need to be documented for posterity. A networked IT solution to archive such data is required so that multiple stakeholders can simultaneously load and access this data. This nodal agency would also document results of risk mitigation strategies implemented during induction management thereby contributing to decision making related to consideration of IFEP on future platforms.

10. **Conclusion and Way Ahead**. IFEP technology is rapidly gaining a strong foothold in the field of Marine Propulsion Systems and its induction in the *IN* ships is also imminent with the issue of RFP for construction of future LPDs. In order to harness this technology and accrue maximum benefit from the same, technical support, training and administrative issues are required to be planned and executed in a time bound manner. Only a well-prepared Navy with adequate infrastructural and manpower support will be able to derive the advantages of this technology and propagate it further onto various classes of ships. The various conclusions and way ahead can be summarised as follows: -

(a) It is emergent that while induction, life-cycle and change management has been individually worked upon in some measure or the other, it is a co-ordinated multi-disciplinary systems approach that is the need of the hour. Due to the multidimensional nature of the electric propulsion technologies spanning engineering, electrical and weapons systems, a nodal agency would need to be nominated to manage all data pertaining to Electric Propulsion. Formal contracting of the LPDs would be a catalyst in the process of inducting Electric Propulsion technology in the ***IN***.

(b) As brought out above, the Propulsion system of IFEP ships is going to be a combination of mechanical units (primemovers, podded propulsors, etc.) and electrical drive units. Although the complexity of mechanical units such as engine for power generation would remain more or less same as DGs/ GTGs of any other conventional ships presently in use in the Indian Navy, introduction of podded and shaft-less rim driven Propulsors and the medium voltage (MV) components as electrical units of propulsion system would be a paradigm shift and a challenging concept.

(c) Operation and maintenance philosophy of electrical propulsion system, specific training for handling of MV (4.16 kV and beyond) components, development of necessary infrastructure, fire fighting training with regards to MV components and miscellaneous specific issues brought out in this report would need to be put in place prior to induction of IFEP ships.

(d) Operation and maintenance of propulsion system is traditionally the domain of mechanical engineers. However, as the lines between electrical and engineering systems are progressively blurring, with advanced control systems, remote monitoring technologies, automation and integrated platforms, specific steps are required to be initiated to ensure its smooth operation and maintenance, especially with the advent of advanced electrical propulsion systems.

(e) Operation and maintenance of general systems including all electrical systems i.e. PGD, electrical propulsion etc. (except weapon systems) should be brought under the purview of one single cadre to ensure smooth functioning and preclude ambiguity of responsibility.

(f) Plan for gradual transition towards successful manpower model on Engineering & Weapons and restructuring of training infrastructure and curriculum. Along with augmentation of training facilities at INS Shivaji and INS Valsura for handling the transition.

(g) Restructuring of marine engineering and marine electrical specialisation courses conducted at INS Shivaji and INS Valsura respectively to cater for merging/ re-distribution of responsibilities.

(h) Setting up of necessary R&D and training support infrastructure at professional schools (INS Shivaji/ INS Valsura) for MV components.

(i) Setting up of necessary maintenance and support infrastructure at Naval Dockyards to repair and maintain MV components

(j) Dedicated NBCD and Fire Fighting training in MV environment to cater.

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