All-Electric Ship Design: From Electrical Propulsion to Integrated Electrical and Electronic Power Systems

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***Abstract*— Electrical propulsion is not a novel concept in marine systems. However, the availability of power electronic converters has proved to be the Key Enabling Technology for electrification of large ships. This paper starts with a summary of EP drives, which led to the birth of all-electric ships. Electric power generation and control systems are then presented, which make it possible to exploit the integrated electrical power system. To ease comprehension of the issues in designing such a system, its conventional design process is given. Then, the reasons that are pushing ahead the research in the shipboard power systems sector are discussed. The need for research in the design methods area is demonstrated through an overview of the latest results of technological research. Finally, a summary of the most significant results on the design tools research is given, including early stage design, dependable-oriented design, and the improvements achievable through software simulators and hardware-in-the-loop are discussed. The goal of this paper is to demonstrate why research on design methods is as important as a technological one, on the basis of the needs concerning the design, integration, and management of future "integrated electrical and electronic power systems" (power systems with power conversion quota approaching 100%).**

***Index Terms*— All-electric ships (AESs), design tools, electric power generation and control, electric propulsion, hardware-in-the-loop (HIL), integrated electrical and electronic power systems (IEEPSs), ship design, shipboard power systems, simulator, technological research.**

I. Introduction

GENERALLY speaking, the mission of a ship is to maximize the quota of payload and to minimize the acquisition and operating costs for the shipowner. Besides this, the history of marine constructions is recurrently pervaded by the intervention of Key Enabling Technologies (KETs). A proof of this regards the transition from the employment of steam engines to reciprocating engines in propulsion and power generation systems onboard. This transition, which happened around the middle of the 20th century, has made it possible to reduce internal spaces dedicated to engines, on the one hand, and to improve efficiency and reliability on the other. Later in the 20th century (around 1990), another relevant example has been given by cruise liners, for which a massive introduction of electric technologies has made it possible to install new large electric propulsion (EP) drives. The availability for marine systems of new electric technologies, coming from different industrial fields (steel industry, rolling mills, railways, petroleum and chemical plants, and so on), was made possible by the developments brought, in those years, by power electronics. The introduction of power electronic devices and converters has made it possible to redesign the whole architecture of shipboard power generation, distribution, and utilization, completely from scratch. This fact has brought relevant changes in the entire ship design, allowing room saving, fuel efficiency, and increased flexibility without impairing reliability, so that, nowadays, 100% of new-built cruise liners are electrically propelled (and many older ships have been already retrofitted in the same way) [1]. In this way, large cruise liners have become all-electric ships (AESs), in the sense that onboard, thermal engines (diesel and/or gas turbines) are used exclusively as prime movers of the synchronous generators. Such an evolutionary process is shown in Fig. 1 in an extremely simplified form [2], while an example of the most salient characteristics of a new-built large all-electric cruise liner is given in Table I. AESs are endowed with a power station that generates the electrical power that feeds all shipboard loads (propulsion, hotel, and auxiliaries) through the so-called

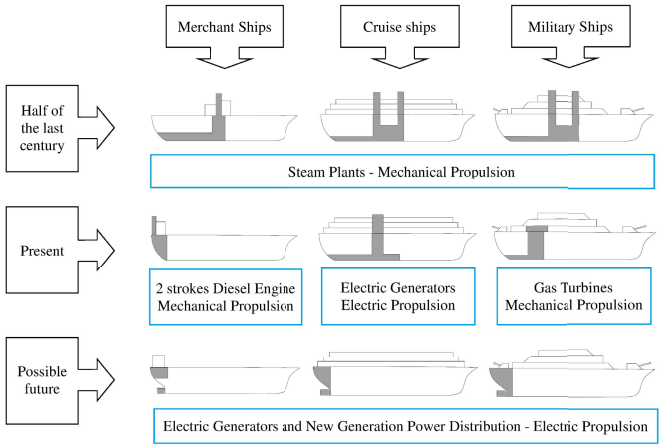

Fig. 1. Ship configuration [2].

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