Simulation-Based Performance Evaluation of Hydrogen Proton Exchange Membrane Fuel Cells for Hybrid Marine Propulsion System

W.M.S.R. Weerasinghe[1*], B.Y.C. Fernando[1], S.N. Ranathunge[2], D. Vakeeson[1], E.P. Rohan[3]

[1]*Department of Mechanical Engineering, Faculty of Engineering Technology, The Open University of Sri Lanka, Nawala, Sri Lanka*

[2]*Centre for Environmental Studies & Sustainable Development, The Open University of Sri Lanka, Nawala, Sri Lanka*

[3]*Department of Marine Engineering, Faculty of Engineering and Management, Ocean University of Sri Lanka, Colombo 15, Sri Lanka*

**shalikarajinda98@gmail.com*

The maritime transport sector is a major contributor to global greenhouse gas (GHG) emissions due to its reliance on fossil-fuel-based propulsion systems. Increasing environmental regulations and international decarbonization initiatives have accelerated the search for sustainable and energy-efficient alternatives. Hydrogen fuel cells (HFCs) have emerged as a promising clean energy solution for marine applications, generating electricity through an electrochemical reaction between hydrogen and oxygen, producing only water as a by-product. Among available technologies, Proton Exchange Membrane Fuel Cells (PEMFCs) are particularly suitable for marine propulsion due to their high-power density, low operating temperature, and rapid response to dynamic load variations. This study evaluates the performance of a 200 kW PEMFC system for hybrid marine propulsion using a MATLAB-based semi-empirical simulation model. The model incorporates key electrochemical losses, including activation, ohmic, and concentration losses, which significantly influence voltage output and system efficiency. Key operational parameters such as cell active area, stack configuration, operating temperature, and electrochemical constants were obtained from published literature and manufacturer specifications. The model simulates polarization behaviour, power output, system efficiency, and hydrogen consumption under varying current density conditions relevant to marine applications. Results of the simulation demonstrated the typical PEMFC polarization characteristics, where output voltage decreases from approximately 0.95 V to 0.65 V per cell with increasing current density. Activation losses dominate at low current densities, while ohmic losses become significant in the moderate region, and concentration losses affect performance at higher current densities due to mass transport limitations. The system achieved a maximum power output close to 200 kW within an optimal current density range of 0.6-0.9 Acm^{-2}, with an electrical efficiency of 52-58% under moderate load conditions. The findings indicated that PEMFCs can provide stable and efficient power generation for hybrid marine propulsion systems, and the developed MATLAB model serves as a valuable tool for performance evaluation and system optimization.

Keywords: *Hydrogen Fuel Cell, PEMFC, Marine propulsion, MATLAB simulation, GHG Emission*