Senior Design: Modeling and Real-Time Simulation of a Marine Current Turbine Driven DFIG System Using Hardware-in-the-Loop

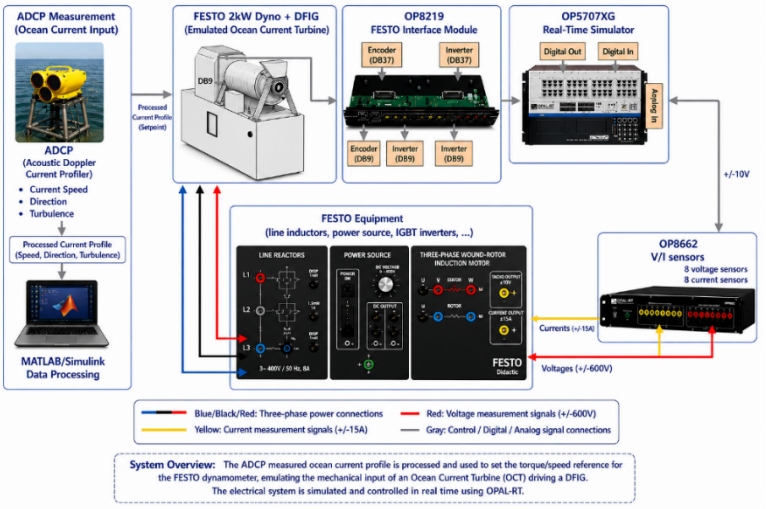
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1.1 Background/Objectives

Marine hydrokinetic energy, particularly from the Gulf Stream, offers a highly predictable and continuous renewable energy resource with strong potential to support coastal electrification and grid resilience. However, the development and validation of marine current energy systems remain challenging due to limited access to real-world testing environments and the complexity of coupled hydrodynamic, electromechanical, and grid interactions. This senior design project aims to develop a high-fidelity, hardware-in-the-loop (HIL) simulation platform for a marine current turbine driven a doubly-fed induction generator (DFIG), enabling real-time evaluation of system dynamics, control strategies, and grid integration under realistic operating conditions.

1.2 Approach/Activities

The project integrates MATLAB/Simulink-based system modeling with OPAL-RT real-time simulation (RT-LAB) to emulate key components of a marine current turbine energy system, including turbine dynamics, DFIG behavior, power electronics, and grid interface. Measured Gulf Stream data through ADCPs are incorporated to ensure realistic environmental inputs. A dynamometer-based setup is used to emulate turbine-generator interactions, while HIL architecture enables real-time testing and validation of control algorithms. The development process includes model construction, hardware-software integration, controller design, and system calibration. Emphasis is placed on achieving stable real-time performance, accurate power electronics modeling and operation, and seamless synchronization between simulation and physical hardware.



1.3 Results/Lessons

The developed platform demonstrates the feasibility of using HIL simulation for marine current energy system validation, providing insights into system dynamics, power conversion efficiency, and grid interaction. Initial results show that the framework can effectively capture transient behaviors and support controller tuning under varying current speeds and load conditions. Key lessons include the importance of model fidelity for real-time execution, challenges in hardware–software synchronization, and the need for robust control design to handle uncertainties in marine environments. This senior design work establishes a scalable testbed for future research and education in marine renewable energy systems and contributes toward accelerating the deployment of reliable ocean energy technologies.