Modeling and Implementation of a Wave Energy Converter Emulator for Testing Multi-port Power Converters in a Marine DC Microgrid

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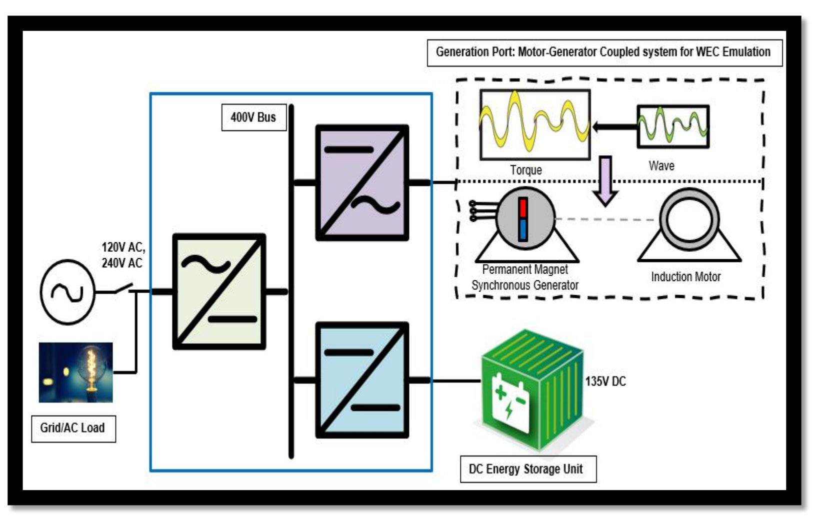
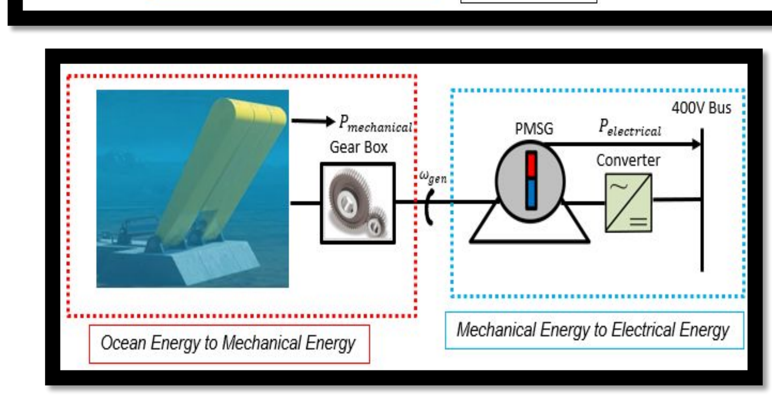
This research presents the modeling of a WEC emulator with real WEC characteristics that can provide a reliable testbed to facilitate the development of a DC microgrid system for marine renewable energy resources.

Background

- A marine microgrid system is crucial for extracting ocean wave energy and providing uninterrupted power to coastal communities in remote locations. However, experimenting with Wave Energy Converters (WECs) and power converters during microgrid development faces challenges due to limited access to physical WECs.
- A motor-generator-based WEC emulator aids controller development with maximum power extraction from renewable sources. A multiport power converter (MPC) is used to integrate the renewable generation, storage, and load through a single power electronic unit with a 400 V internal DC bus to be validated in a lab for safe deployment.

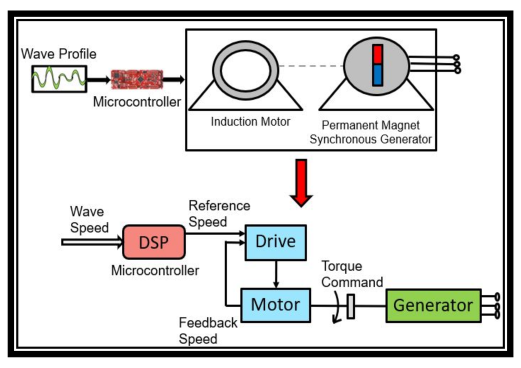


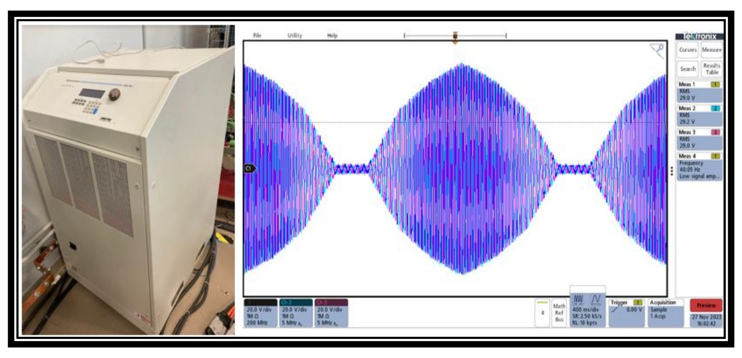


Wave Energy Converter Emulator

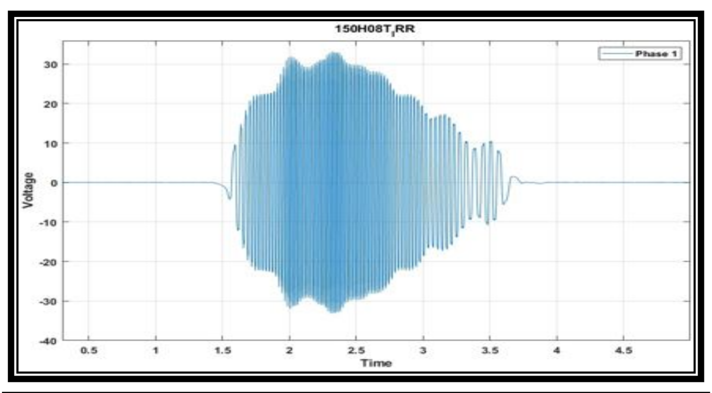
- Two types of emulator methods have been proposed:

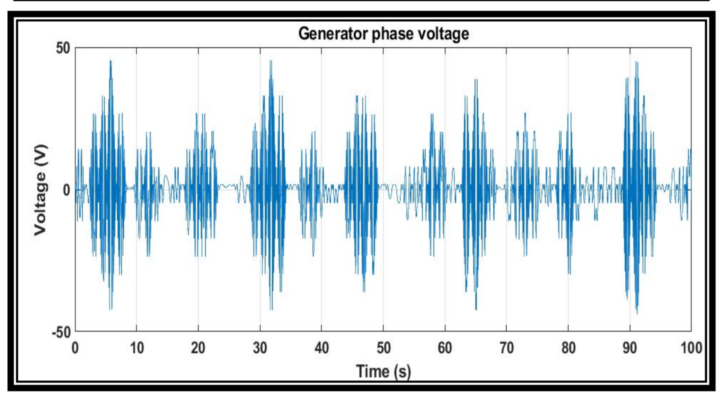
1. The proposed emulator replaces traditional paddle-type WEC components with an electronically controlled drive and induction motor. It uses a reference speed command to rotate the permanent magnet synchronous generator via the induction motor, producing variable-frequency, variable-voltage output. The microcontroller models the WEC's dynamic behavior to control the motor's driving torque, accurately emulating WEC performance
2. The WEC's paddle, gearbox, and generator dynamics can be emulated through a power amplifier. This grid simulator and its controller will replicate WEC dynamics using actual wave data and WEC parameters.

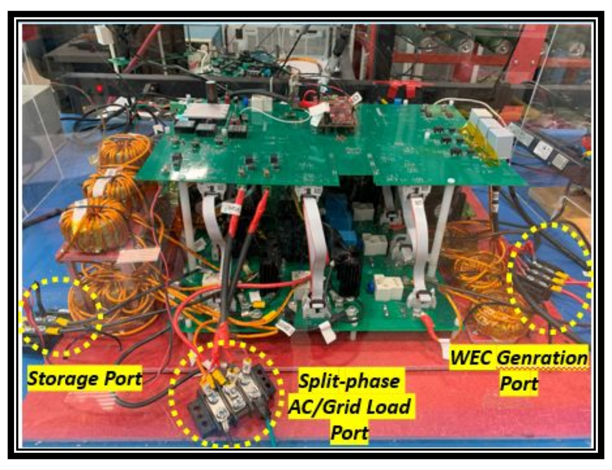


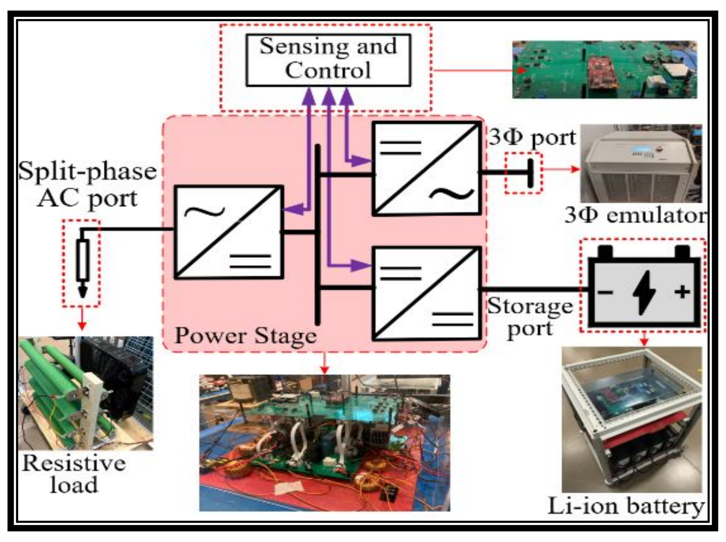


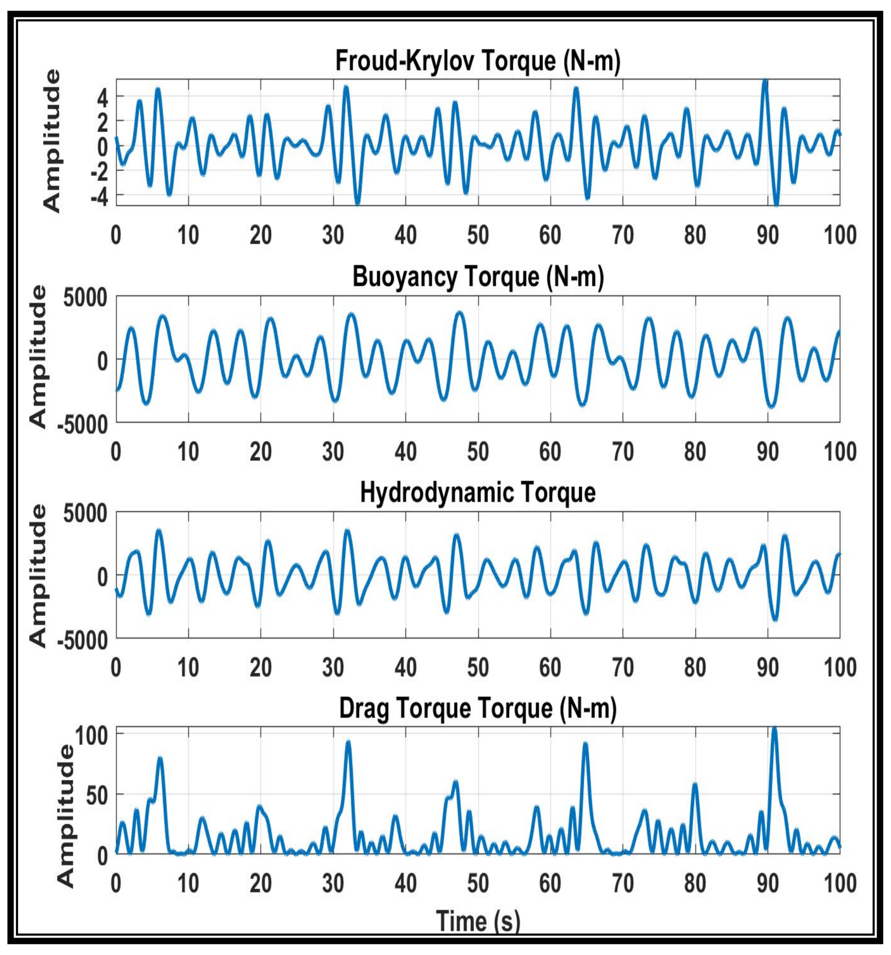
RESULTS

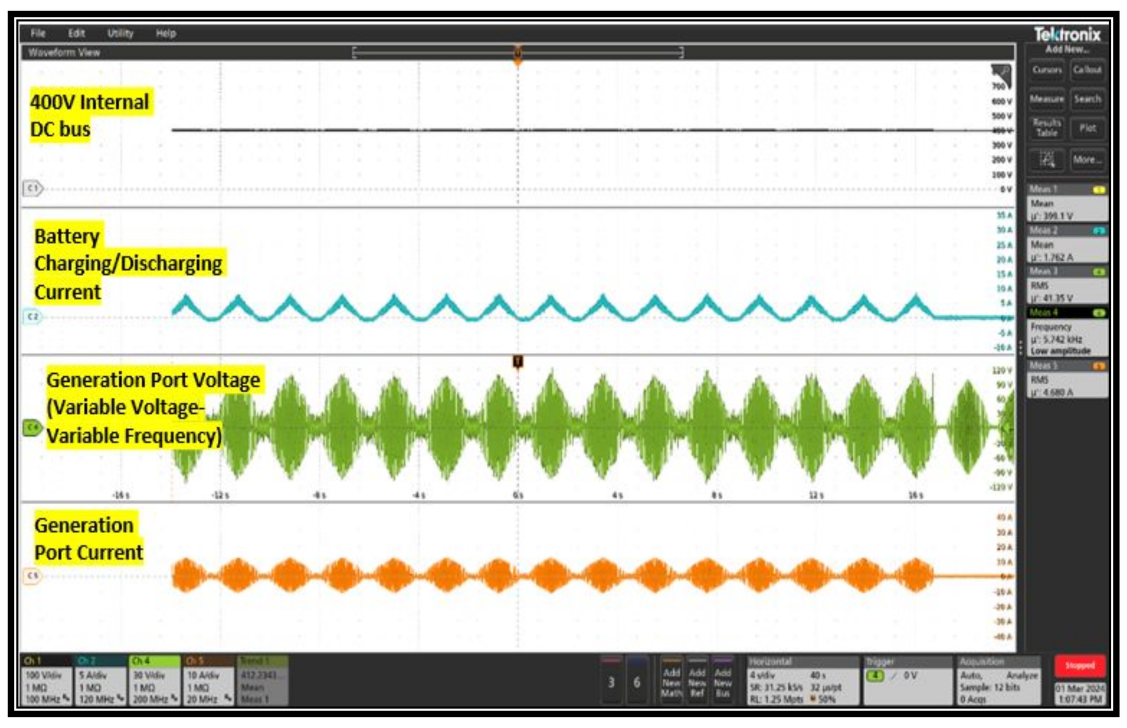








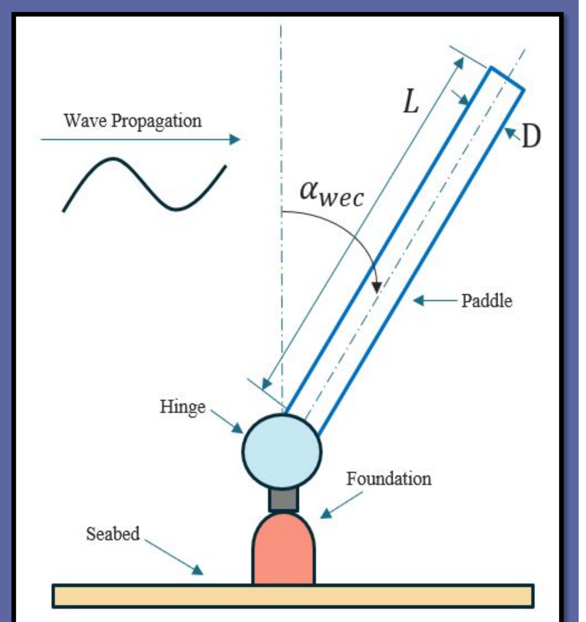




Wave Energy Converter Modeling

The paddle's mechanical structure is crucial for maximizing power extraction from waves to the Power-Take-Off (PTO) device.

- According to the Morison Equations:
  $F_T = F_{FrKr} + F_{hd} + F_{dr}$
- Total mechanical torque acting on the paddle:
  $T_{mech} = T_{Frkr} + T_{hd} + T_{dr} - T_{buoy}$
- The speed of the generator:
  $\omega_G = \frac{T_{mech} G_r}{E_b + s I_G}$
- The terminal voltage of the generator:
  $V_\varphi = E_b \omega_G \sin\left(\frac{p}{2}\omega_G t\right)$



Testing Methodology

- The actual data from a buoy-type WEC of NREL's (National Renewable Energy Laboratory) HERO (the Hydraulic and Electric Reverse Osmosis) WEC is used to verify the MPC's performance.
- A programmable power supply is used to emulate the WEC, three-phase generation for a voltage range of 0-35V and a frequency range of 16-40Hz.
- The WEC output from the programmable power supply has been used to test a modular 5-kW power electronic MPC that harnesses the wave energy. The physical testbed incorporates the WEC Emulator, MPC, storage, and load. The internal DC bus is set at 400V. The energy storage will charge or discharge depending on the command it gets from the controller.

Conclusions and Future Work

- System modeling and implementation of a WEC emulator that can take real ocean wave energy data and output the generated voltage tracking the energy available from the waves.
- To ensure efficient power processing and integration into marine DC microgrids, the three-phase AC output of the generator is subjected to processing using a power scaled-down 5-kW multi-port converter (MPC) prototype developed in the FREEDM laboratory.
- This research will highlight the industrial applications of the proposed WEC emulator testbed in controlling and testing power electronic units before deployment in marine DC microgrids. In the future, the wave energy capacity model will also be incorporated. Furthermore, multiple MPCs will be paralleled to boost power processing capabilities, allowing for the harnessing of larger amounts of ocean wave energy.

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[2]S. Hazra and S. Bhattacharya, "Modeling and Emulation of a Rotating Paddle Type Wave Energy Converter," IEEE Transactions on Energy Conversion, vol. 33, no. 2, pp. 594-604, June 2018.