A Marine Microgrid System with Multiport Power Converter, Wave Energy Resource Interface and Coordinated Protection

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Objective

The proposed multiport power converter (MPC) is a key building block of a coastal power distribution to support coastal communities.

- Interfaces 3 types of energy sources and loads through a single Power Electronics Unit
- Operates in Islanded and Grid-connected mode
- Uninterrupted supply to load by harvesting renewable energy with support from grid and DC storage
- Integrated over current and over voltage protections

Marine Microgrid with Multi-Port Converter

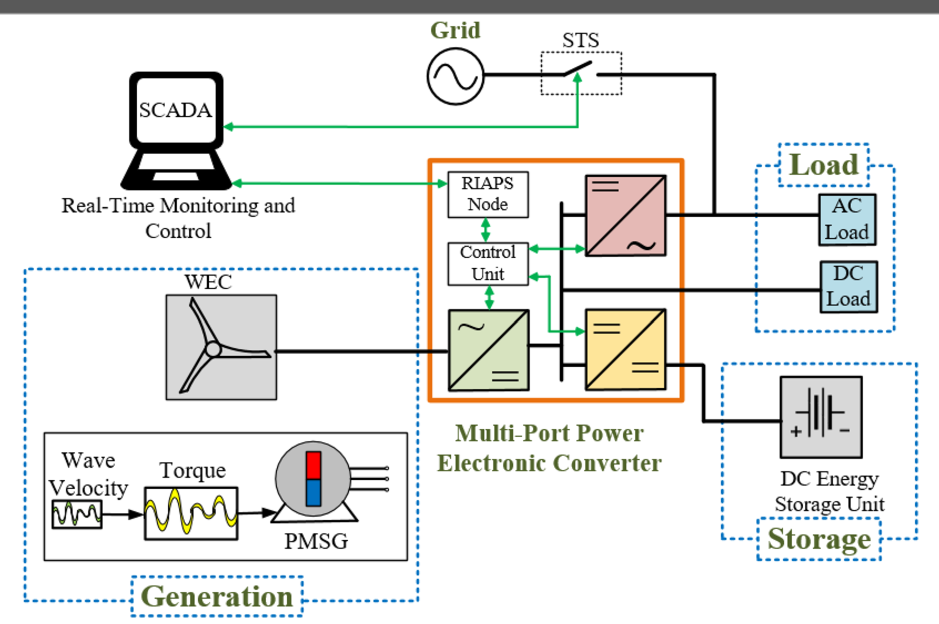


Fig. 1 – Marine microgrid with multi-port power electronic converter.

- Renewable Port: Interfaces wave energy converter (WEC)/ other renewable source
- AC Grid/Load Port: Interfaces electric grid and AC load
- DC Port: Interfaces battery storage unit

Table 1: Multi-port converter ratings

Port Name	Converter Ratings
AC Grid Interfacing Port	Rated power: 5kVA Nominal voltage: ±120V (240V)
Energy Storage Interfacing Port	Rated power: 4kW Nominal battery voltage: 135V
Renewable Generation Port	Rated Power: 5kW Rated Torque: 64Nm

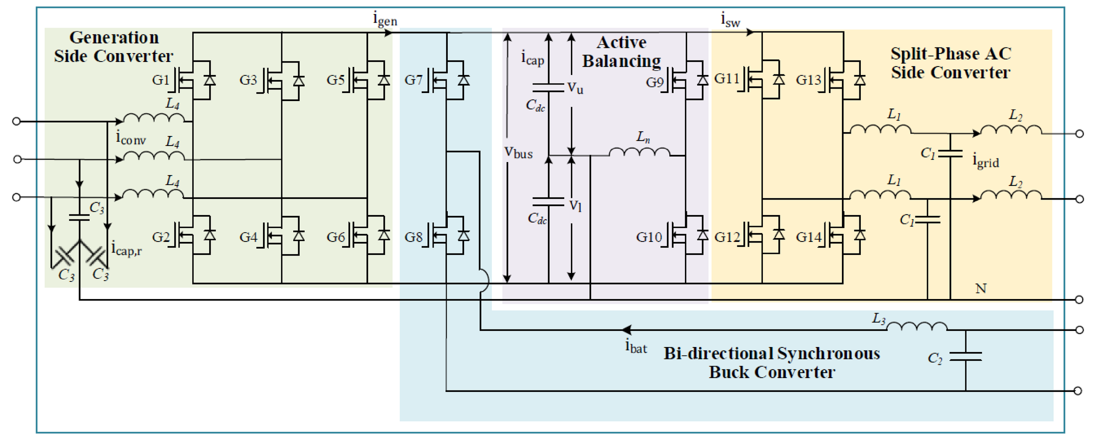


Fig. 2 – Proposed multi-port converter topology.

Control System Design

A. Generation Side Converter

- Decoupled d-q control structure with observer based active damping implemented to control power extraction from emulated WEC system for stable operation and to mitigate system noise.

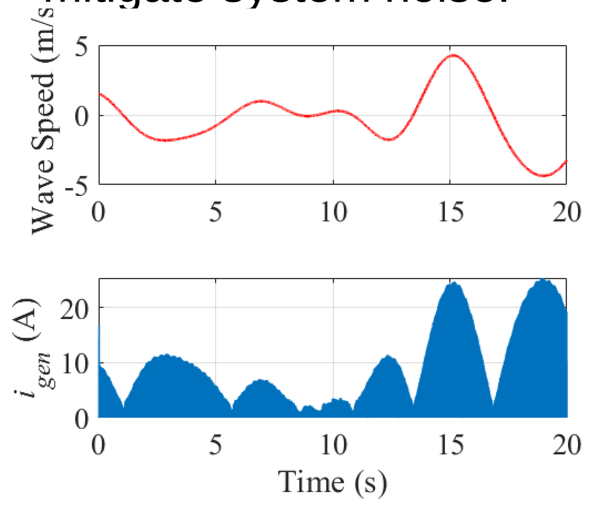


Fig. 3 – Wave speed profile and oscillatory current injection into the DC bus.

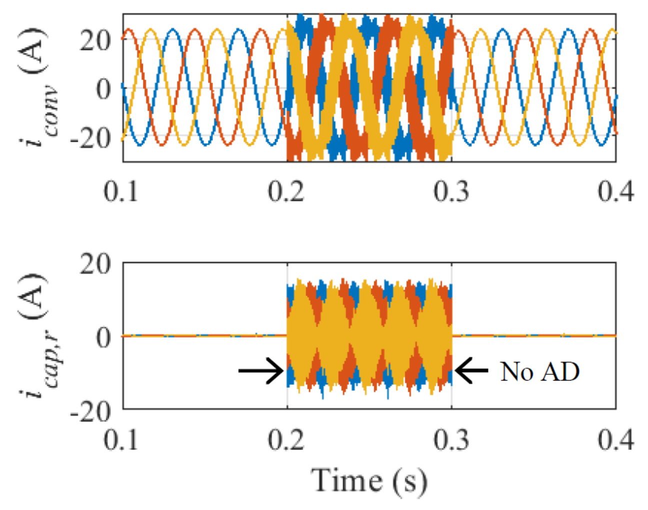


Fig. 4 – WEC interfacing converter current with and without active damping.

B. Split-Phase AC Converter

- This grid forming converter with droop based control is capable of grid synchronization and seamless transition from grid-connected to islanded mode. A proportional-resonant compensator is used to control bidirectional power flow from/to the grid. Proportional controller is implemented for active voltage balancing to mitigate device stress.

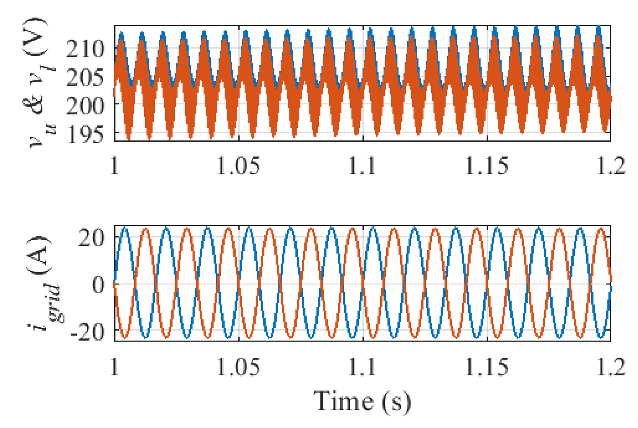


Fig. 5 – Voltage across upper and lower capacitor and current injected into grid.

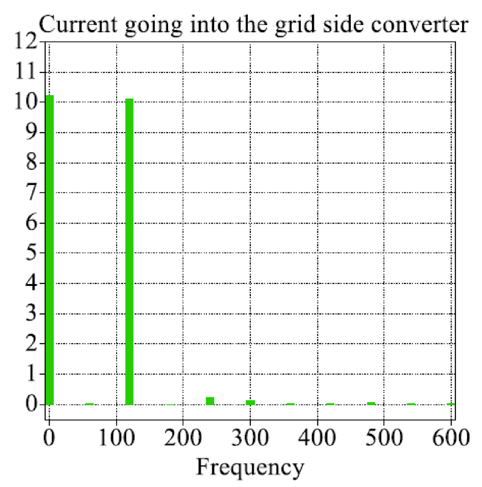


Fig. 6 – FFT of current i_{sw}.

C. Storage Side Converter

- Implemented dual loop cascaded control structure with resonant compensator to reduce DC capacitor size.
- Establishes the 400V internal bus in the absence of a grid and helps to initiate islanded mode microgrid operation enabling black start.

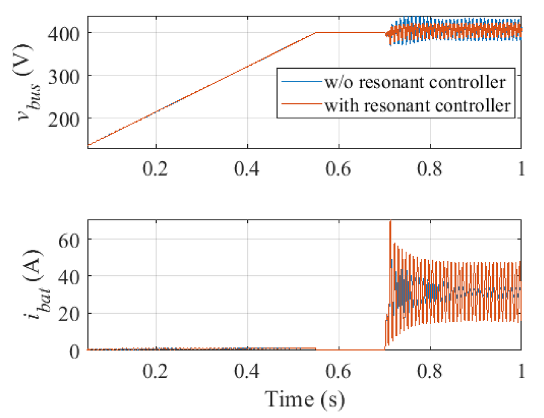


Fig. 7 – Bus voltage and battery current.

System Simulation

- The storage side converter black start and ramps up the internal bus to 400V.
- The generation side converter starts to inject 2.5kW power at t = 0.7s. As there is no load, the battery absorbs current to maintain bus voltage.
- The grid side converter starts to inject total 4kW power into grid at t = 1.0s, system remains stable validating controller performances.

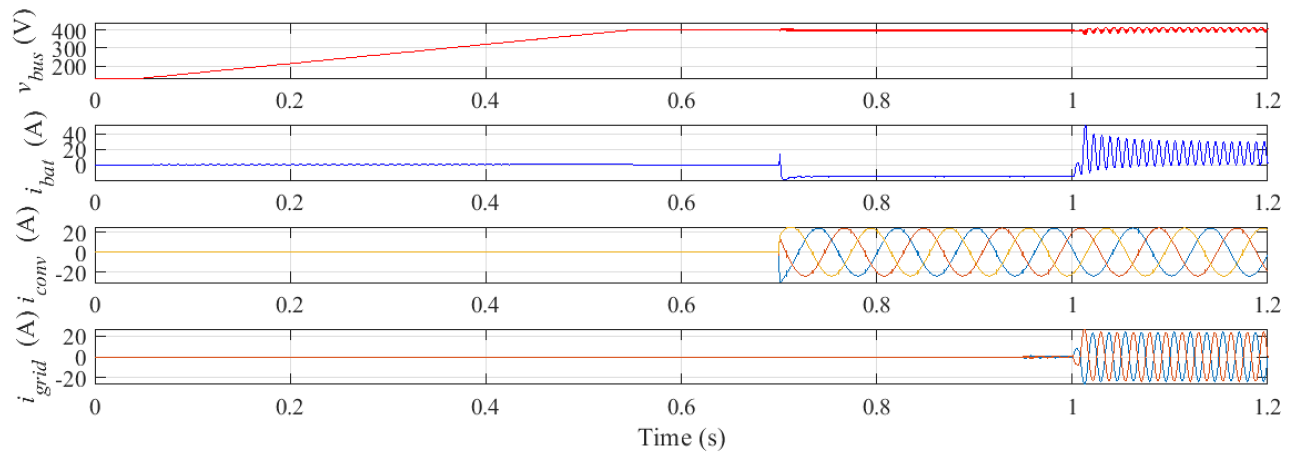


Fig. 8 – Combined system simulation.

Thermal Analysis

The heatsink of the converter is forced air-cooled. ANSYS thermal model shows temperature for discrete MOSFET has the highest temperature of 330 K (57 ℃), correspond to ~70 ℃ junction temperature.

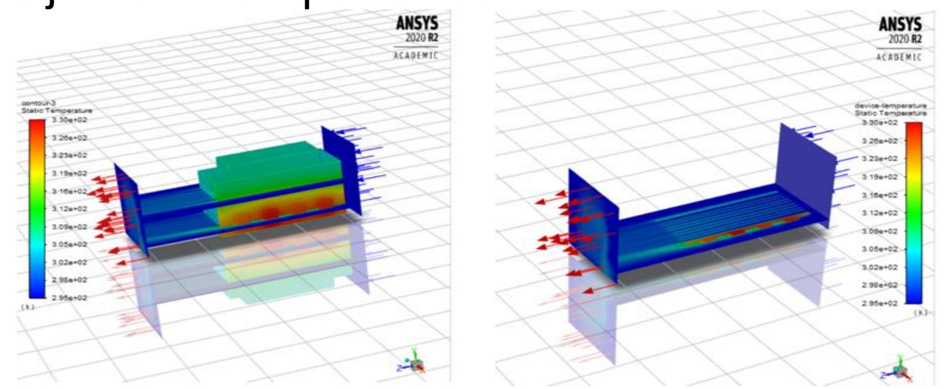
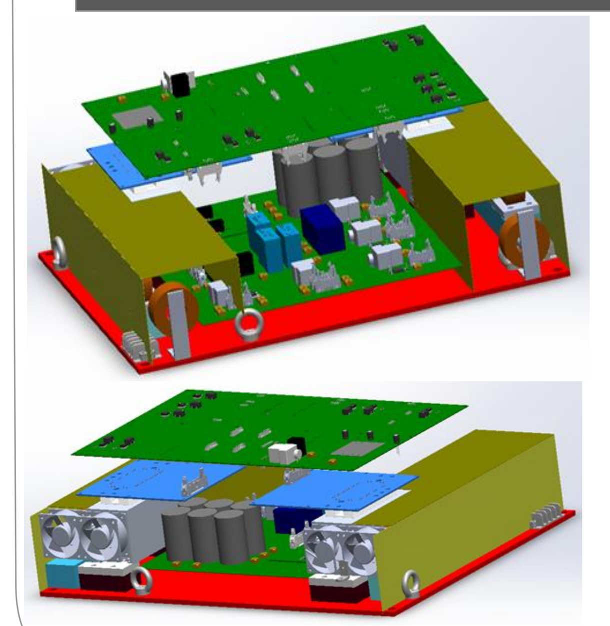


Fig. 9 - Thermal simulation in ANSYS

Virtual Prototype



- The virtual prototype contains designed power board, control board, discrete device gate driver board and other major components.
- Fans and dedicated wind channels facilitate necessary system cooling.
- This helps to assess optimal component assembly.

Fig. 10 - virtual prototype (front/rear view)

Future Work

- Finishing prototype hardware fabrication, Implementing designed controller
- Implement over current and voltage protection
- Conducting hardware experiments in the lab
- Installing multiport converter unit in the field

Potential Impacts/Conclusion

- Detailed converter model along with necessary control developed to validate the system design and controller performance for seamless power and energy transfer among three different power sources.
- MPC concept along with its hardware and control features established to integrate WEC, storage, load and grid in a microgrid.
- Fundamental modeling and design tools developed to enable system scale-up for various marine microgrid applications.

References

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[2] M.R.K. Rachi, Md Rashed Hassan Bipu, Siye Cen, Mehnaz Akhter Khan and I. Husain "Design and Development of A Multi-Port Converter for Marine Microgrid Application," *2021 IEEE Energy Conversion Congress and Exposition (ECCE)*, Vancouver, Canada, 2021. **(Digest Accepted)**

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