

FREEDM



SYSTEMS CENTER

Developing a Three-Node Marine DC Microgrid with Integrated Storage for WEC and PV Testing

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2/11/2026

- Atlantic Marine Energy Center overview
- AMEC Microgrid Structure
- Different Nodes of AMEC Microgrid
- Test Scenarios
- TEAMER (Testing Expertise and Access for Marine Energy Research) Testbed
- Distributed Control Structure
- Future Works and Publications



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DOE Water Power Technologies Office (WPTO) and NMEC Program

- Leads marine energy research with powering the blue economy initiative
- Funds the four National Marine Energy Centers (**NMECs**)
- Over \$41M invested in US Marine Energy research



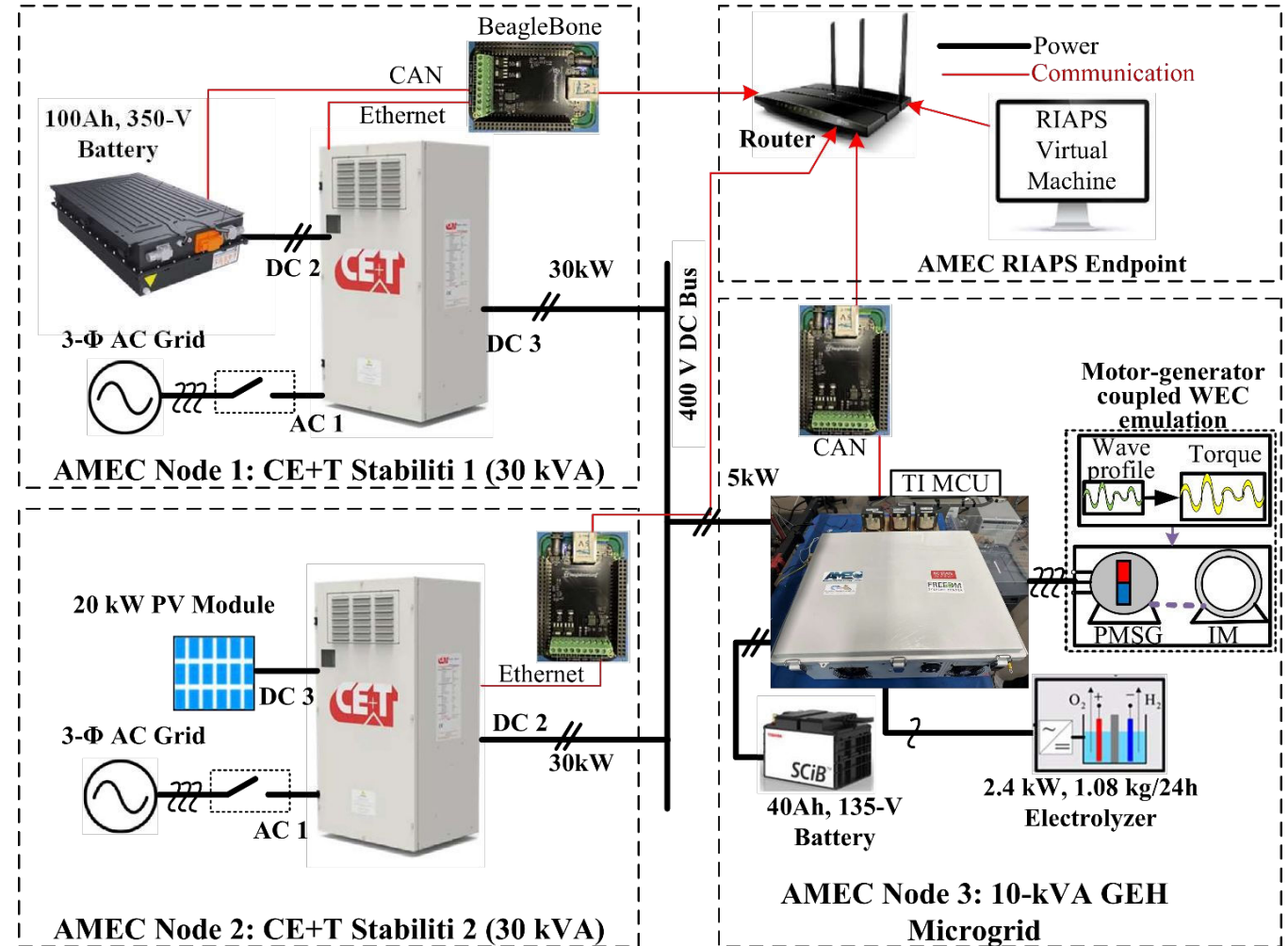
Atlantic Marine Energy Center (AMEC)

- Provides Atlantic-region infrastructure and expertise for marine energy research
- **AMEC Partner Institutions**
 - University of New Hampshire
 - Stony Brook University
 - Lehigh University
 - Coastal Studies Institute

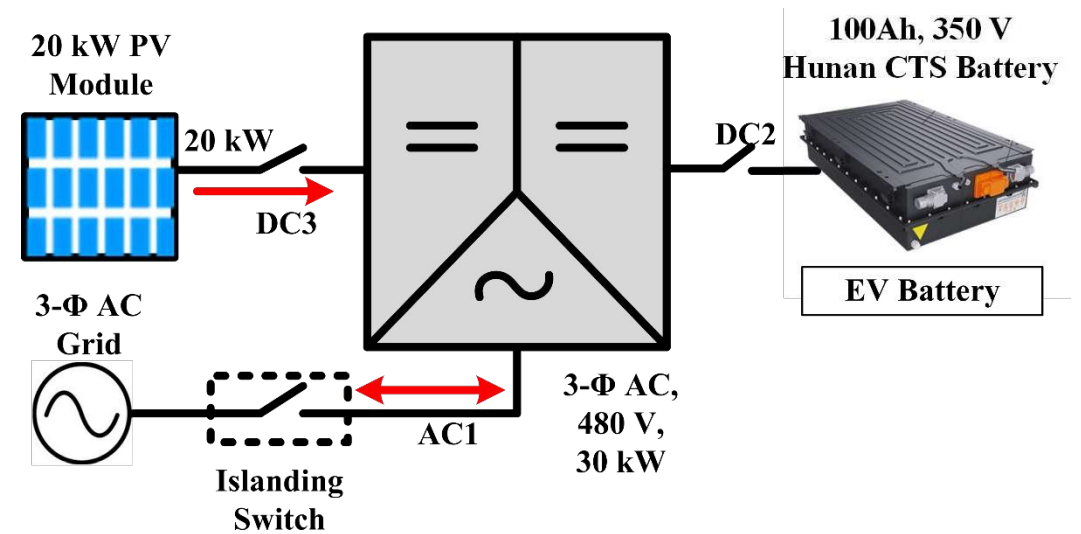


NC State University, in collaboration with CSI, is developing a three-node scalable marine DC microgrid for wave energy integration and system-level validation

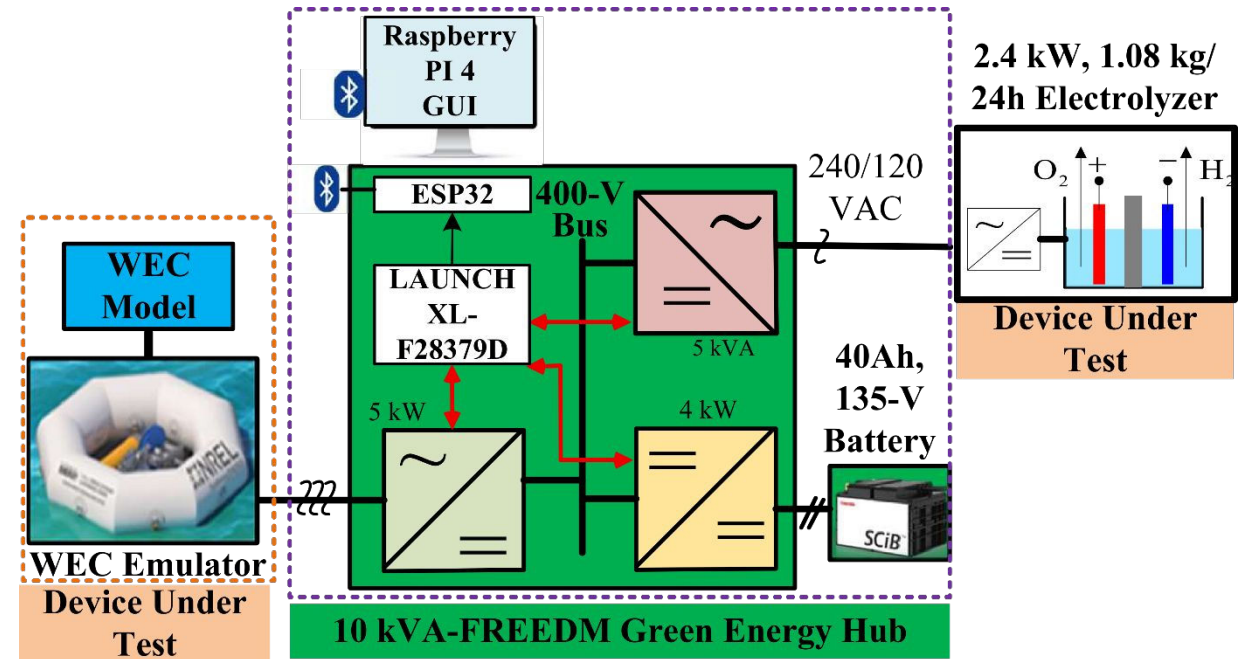
- Enhance Resilience by replacing centralized controls with a decentralized architecture
- A "plug-and-play" architecture for the seamless integration of Wave Energy Converters (WECs) and storage.
- Shared 400 V DC bus enabling power exchange among sources, storage, and loads.
- Multi-port power conversion supporting grid, PV, EV charging, electrolyzer, and WEC interfaces.
- Every node has its local controller.
- Real-time monitoring and control using distributed embedded controllers and RIAPS framework



- CE+T Stability 30C3 is a commercial off-the-shelf multiport converter.
- It has two DC ports and one AC port with a 30kW rating.
- AC port is capable of Grid Forming and Grid Following control.
- DC ports support PV and BESS with voltage, current, power, and MPPT control mode.
- Every port has a NET mode that can supply and sink power when needed by the other ports.
- Use Modbus communication protocol for control.

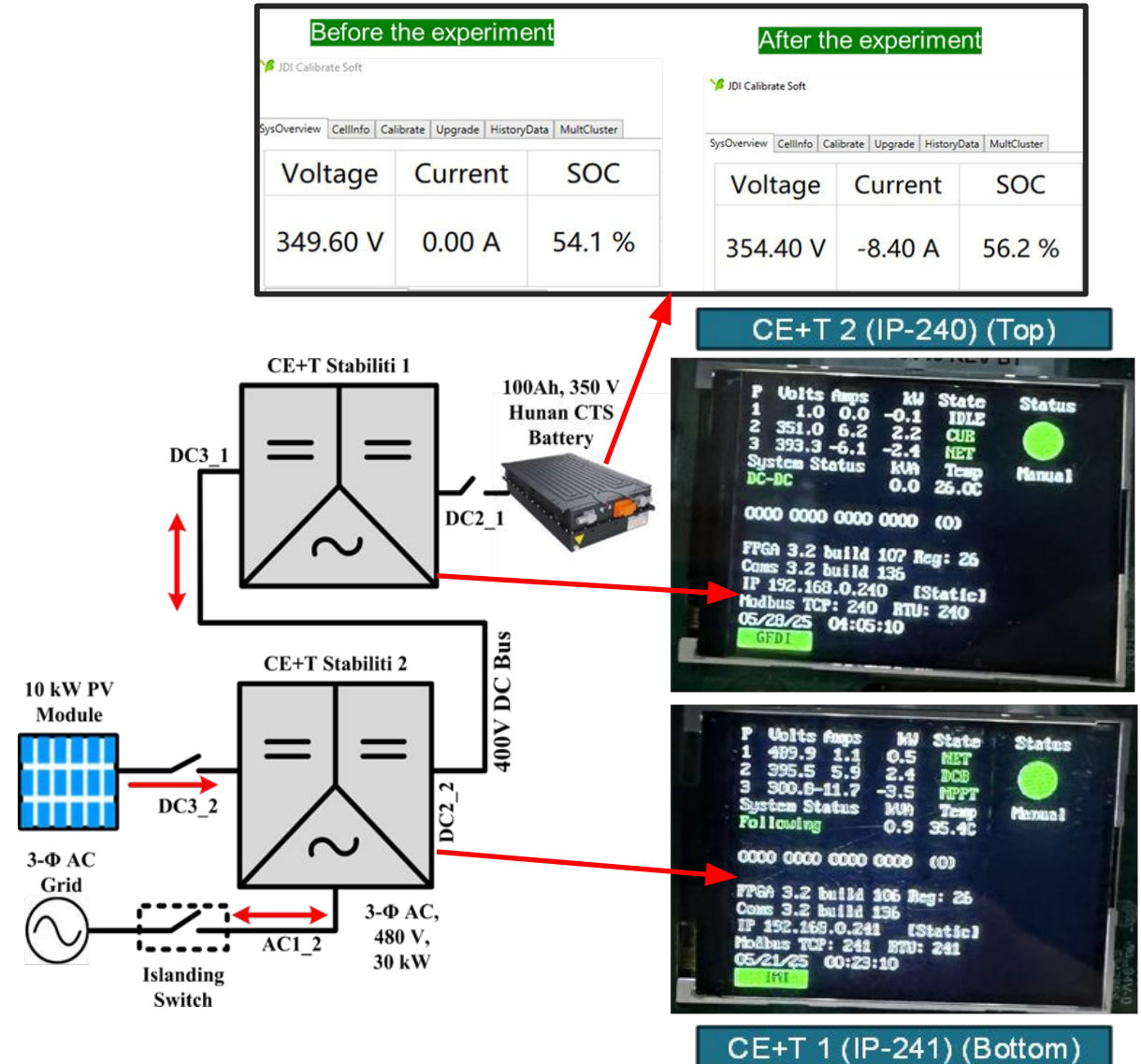


- 10kVA FREEDM Green Energy Hub is a multiport power electronic converter.
- 40Ah, 135V battery maintains the 400 V bus for the AMEC microgrid through the BESS port.
- Extracts the Wave Energy Converter output using the 5 kW AC/DC converter.
- Supports single-phase loads (electrolyzer or lighting load) through the split-phase inverter port.
- Emulated a variable frequency and variable magnitude WEC output using a programmable power supply.

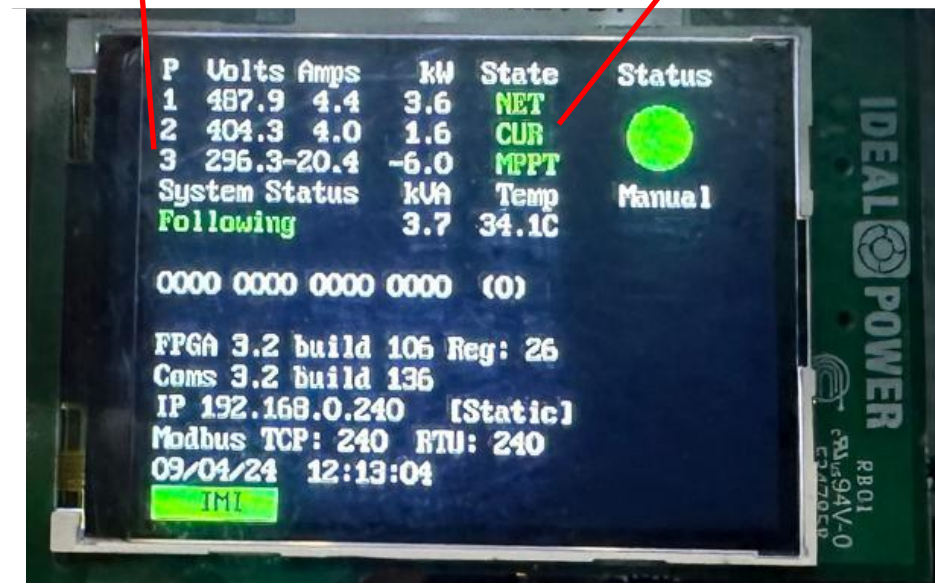
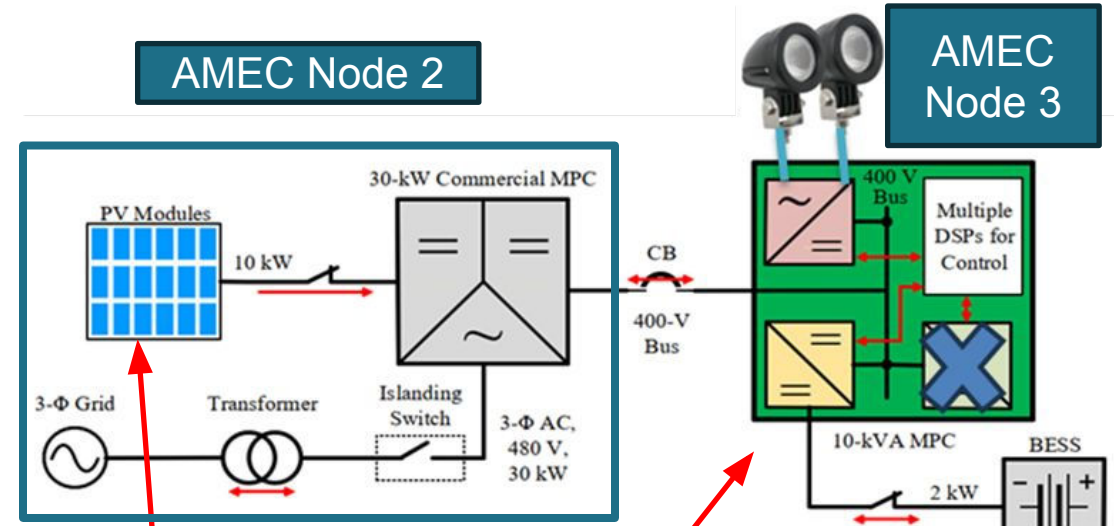


The purpose of this test was to charge the 100Ah, 350V EV battery using the renewable energy through AMEC Node 1 and 2

Port	Power Flow	Mode
PV	Generated 3.5 kW	AMEC Node 2 PV (MPPT mode)
Inter-Node Dispatch	2.4 kW	AMEC Node 2 -Node 1 (DC Bus Mode)
AC Grid	Sinked 0.5 kW	AMEC Node 2 (NET)
BESS	2.2 kW Charging	AMEC Node 1 (Current Control) 350V EV Battery



The purpose of this test was to use a 10 kW PV and CE+T three-phase (NET mode) to charge the 40Ah, 135V battery and feed the FREEDM GEH split-phase inverter lighting load.



Port	Power Flow
PV & AC Ports (AMEC Node 2)	6 kW generated by PV (MPPT); 3.6 kW sinked by AC grid (NET mode)
CE+T DC Port (AMEC Node 2)	1.6 kW delivered to 10kVA FREEDM GEH
BESS Charging (AMEC Node 3)	40Ah, 135 V battery charged at 1.3 kW
Split-phase Inverter (AMEC Node 3)	0.3 kW for lighting load

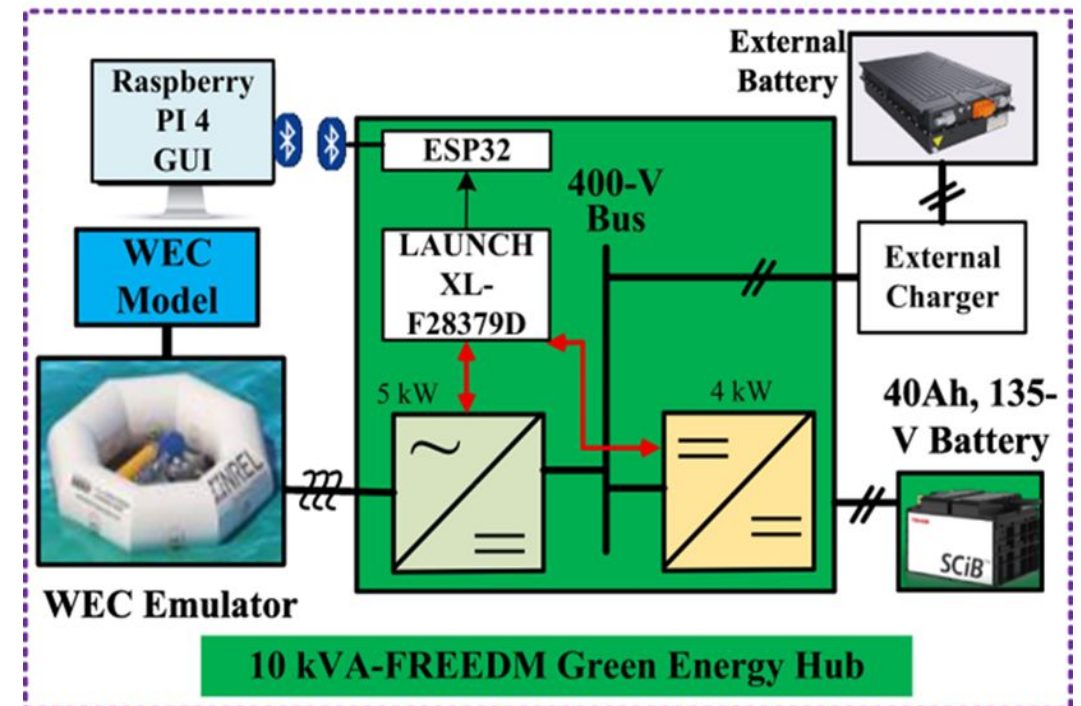
TEAMER (Testing Expertise and Access for Marine Energy Research)

- DOE-sponsored program providing marine energy developers access to U.S. testing facilities managed by Pacific Ocean Energy Trust (POET)
- TEAMER has 91 listed Open-Water and Non-Open Water testing facilities all over the US
- Coastal Studies Institute in Outer Banks and 10kVA FREEDM GEH are now accepted as TEAMER facility

10kVA FREEDM GEH is a TEAMER-approved testing site, enabling external researchers to validate technologies using the AMEC microgrid

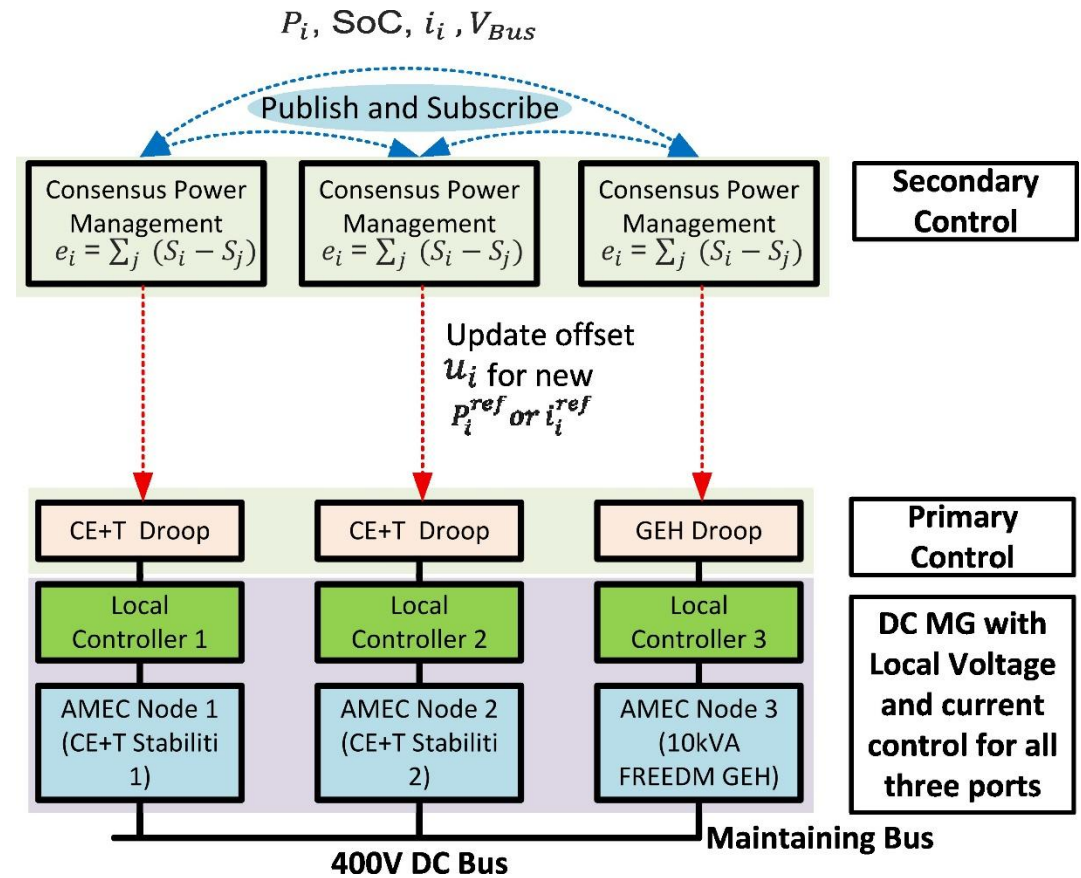
Capabilities:

- Emulating diverse WEC outputs
- Validating AC loads with Flexible 120V/240V ports
- Testing the external Charge Controller and BESS



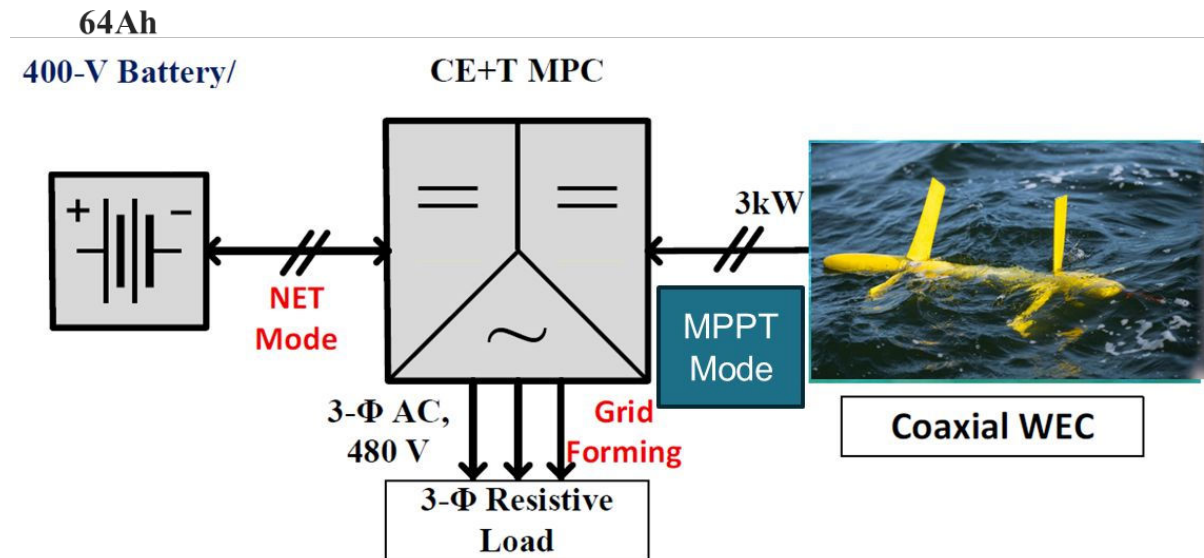
Let's work together to power the Blue Economy

- Distributed control is adopted to avoid single-point failure and enable scalable, resilient operation
- Three-node DC microgrid interconnected by a common 400 V DC bus, each node operating autonomously
- Local droop-based voltage/current control is implemented inside each converter
- RIAPS publish–subscribe network enables distributed coordination among nodes
- **Consensus algorithm** computes the error, $e_i = \sum_j (S_i - S_j)$ (here $S_i = \frac{P_i}{P_{i,rated}}$) and generates an offset u_i to correct droop references for balanced power sharing and SoC coordination.



- Currently testing the RIAPS communication network for connecting all three AMEC Nodes to operate together
- Finish developing a distributed control algorithm for the three node AMEC Microgrid
- Testing the 2.4kW Electrolyzer with the AMEC node 3.
- Performing hardware test on all three nodes of the AMEC Marine DC microgrid together using a RIAPS-based distributed control.

In March, we will deploy an AMEC microgrid node integrated with a coaxial turbine for tow testing at Jennette's Pier



- A. Billah, M Abdelraziq, Z. Pantic, and I. Husain, “Adaptive Current Control in a Multi-Port Converter for Reduced Current Ripple and Improved System Performance in Wave Energy Generation”, IEEE-Energy Conversion Congress and Expo (ECCE), 2024.
- A. Haque, Z. Pantic, and I. Husain, “Modeling and Implementation of a Wave Energy Converter Emulator for Testing Multi-port Power Converters in a Marine DC Microgrid,” IEEE-Energy Conversion Congress and Expo (ECCE), 2024.
- A. Haque, Z. Pantic, and I. Husain, “Modeling and Implementation of a Wave Energy Converter Emulator for Testing Multiport Power Electronic Converters in Marine DC Microgrid Applications”, University Marine Energy Research Community (UMERC) conference, 2024.
- S.M.H. Gillani, HBA Majeed A. Billah, A. Haque, Z. Pantic, and I. Husain, “Design of a Modular Marine DC Microgrid Testbed with Controller-Hardware-in-the-Loop (CHIL) for Real-Time Evaluation”, IEEE 6th International Conference on DC Microgrid, 2024.
- A. Haque, S. Fobi, Z. Pantic, and I. Husain, “Power Curve Modeling and Maximum Power Point Tracking of a Paddle-Type Wave Energy Converter ”, digest submitted in IEEE-Energy Conversion Congress and Expo (ECCE), 2025.

Thank You