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Multiport Converter Development for Marine DC Microgrids Deployed in Coastal Communities

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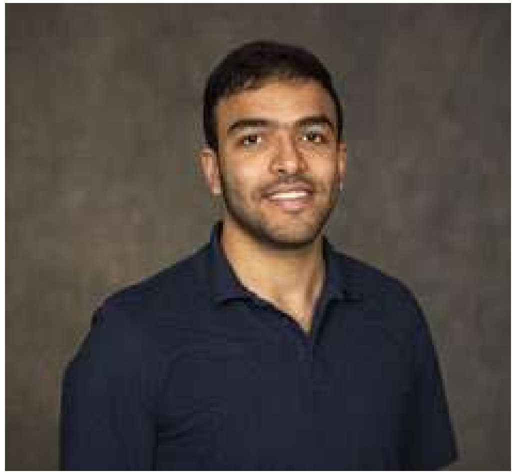

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Overview

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- Point-Absorber Buoys | Wave Power.
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- Point-Absorber Buoys | HERO WEC Electrical System.
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- Sample Results.
- Output Marine DC Microgrid Integration.

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Motivation

Need

- Coastal ecosystems produce tremendous amounts of services/products necessary for human well-being.
- Society's reliance on fossil fuels is not sustainable. ocean waves alone offer huge renewable energy.
- Research of harnessing energy from the "motion of the ocean" is in its infancy.

Proposed Solutions

- Using Wave Energy Converters (WECs) to harness the ocean wave energy.
- Developing marine DC microgrids that use Multiport converters capable of interfacing with WECs.
- Ensuring modularity and scalability.

Impact

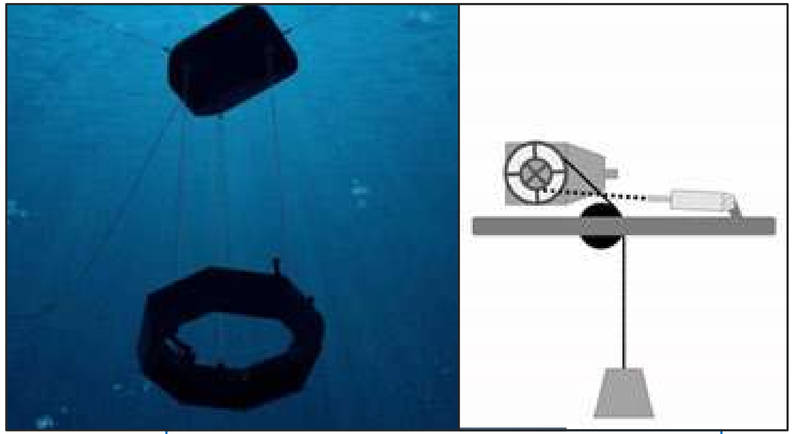
- A total energy potential of **2.64 TWh/yr** along the U.S. continental shelf edge is available offering a higher energy density than solar and wind.
- Through DC microgrids, hydrokinetic resources can supply clean electricity to coastal communities.
- This includes onshore electric vehicles, offshore electric boats, and underwater loads.

The Potential of Ocean Wave Energy

- Waves off the coast of the U.S. could theoretically generate **2.64 TWh/year.** (Source: US Energy Information Administration)

- The wave energy's potential future contribution to the electricity mix is estimated to be **10%-20%.**
- There are a variety of marine hydrokinetic resources and their wave energy generators (WECs), such as:

WECs designed for tidal and stream motions in seas or oceans' depths.
Source: TTTGLOBAL.



Offshore WEC
Source: OSCILLApower, Inc, nrel.gov.

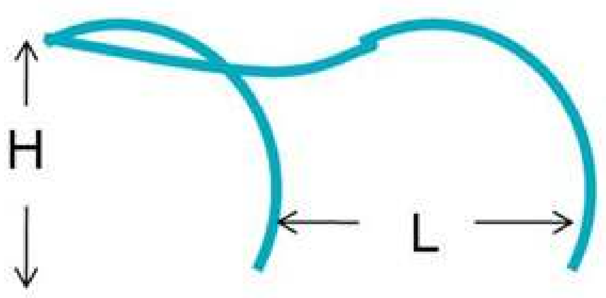
Onshore WEC
Source: Eco Wave Power.

Point-Absorber Buoys | Wave Power

- The power that can be extracted from a wave is:

$$P = \frac{\rho g^2 T H^2 L}{32\pi}$$

H is the height of the wave.
L is the wavelength.
T is the average period of the wave.



Illustrative drawing of two consecutive ocean waves.

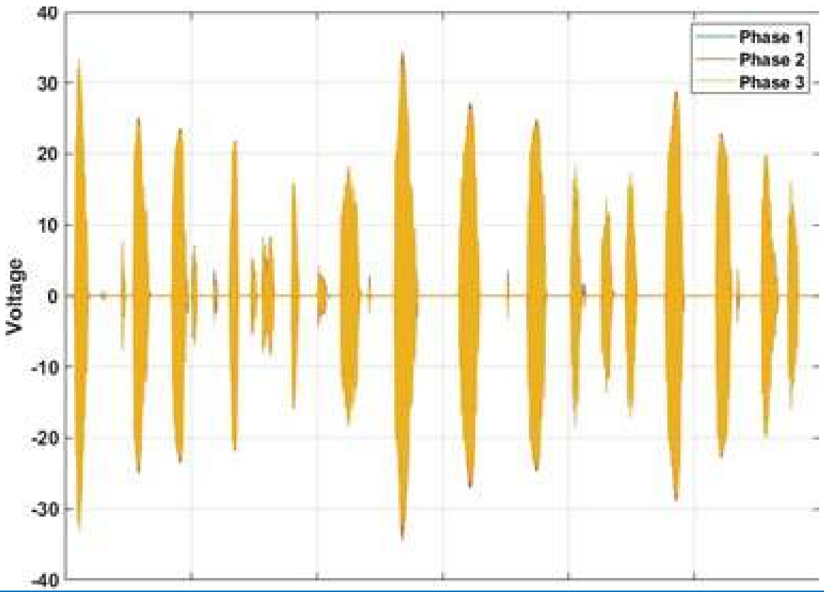
The National Data Buoy Center's source of meteorological and oceanographic measurements for the marine environment..
Source: https://www.ndbc.noaa.gov/.

- Based on observed wave patterns, one could estimate how much is available for extraction in a given period of time.

- The power electronic unit needs to be able to process such power.

Point-Absorber Buoys | HERO WEC Electrical Output

The HERO WEC, NREL's first wave-powered desalination system, rides the waves off Jennette's Pier in Nags Head, North Carolina, enabling researchers to gather real-world data that advance critical research on small-scale WECs.
Source: nrel.gov.



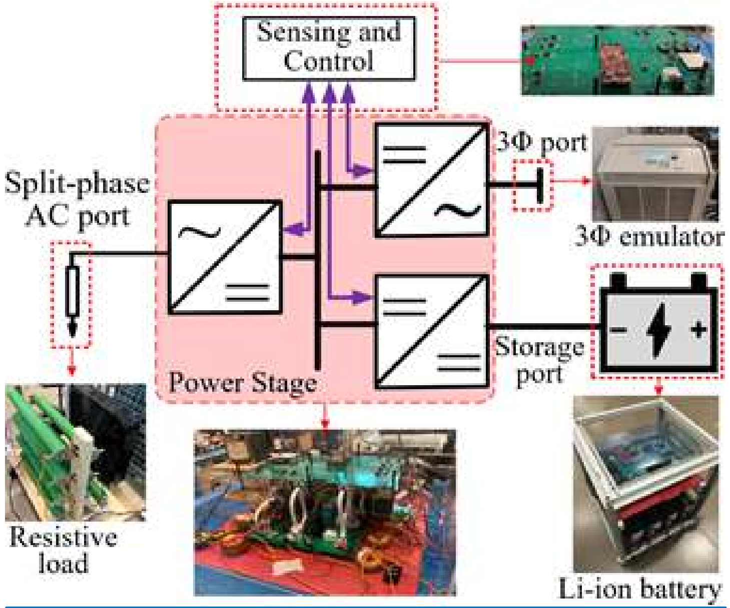
Sample voltage output of the HERO WEC prototype.
Source: nrel.gov.

- A key part of the HERO WEC's electrical system is the onshore power electronics enclosure—a box of components that regulates the voltage coming in from the waves.

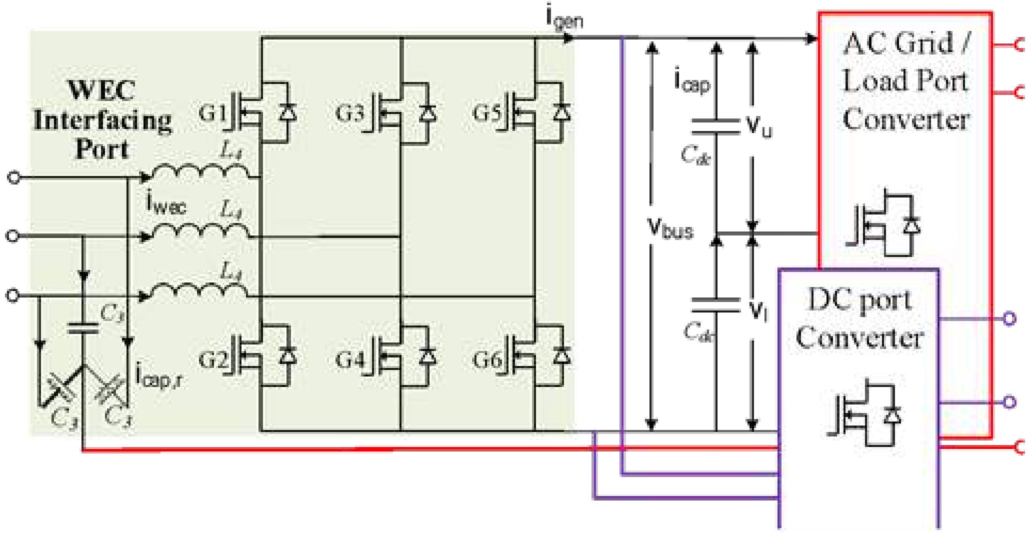
- Wave energy is extremely scattered causing the voltage of that power to be never constant.

- The power electronic unit needs to be able to process variable-frequency variable-amplitude voltage.

Point-Absorber Buoys | MPC Electrical System



Hardware Experimental Setup of the Multi-port converter unit developed at FREEDM.



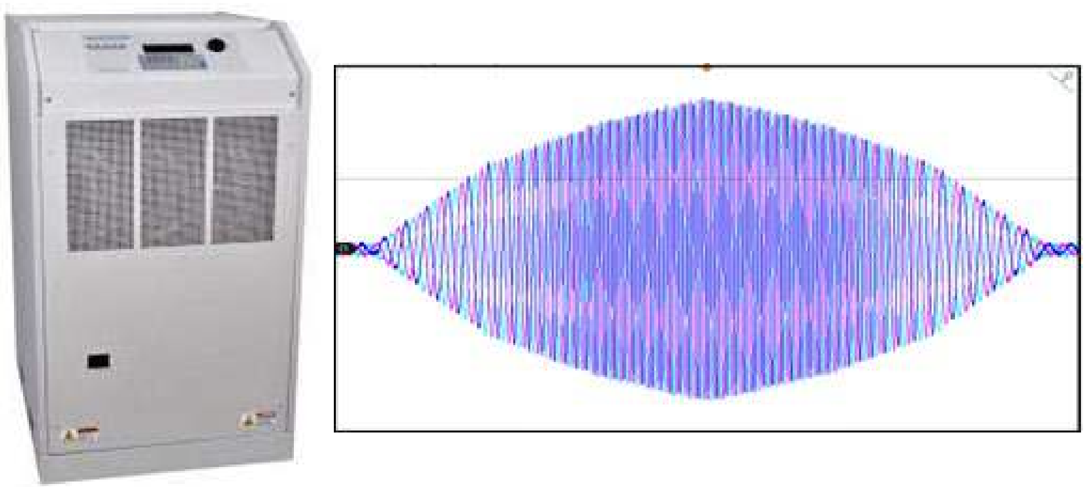
Circuit diagram of the MPC.

- ➢ The WEC port is programmed to work with a variable-frequency and voltage.
- ➢ The WEC interfacing port taps directly to the DC bus of the marine DC microgrid.
- ➢ This allows the WEC energy to be used directly in supplying loads or stored in batteries.

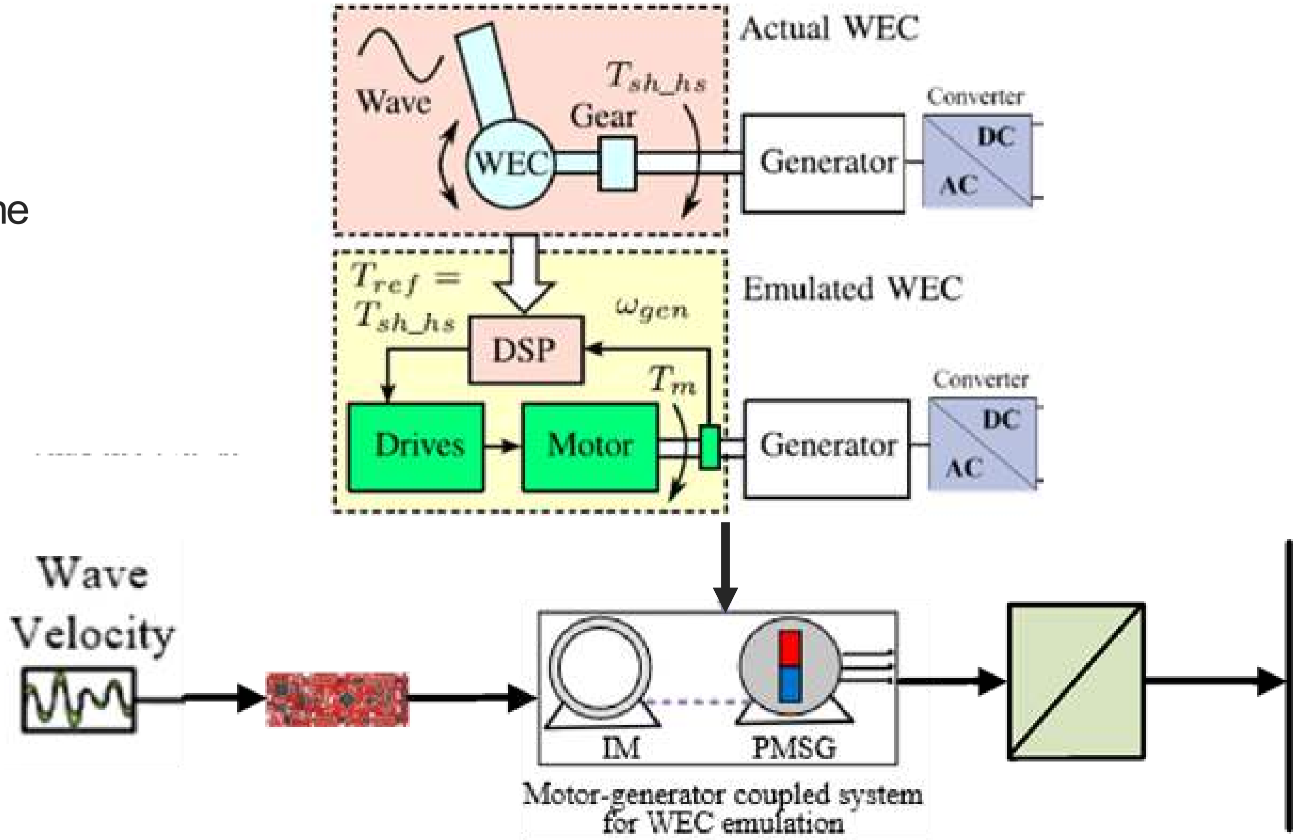
- ➢ A key part of the HERO WEC's electrical system is the onshore power electronics enclosure—a box of components that regulates the voltage coming in from the waves.

Point-Absorber Buoys | HERO WEC System Modeling

- To aid with the design and prototyping of WEC-compatible MPCs and control algorithms, WEC models are necessary.
- This helps save costs since WEC deployment is costly.
- Programmable power supplies are limited in terms of the lowest frequency they can output.



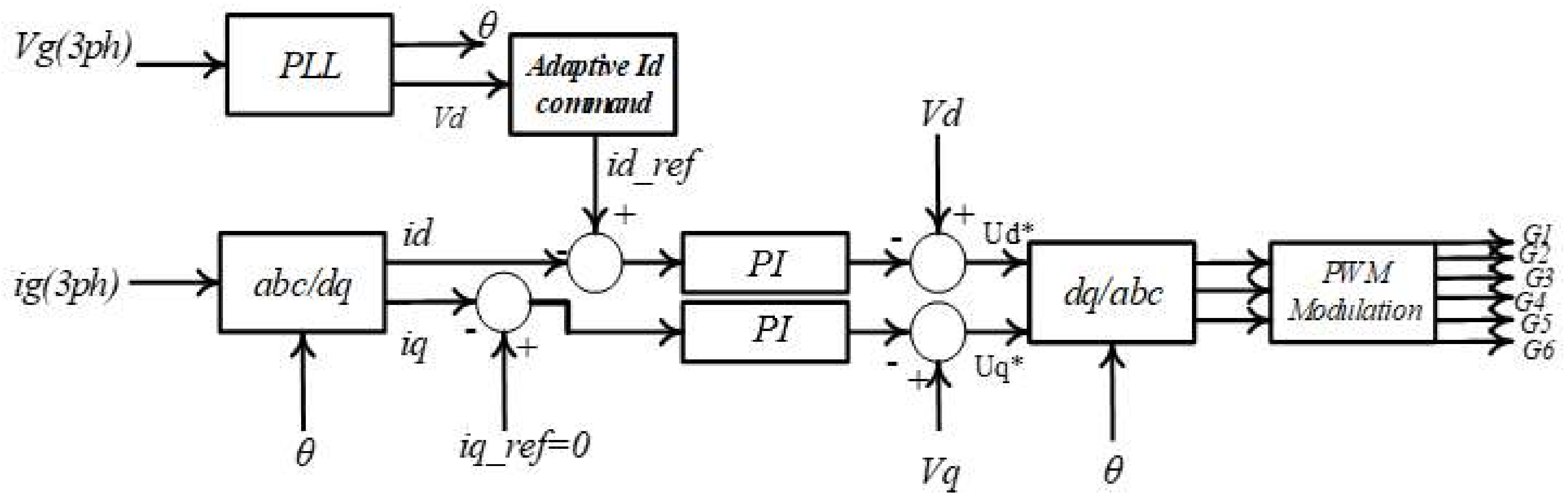
Programmable three-phase AC power supply with a sample emulated-WEC voltage output.
Source: California Instruments.



Implementation of the emulated WEC system with motor-generator coupling.

MPC | WEC Port Control

- Given the WEC acts as a voltage source, the power extraction is controlled by the current.
- The current determines the power extracted which can be less that what is available by the WEC device.
- The controller must be adaptive in the sense that it requests power only when voltage is available, otherwise, instabilities occur.
- MPPT implementation requires extensive learning and knowledge of the WEC devices and wave nature.

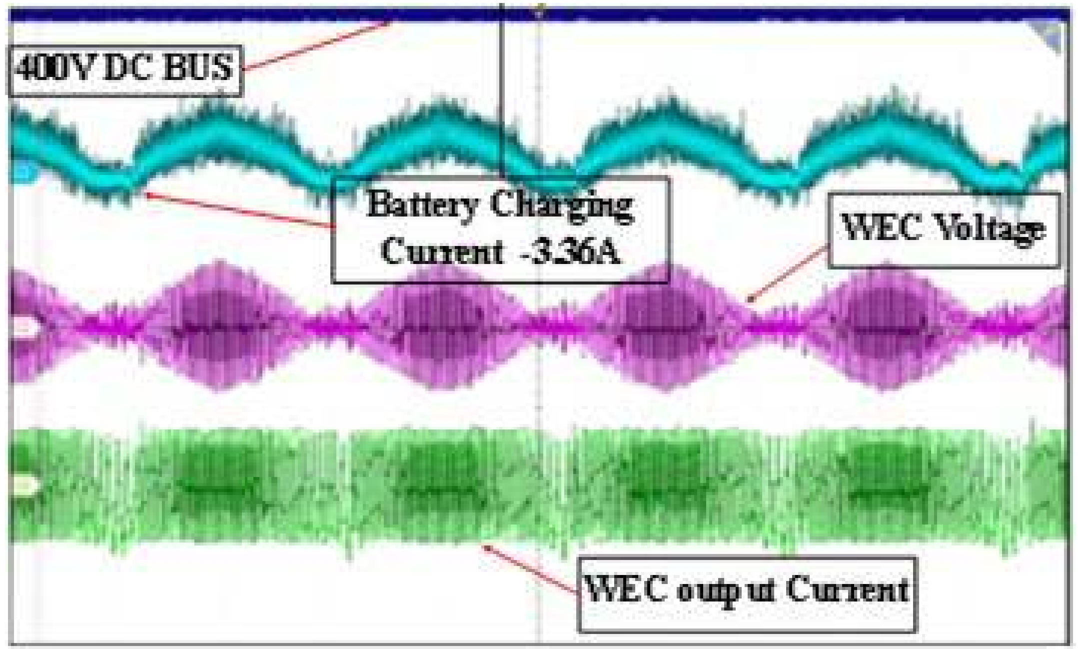


Used control structure of the WEC-interfacing port with the option to implement an MPPT algorithm for maximum power capturing.

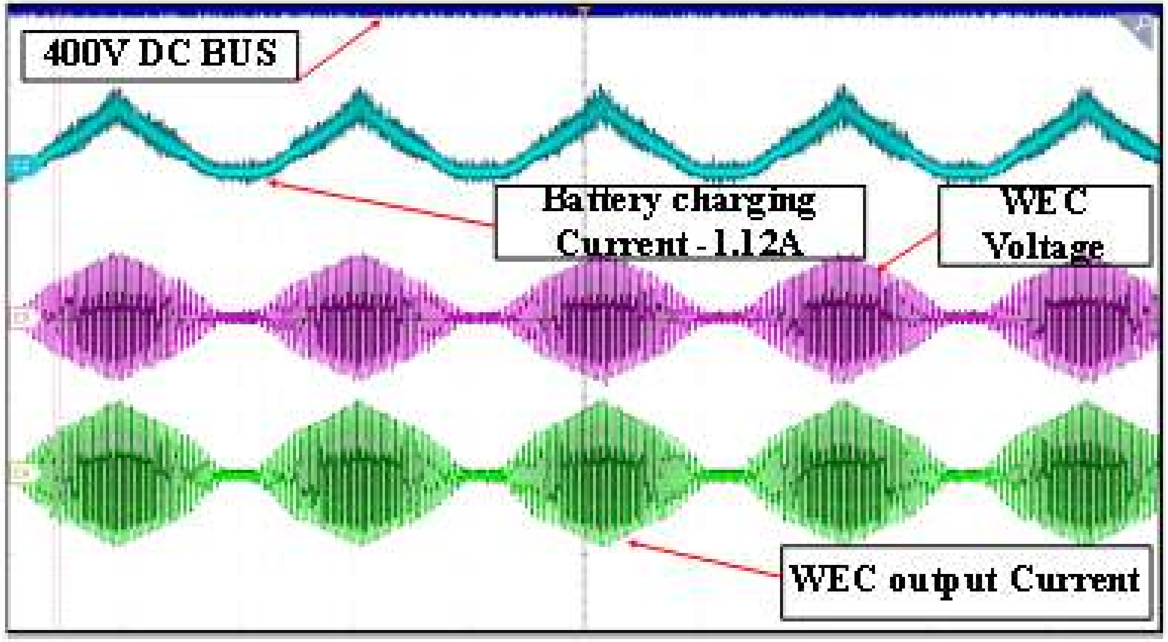
MPC | Controller Performance Example

- Given the oscillatory nature of wave energy, the controller needs to adaptively request power once voltage is available.
- A current proportional to the voltage can be requested during each cycle.
- A varying proportionality constant leads to an MPPT algorithm.

$$Factor = \frac{Rated\ Power\ of\ WEC}{Maximum\ Voltage\ of\ the\ WEC^2}$$

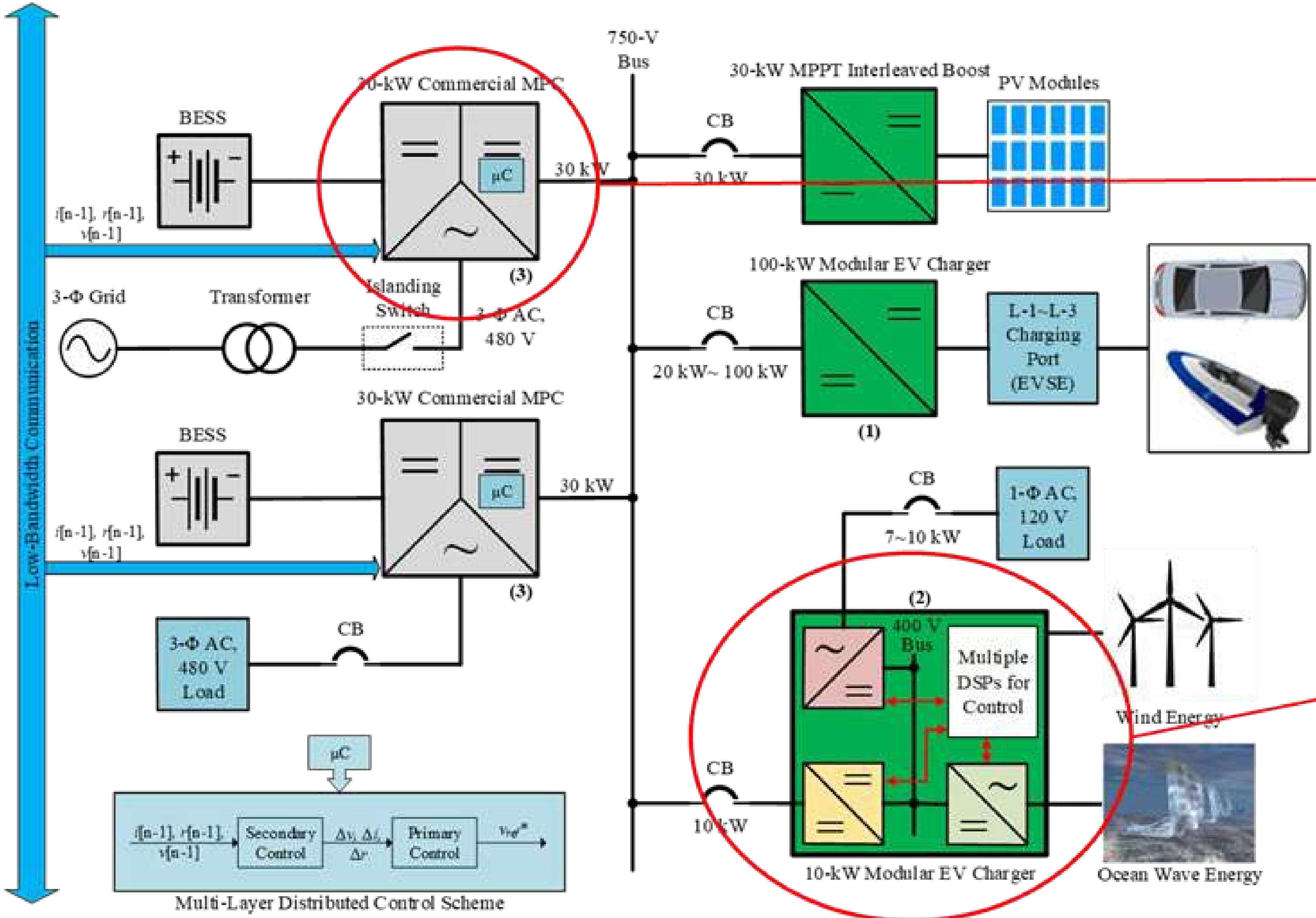


Experimental results when demanding a constant Power (i.e., current) from the WEC.



Experimental results when adaptively demanding Power proportional to the WEC output voltage. The proportionality constant can be varied to apply an MPPT algorithm.

Envisioned HERO WEC Integration in a DC Microgrid



Modular and Power-Scalable Converter-Based DC Microgrid System.

Commercial-of-the-Shelf (CETS) MPCs.

MPC completed at FREEDM.

Acknowledgement

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- University of North Carolina Coastal Studies Institute
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