Grid Emulator for Compliance Testing of Wave Energy Converters

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Outline

- Introduction to Wave Energy
- Grid Emulator Overview
- Grid Emulator Design and Simulations
- Future Work

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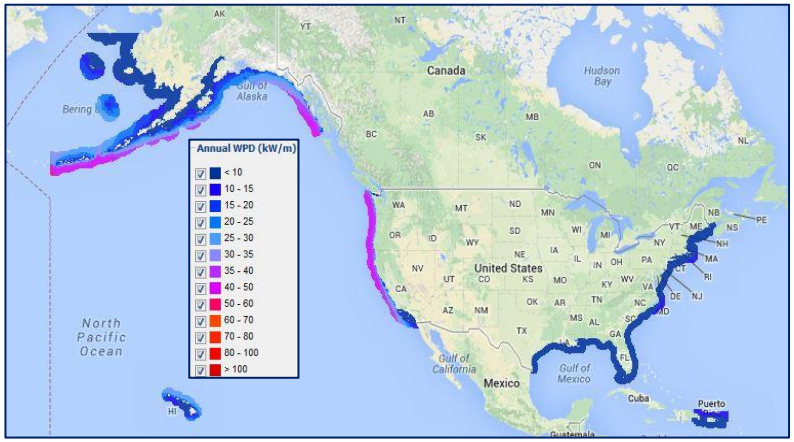
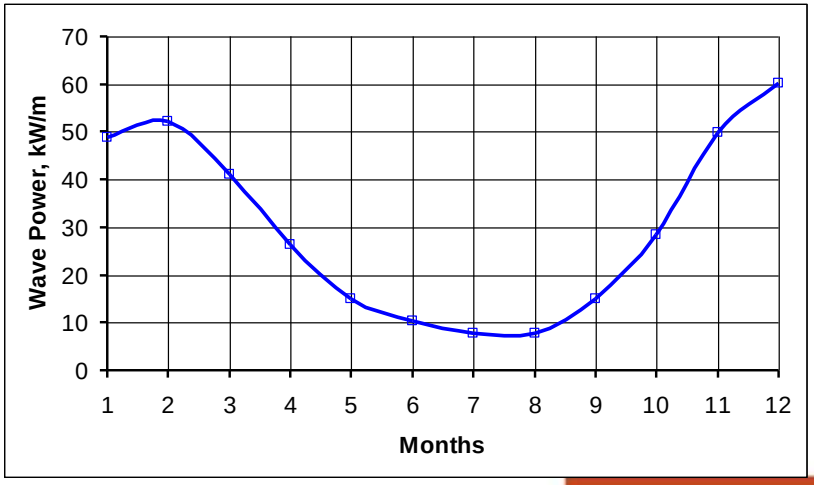
Introduction to Wave Energy

Wave Energy Potential

- Wave energy: High energy density, availability and predictability.
- US annual energy consumption: 4000 TWh *(BOEM)*
- Annual wave energy potential in US: 1200 TWh *(BOEM)*
- Oregon coastline: 460 km
- Oregon coast raw wave power potential: 500 MW *(EPRI)*



Wave Energy potential for the United States *(NREL)*



Wave data from National Data Buoy Center, power estimated from 5 buoys off the Oregon coast over past 10 years

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Introduction to Wave Energy

Wave Energy Converter (WEC)

Surface attenuator: Pelamis Wave Power

Oscillating water column: Oceanlinx

Submerged surge converter: AW Energy

> 1000 patents

< 5 MW installed

Point absorber: Ocean Power Technologies

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Introduction to Wave Energy

Wave Energy at Oregon State University

Wallace Energy Systems & Renewables Facility (WESRF)

- Wave Energy initiative began at OSU in 1998
- 11th prototype successfully ocean tested with CPT Sept. 2008
- Northwest National Marine Renewable Energy Center (NNMREC) established in 2008

Deployment of 10 kW point absorber off the coast of Newport, OR

O.H. Hinsdale Wave Research Lab (HWRL)

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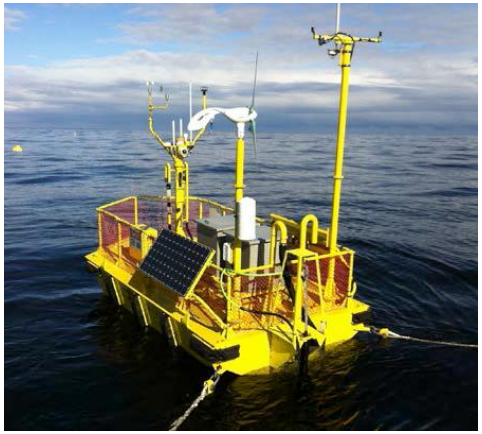
Introduction to Wave Energy

Northwest National Marine Renewable Energy Center

NNMREC open water test sites

The half-scale WET-NZ WEC

- Pacific Marine Energy Center (PMEC): Open water and lab testing facilities
- North Energy Test Site (NETS): WEC prototypes up to 100 kW
  - Ocean Sentinel instrumentation buoy
  - WET NZ testing in summer 2012
- South Energy Test Site (SETS)
  - Grid connected site available in ~ 2017



Ocean Sentinel Instrumentation buoy on station

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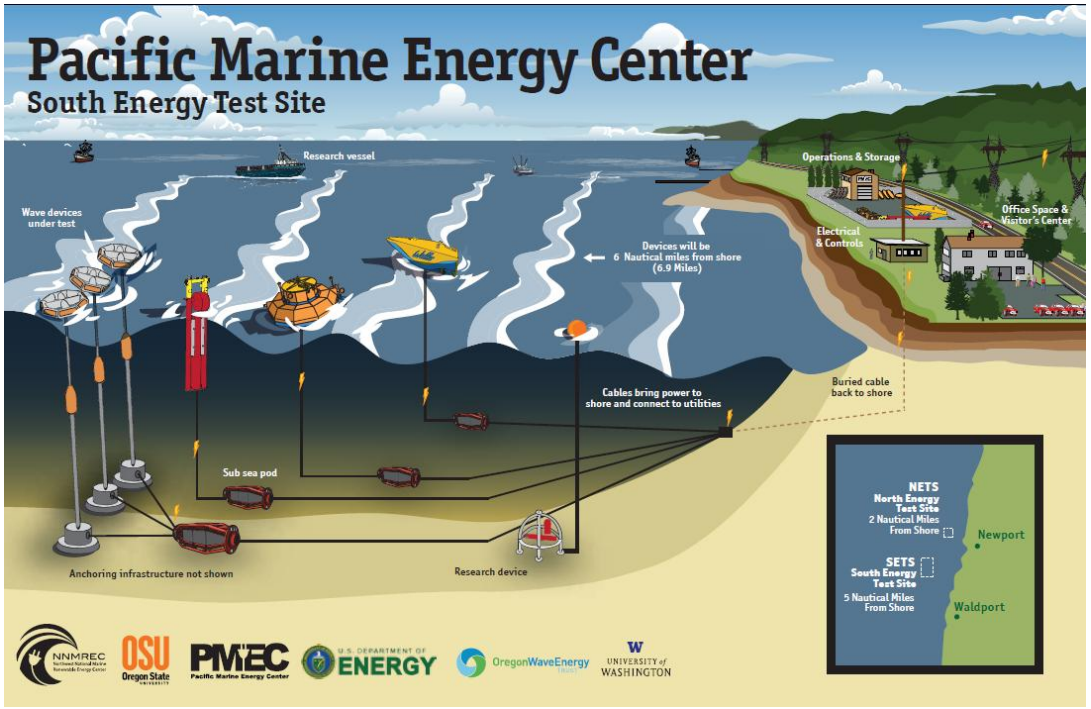
Grid Emulator Overview

South Energy Test Site

- South Energy Test Site - grid connected
- 8-10 km from shore
- 60-70 m depth
- Up to 4 submarine cables
- Medium voltage submarine cables rated up to 35 kV



Proposed Pacific Marine Energy Center – South Energy Test Site (PMEC-SETS) for testing full-scale wave energy converters

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Grid Emulator Overview

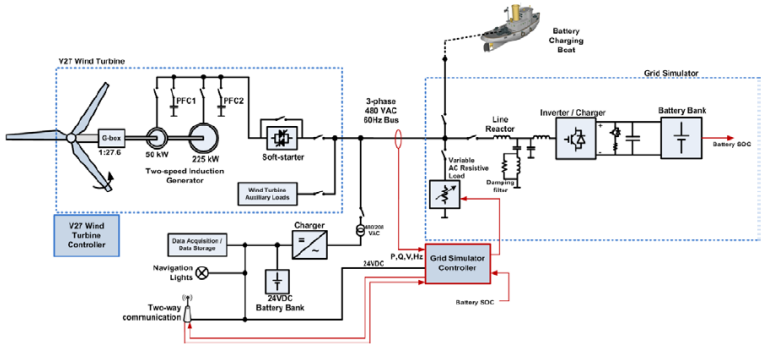
Grid emulator and its need

- Device emulates actual grid scenarios
- One device, multiple grid conditions
- Increasing integration of renewable energy sources
- Lack of standardized WEC design
- Stability of the power grid varies from point to point
- Validation of variable power output before grid connection
- Faster certification of distributed resources
- Isolation between the WEC and the grid during initial testing

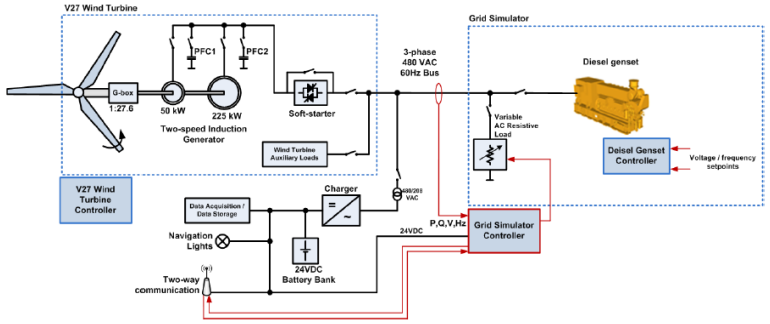
Grid Emulator Overview

Topologies and previous work

- NREL investigated topologies
  - Battery inverter topology
  - Diesel generator topology
  - Controllable Grid Interface (CGI): 7.5 MVA – *chosen topology*
- Clemson University
  - HIL grid simulator: 15 MVA
  - RTDS
- FSU – CAPS
  - HIL simulator: 5 MVA
  - RTDS and Opal-RT



Battery inverter topology of the grid simulator *(NREL)*



Diesel generator topology of the grid simulator *(NREL)*

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Grid Emulator Overview

Specification and Preliminary Functions

Item	Specification
Nominal rating	5 MVA
Supply line voltage	12.47 kV AC
Line voltage tolerance	+/- 10%
Phases	3
Nominal supply line frequency	60 Hz
Line frequency tolerance	+/- 1 Hz
Grid impedance	5% min, 7% max on a 25 MVA base@ 12.47 kV
Available grid fault current	14x min, 20x max on a 25 MVA base @ 12.47 kV
Rectifier rating	5 MVA, 125% overload capacity for short periods
Rectifier power factor	>+/- 0.95
Inverter rating	5, 10, 15 MVA, 125% current overload capacity
Output voltage regulation	+/- 1%
Output frequency regulation	50 Hz / 60 Hz +/- 1%
Inverter output droop characteristics	+/- 10% system impedance

- Synchronization, Power delivery and device fault testing
- Voltage fluctuations: continuous and switching
- Response to balanced and unbalanced low and high voltage faults
- Active power: maximum measurement, ramp rate limitation
- Grid protection
- Reconnection time

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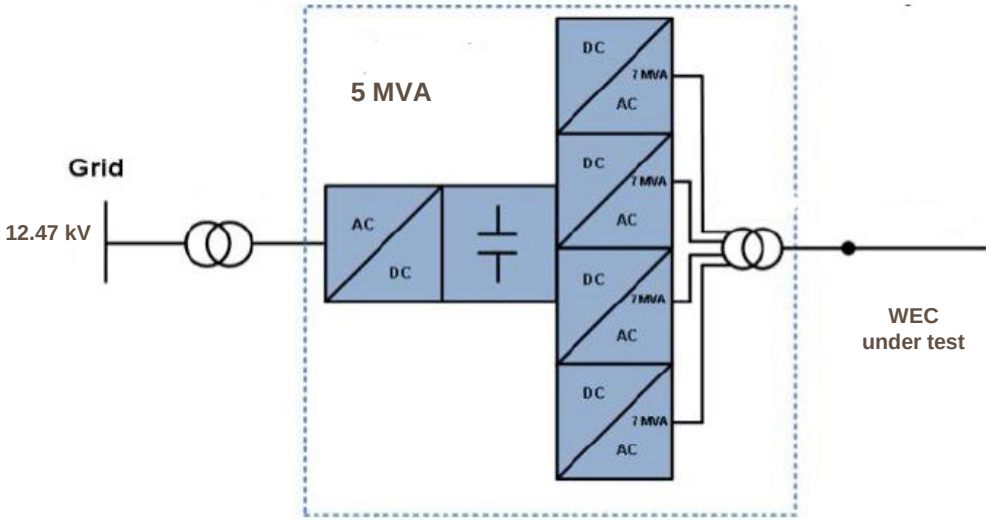
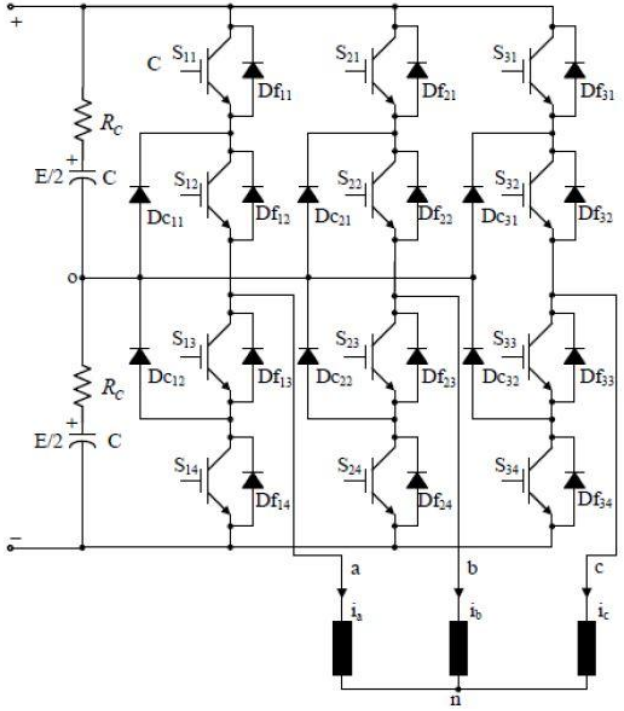
Grid Emulator Design and Simulations

Grid emulator topology



Grid emulator topology *(NREL)*



Topology of the Three Level Neutral Point Clamped Voltage Source Converter

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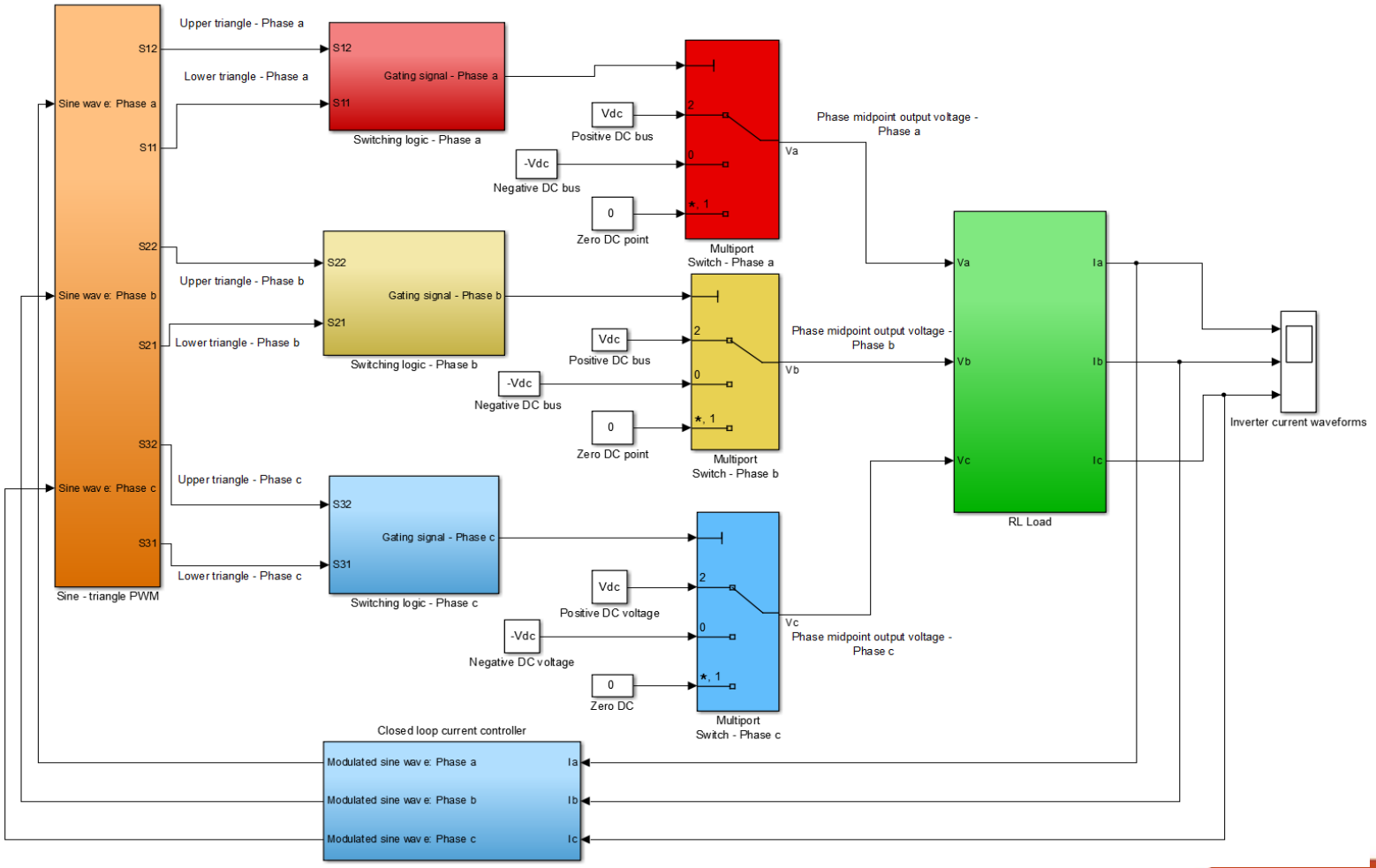
Grid Emulator Design and Simulations

Native Simulink model of the inverter



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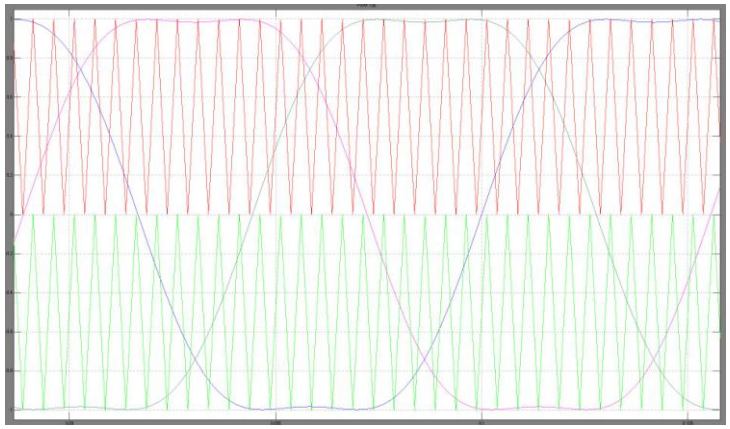
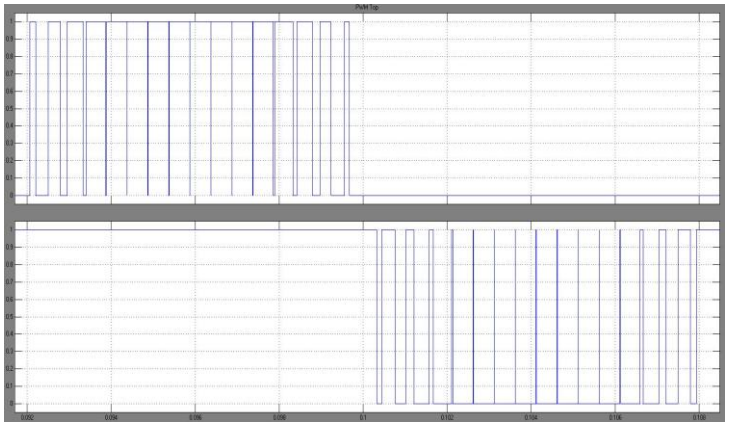
Grid Emulator Design and Simulations

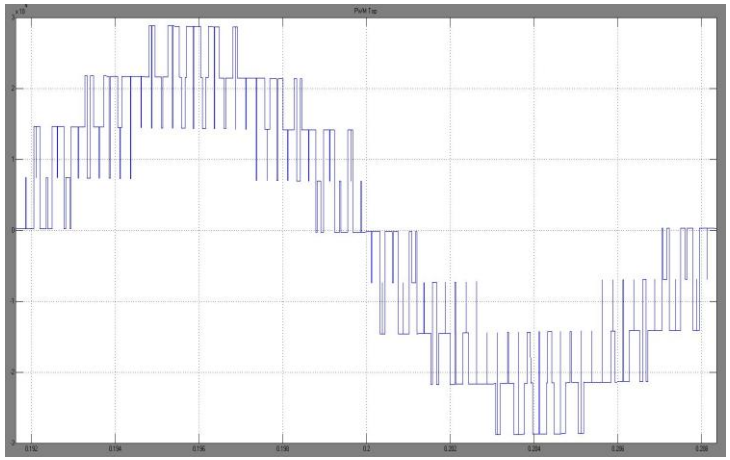
Inverter waveforms



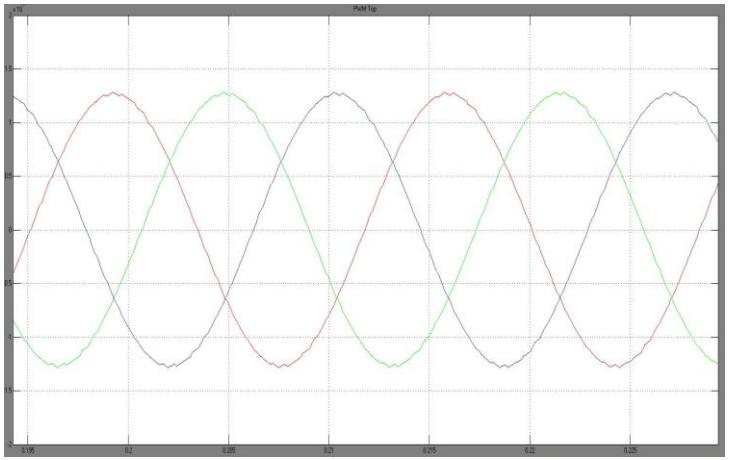
Two level sine-triangle PWM



PWM signals for the top two switches



Nine level phase voltage



Inverter currents with an RL load

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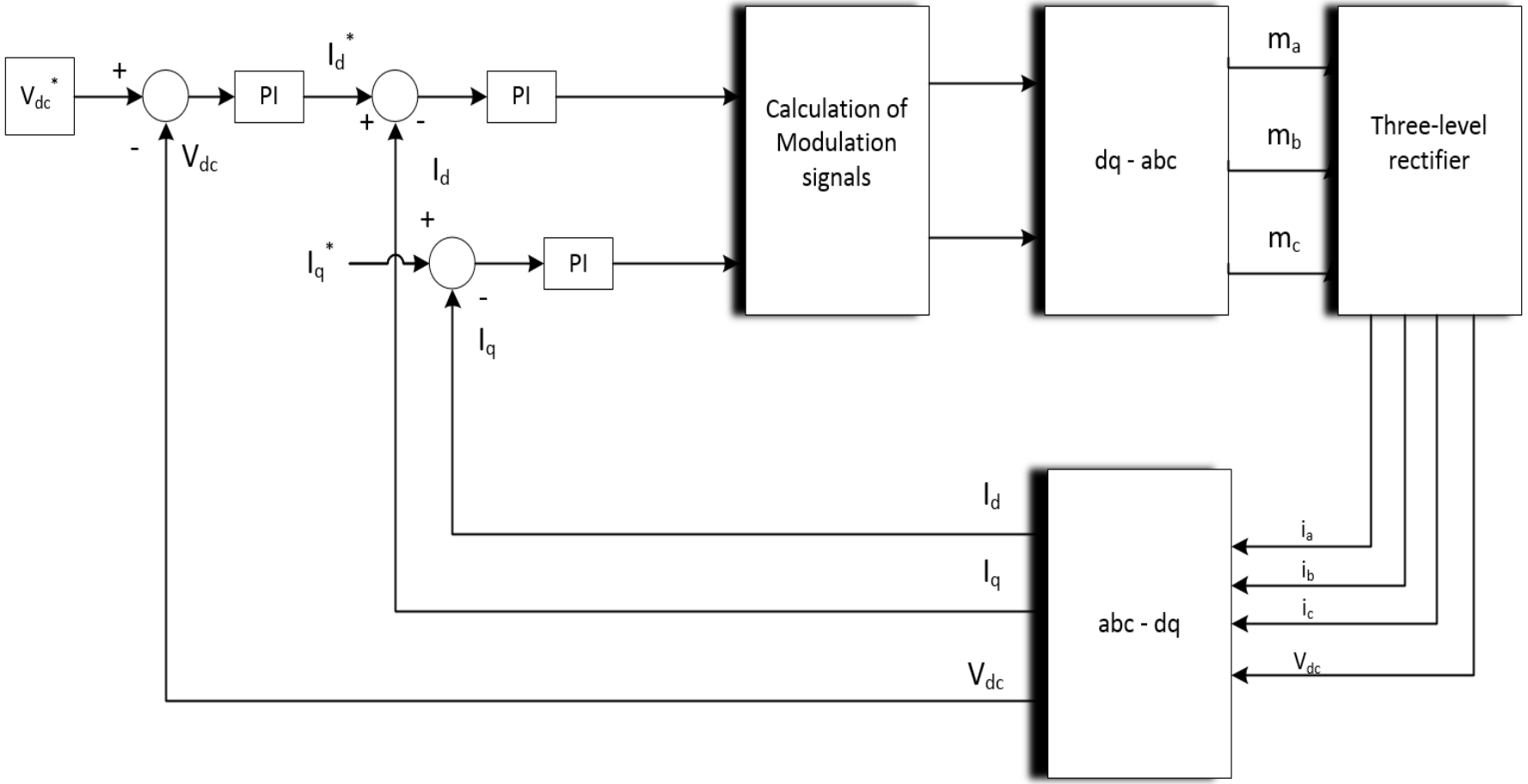
Grid Emulator Design and Simulations

Rectifier



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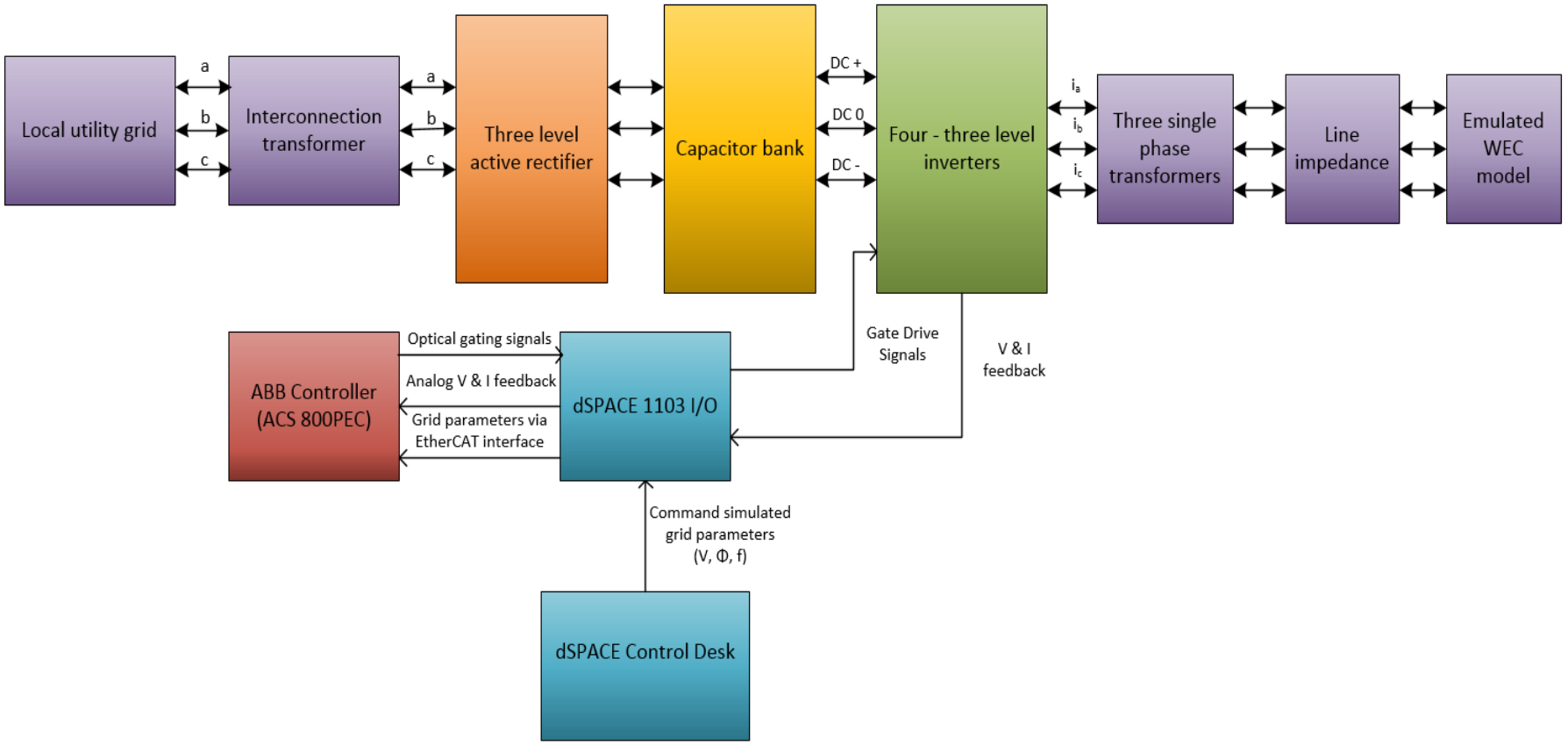
Future Work

Hardware-in-the-loop setup



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Future Work

- Expanding the single inverter design to more accurately represent the four inverter design.
- Transformer design
- Replacing the RL load with WEC models
- Hardware-in-the-loop lab validation of the grid emulator
- Emulation of various grid conditions
- Final design put out for bid
- Development of actual hardware

Thank you for your attention

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