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# *Unlocking the Potential of Marine Energy Resources: Advanced Electrical Solutions for Grid Applications*

*by*

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# Outline

- Background
- Research & Projects
- Research Snapshot
- ONR- To Improve Isolated Site Resilience
- AMEC- Power Conversion for MRE Integration
- HVDC OSW Energy Integration
- Digital Twin: Real Time Condition Monitoring
- Hybrid Energy Storage System

MRE: Marine Renewable Energy, OSW: Offshore Wind

# Academic Background and Work Experience

**2009-2013**

**Muzaffarpur Institute of Technology**
**Bihar, India**

**CGPA- 8.3/10**

**2013 – 2014**

**Installation & Maintenance Engineer,**
Multitech Control Systems
Gujrat, India

**2015-2017**


**Indian Institute of Information Technology**
**MP, India**

**CGPA- 8.8/10**

**2017– 2021**

**Research and Assistant Professor**
Government Engineering College
Bilaspur, India
**Research and Assistant Professor**
Government Engineering College
Bilaspur, India

**2021-Present**

**Stony Brook University**
**NY, US**

**CGPA- 4.0/4.0**

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LinkedIn: https://www.linkedin.com/in/deepi-singh-33b623172/
Google Scholar: https://scholar.google.com/citations?user=CbyiSXgAAAAJ&hl=en&oi=ao

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# Research & Projects

## 1. Robust and Intelligent Integration of Micro-Grids to Improve Isolated Site Resilience

- Developed a 21kW hybrid AC/DC microgrid testbed.
- Seamless operation in Islanded and Grid Tied modes.
- Enhance shipboard microgrid resiliency with renewable energy integration.
- Analyze FACTS devices' impact on microgrid stability and resiliency.

## 2. SBU Smart Grids and Power Conversion for MRE Integration

- Hardware co-design platform for power converters.
- MATLAB/Simulink MBO Algorithm for high-performance converter design.
- Benchmark Models for efficiency and resilience analysis.
- Testbed Platforms, including HIL, for innovative solution validation.

## 3. Comparative Study & Networked Benchmarking for HVDC OSW Energy Integration

- Comparative study for Offshore wind HVDC architectures.
- OSW HVDC benchmarking in software and HIL platforms.

## 4. Establish programmable platforms for MRE energy storage, power conversion, and formal verification.

- Design marine microgrid with energy storage.
- Integrate microgrids and storage converters in HIL prototype.

## 5. Intelligent Power Stage Development

- Digital Twining of interleaved boost converter.
- Health estimation and lifetime prediction for power stage.

## 6. Conduct Hydrogen Research for BNL

- Optimize Hybrid Renewables and Hydrogen Energy System (HRHES) design.
- Model and design efficient HRHES with DC-DC converter and control coupling.

EVERSOURCE ENERGY · Ørsted · U.S. DEPARTMENT OF ENERGY · Office of Naval Research Science & Technology · Brookhaven National Laboratory · GE · Oak Ridge National Laboratory · Atlantic Marine Energy Center

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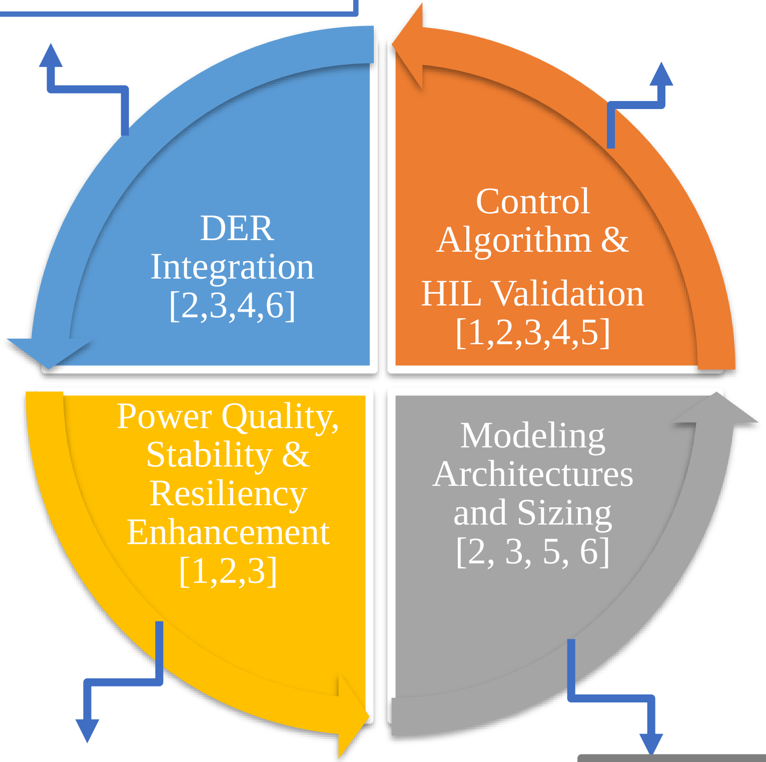
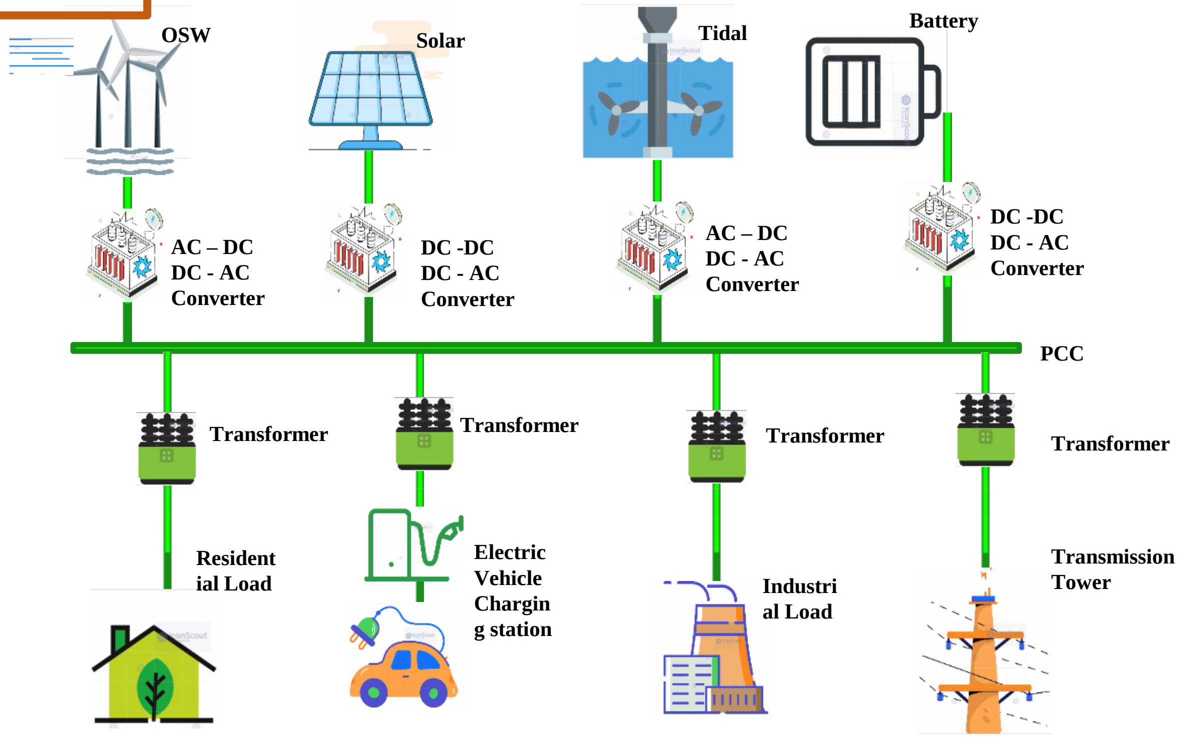
# Research: Snapshot

- Hybrid Energy Sources
- Optimizing Performance & Economics.

- Real time control to address system dynamics.
- FRT control/Coordinated Control
- Economic Model Predictive Control.




- Hybrid Solution: FACTS +ESS + Coordinated Control

- Effective configurations and optimal sizing
- Advanced modeling and simulation tools
- Condition Monitoring

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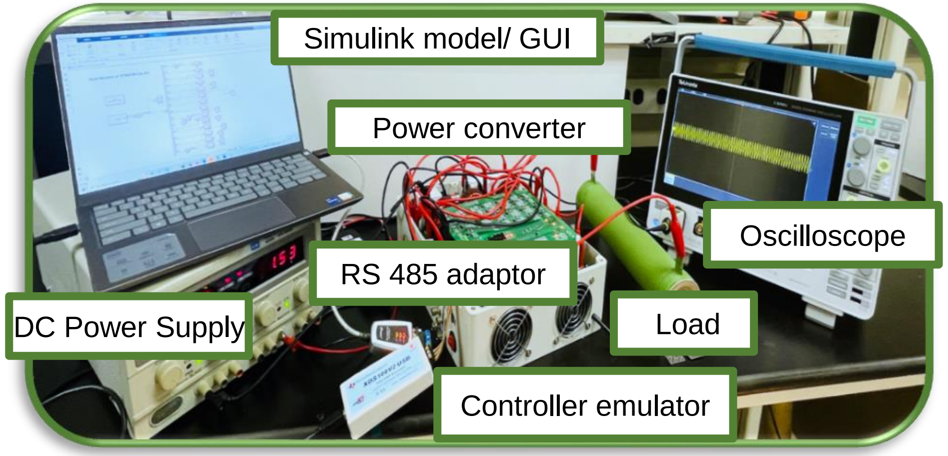
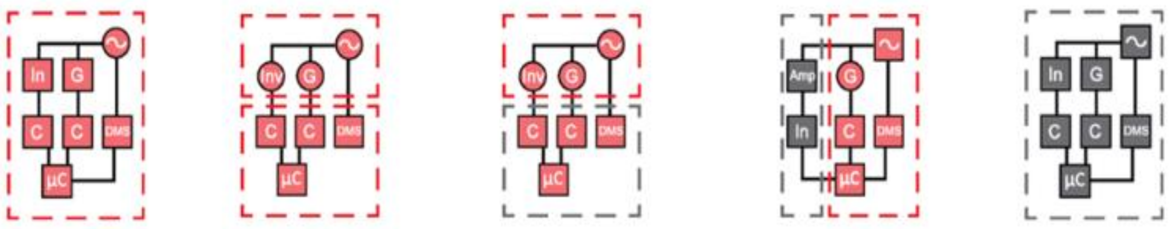
# Validation Platforms

## Hardware Validation Platform




## Testing Methodologies

Model ⟷ Hardware





## SIL Platforms

MATLAB

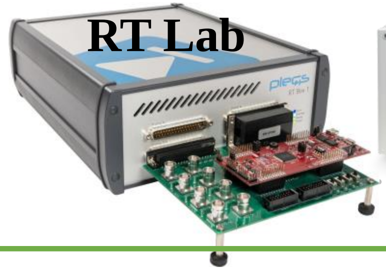
Typhoon HIL

LabVIEW

plecs

LTspice

## HIL Platforms



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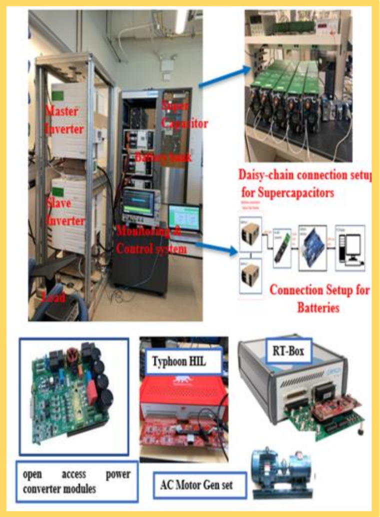
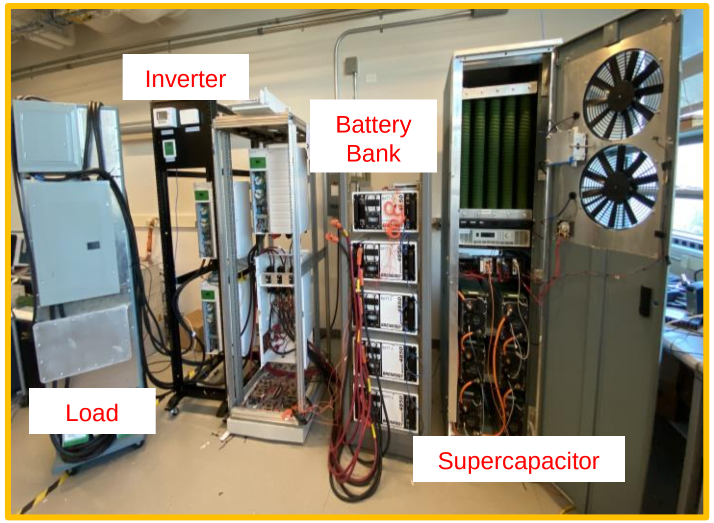
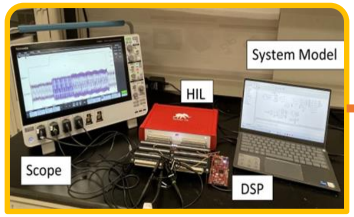
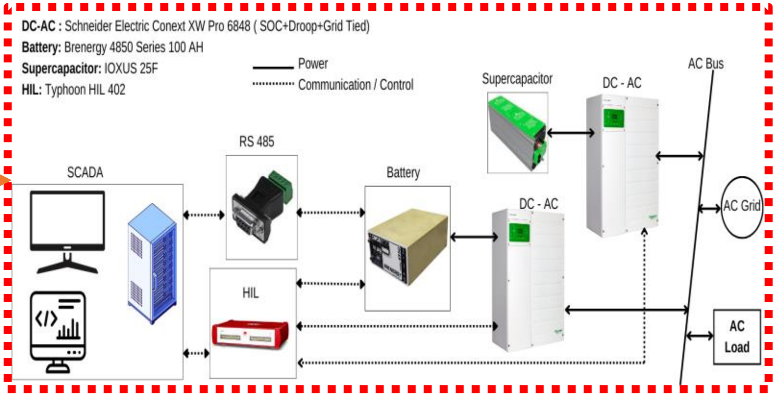
# Microgrid CHIL Platform with Hybrid Energy Storages




- ➢ Impact of different transients at load bus and PCC are examined at the Microgrid setup.
- ➢ Modes of transients:
- ❖ Nature of load ( Resistive, Inductive)
- ❖ Turning off and on of the loads /inverters.
- ❖ Change in mode of operations

- ➢ Different transients cause **voltage drop and flickers** which can reduce the **power quality.**

- ❖ **Findings: Proper design of controller and custom power devices can mitigate these challenges.**

- ➢ Hybrid: Unified Power Quality Controller (UPQC)

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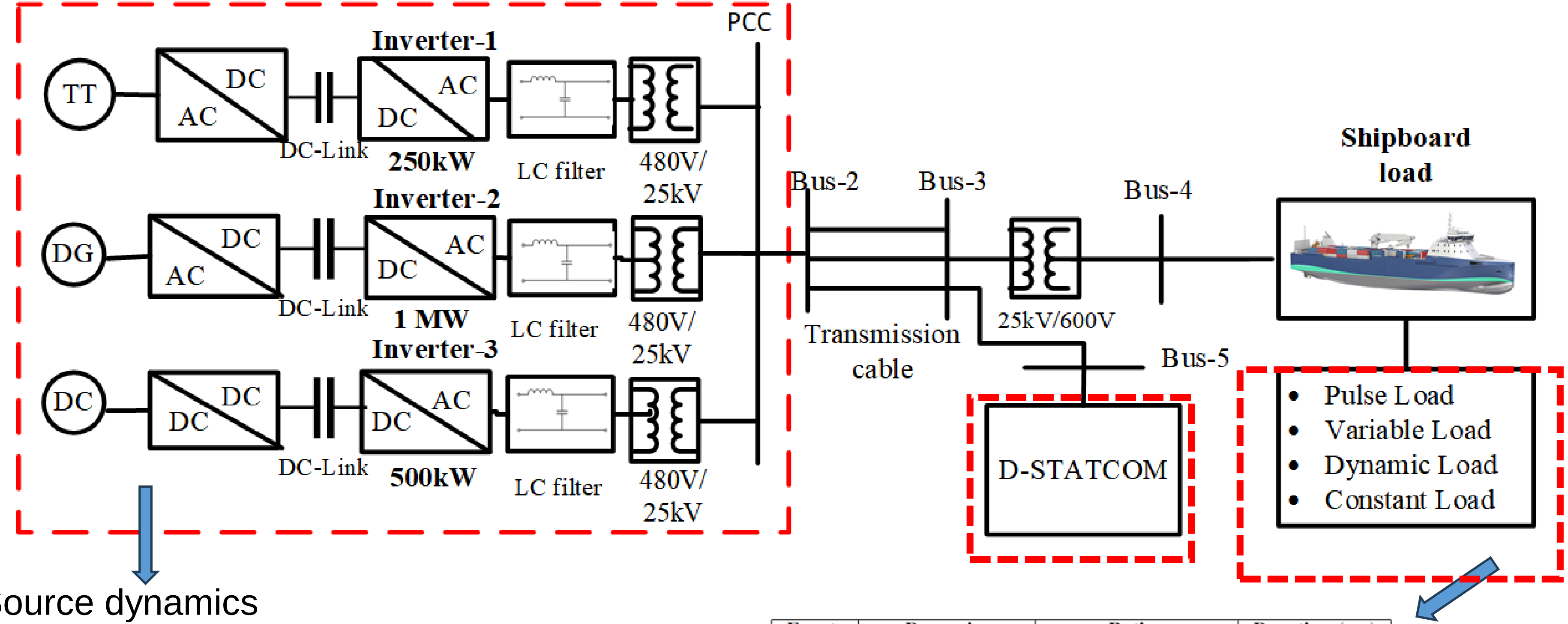
# Modeling of Multi-Energy System

**MATLAB/Simulink-based model of tidal energy integrated seaport microgrid (TESM)**




Source dynamics

Load dynamics

**TESM is developed to understand:**

- Source and Load Dynamics Impact.
- Co-Existence of Different Loads
- DSTATCOM Role in Voltage Regulation & Power Quality Improvement

| Events | Dynamics | Rating | Duration (sec) |
|---|---|---|---|
| 1 | Constant Z Load | P=100 kW | $t_{on}$=0 |
| 2 | Variable load (Constant current) | Nominal load=300 A Modulation : Amp=200 A, f=5 Hz | $t_{on}$=0.05 $t_{off}$=0.8 |
| 3 | Pulse Load | P=500 kW Q=400 kW | $t_{on}$=0.9 $t_{off}$=1.2 |
| 4 | Dynamic Load | P=50 kW Q=50 kW | $t_{on}$=1 |
| 5 | Tidal speed variation | 3 m/s - 1.5 m/s | t=1.5-1.8 |
| 6 | Fault | LLLG & LG | t=2.2-2.4 |


D. Singh, A. Wasay, K. Choksi and F. Luo, "Modeling and Performance Enhancement of Tidal Energy Based Seaport Microgrid for Shipboard Loads Using DSTATCOM," *2023 IEEE Electric Ship Technologies Symposium (ESTS)*, Alexandria, VA, USA, 2023, pp. 469-476, doi: 10.1109/ESTS56571.2023.10220504.

# CONTROL ARCHITECTURE

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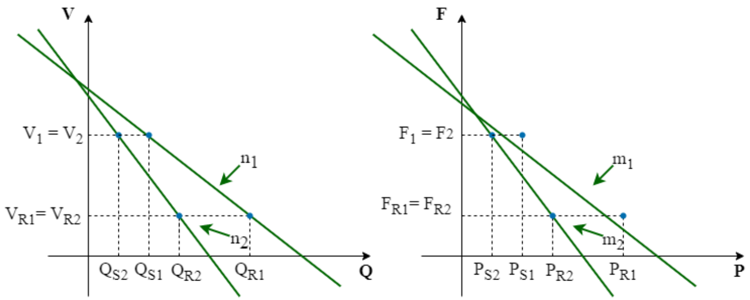
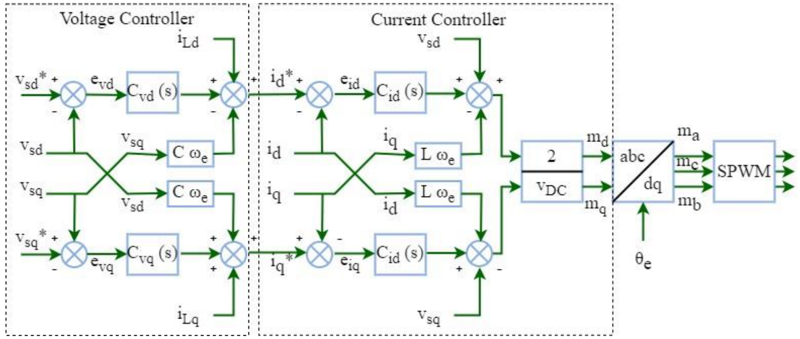
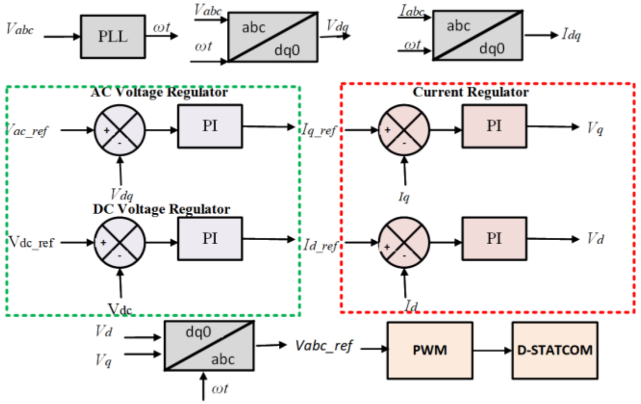
## Parallel connected Inverters control



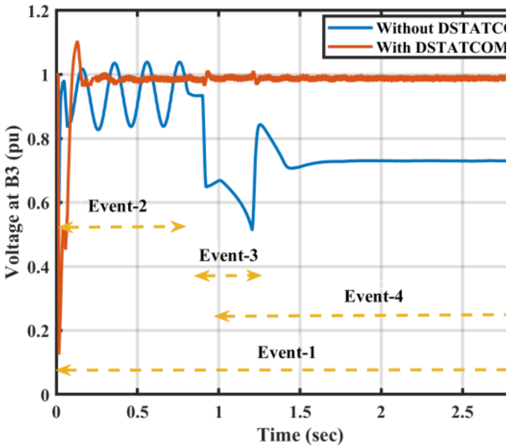

- Droop control mimics the operation of synchronous generators.
- The droop controller uses voltage and current dual-loops.

## DSTATCOM control

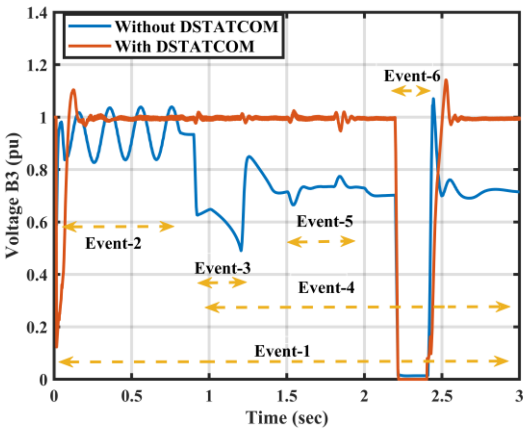



| Events | Dynamics | Duration (sec) |
|---|---|---|
| 1 | Constant Z Load | *ton*=0 |
| 2 | Variable load | *ton*=0.05, *toff* =0.8 |
| 3 | Pulse Load | *ton*=0.9, *toff* =1.2 |
| 4 | Dynamic Load | *ton*=1 |

- Pulse load causes a momentarily sag.
- Decays the overall voltage profile.

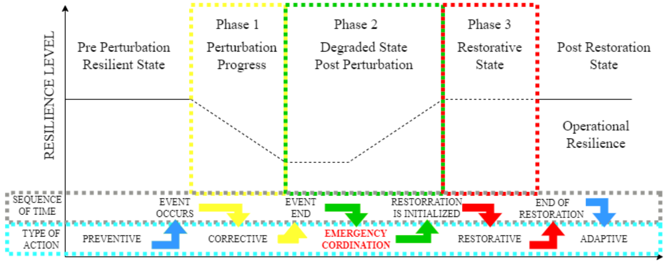



Voltage at Bus-3




Voltage at Bus-3 symmetrical fault.

| Events | Dynamics | Duration (sec) |
|---|---|---|
| 6 | Fault | t=2.2-2.4 |




Operational resiliency curve.

- **DSTATCOM** enhances **microgrid dynamic stability and resilience** with rapid response and flexible control.

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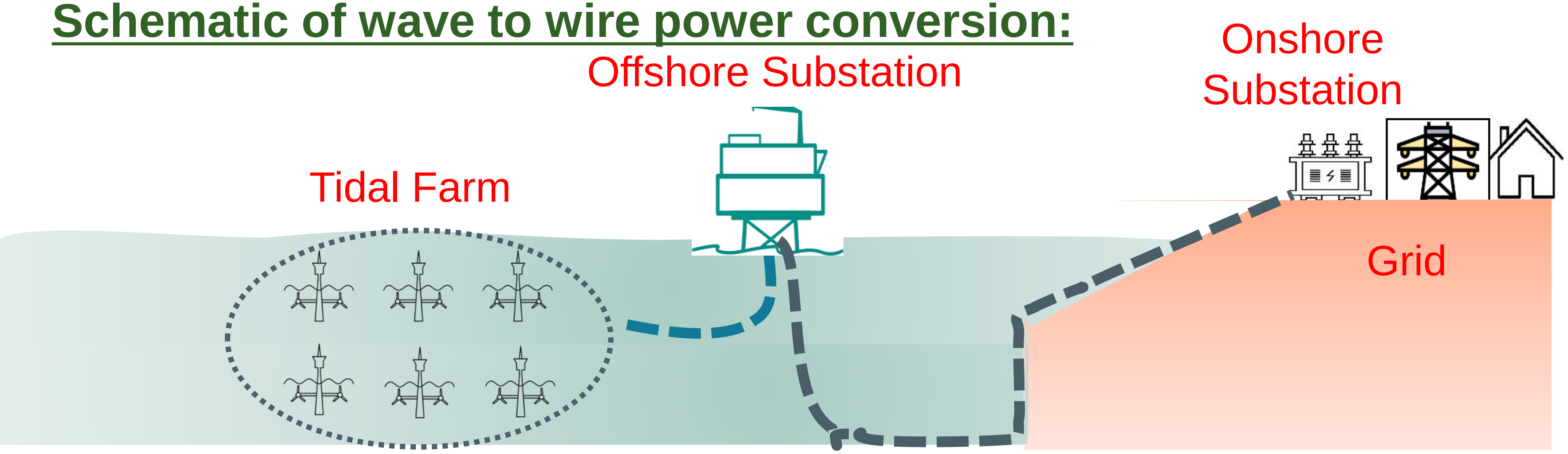
# AMEC: Architectural comparison and selection

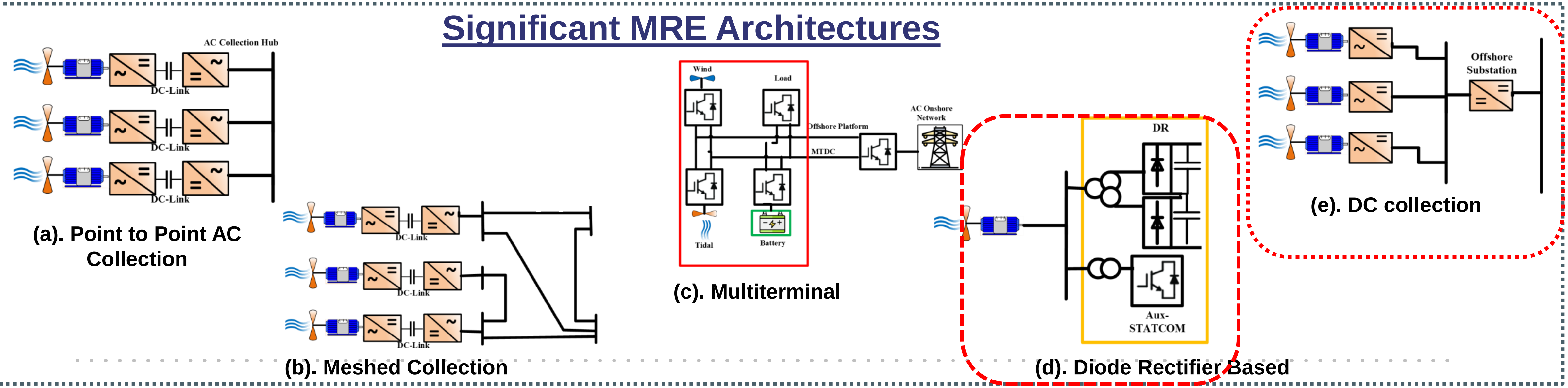
## Schematic of wave to wire power conversion:




Choice of Architecture depends on:

- Size of farm
- Distance from the shore

## Significant MRE Architectures

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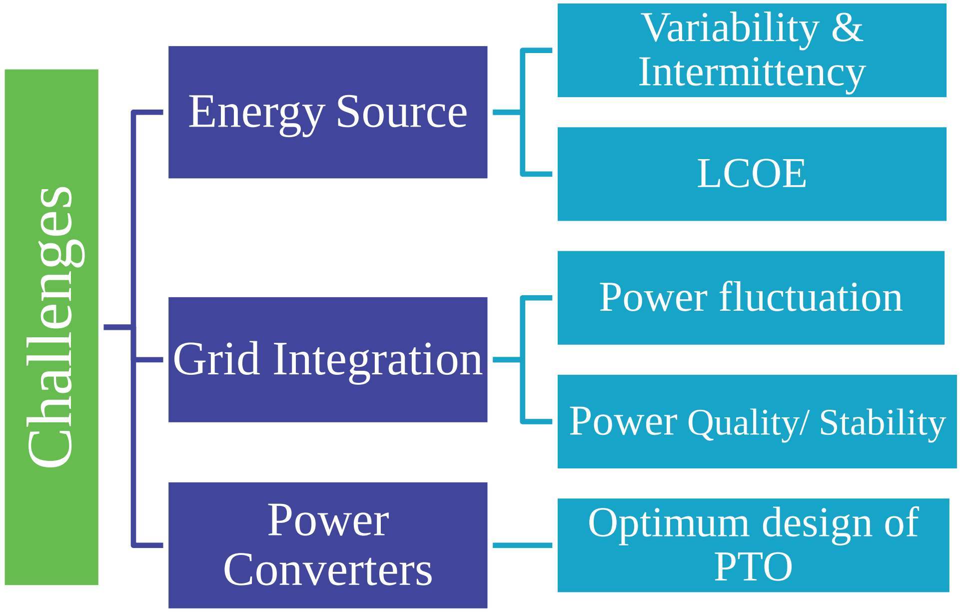
# Challenges and Solution for Harnessing Tidal Energy

## Challenges in Harnessing Tidal Energy




### Performance Enhancement

- Enhancing Tidal Energy
- Competitiveness & Sustainability

- Improve efficiency through:
  - Innovative technologies
  - Optimal Power Conversion Architectures.
  - Control systems.

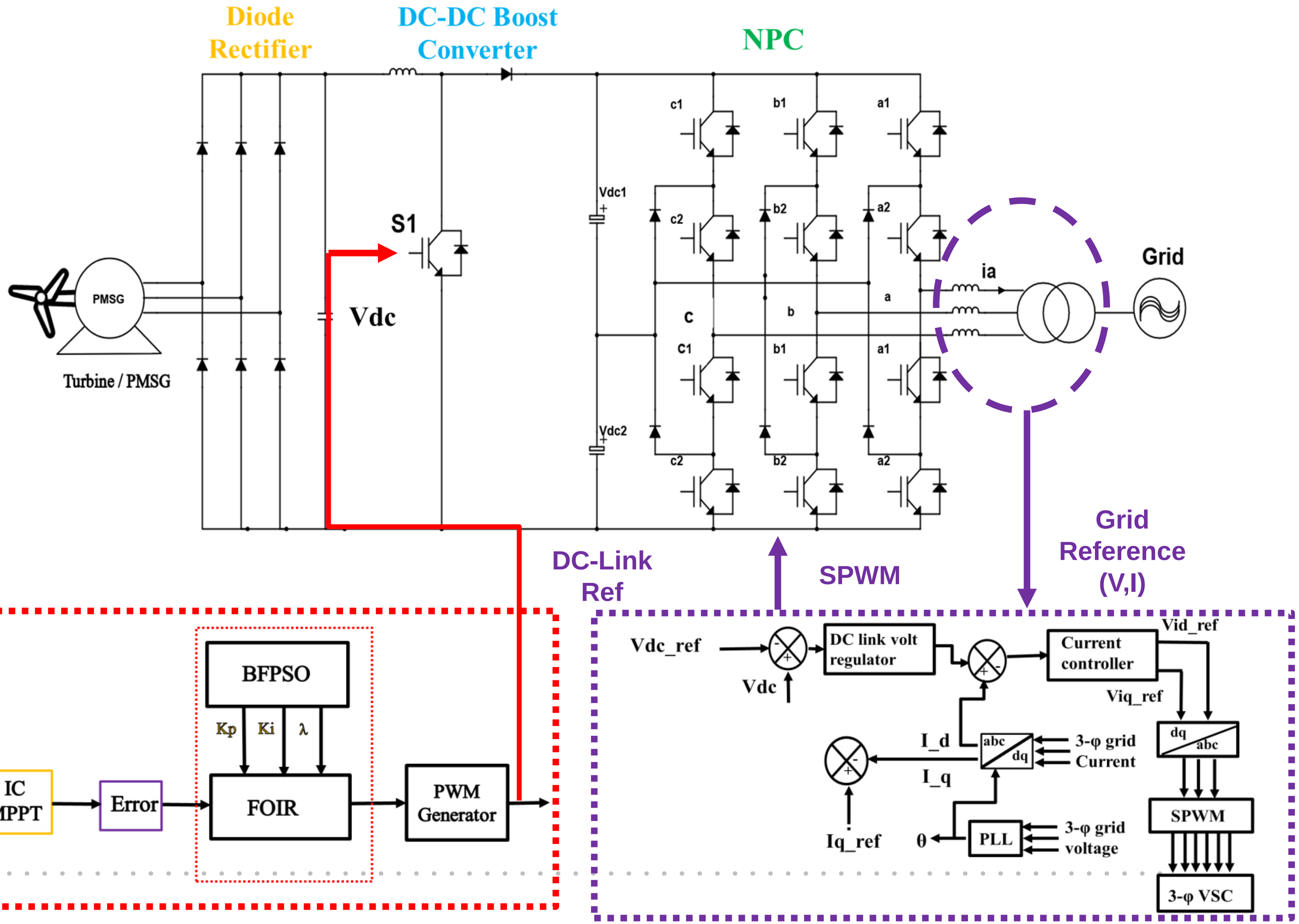
- Power Electronics
- Optimum Placement
- Efficient Architectures
- Maximum Power Point Tracking (MPPT)

# Modeling the Tidal Energy System

| Parameter | Value |
|---|---|
| Rated Power | 100 kW |
| Rotor Radius | 4 m |
| Water Density | 1024 Kg/m³ |
| Rated Tidal Speed | 2.5 m/s |

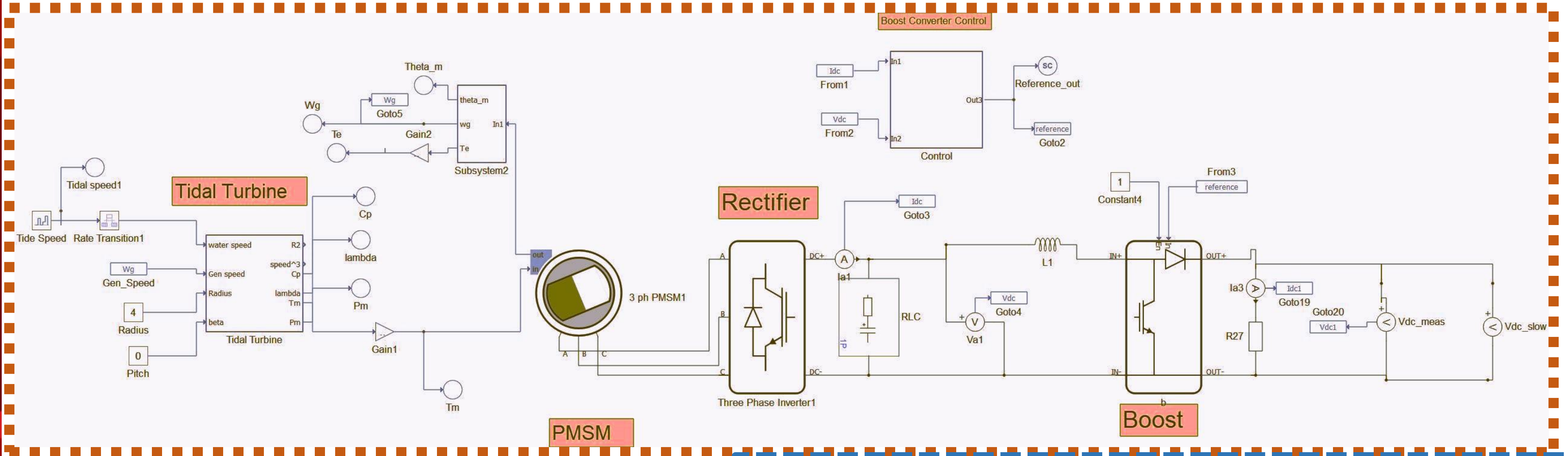
| PMSG | |
|---|---|
| Stator R | 0.09 Ω |
| Stator Ld | 6.03 mH |
| Stator Lq | 1.2 V.s |
| Flux Linkage | 10 kHz |
| fswitching | 1200 V |

| Grid Control | |
|---|---|
| FOPI Controller | Kp=5, Ki=1, λ=0.5 |
| Current Control | Kp=0.5, Ki=10 |
| Voltage Control | Kp=20, Ki=700 |

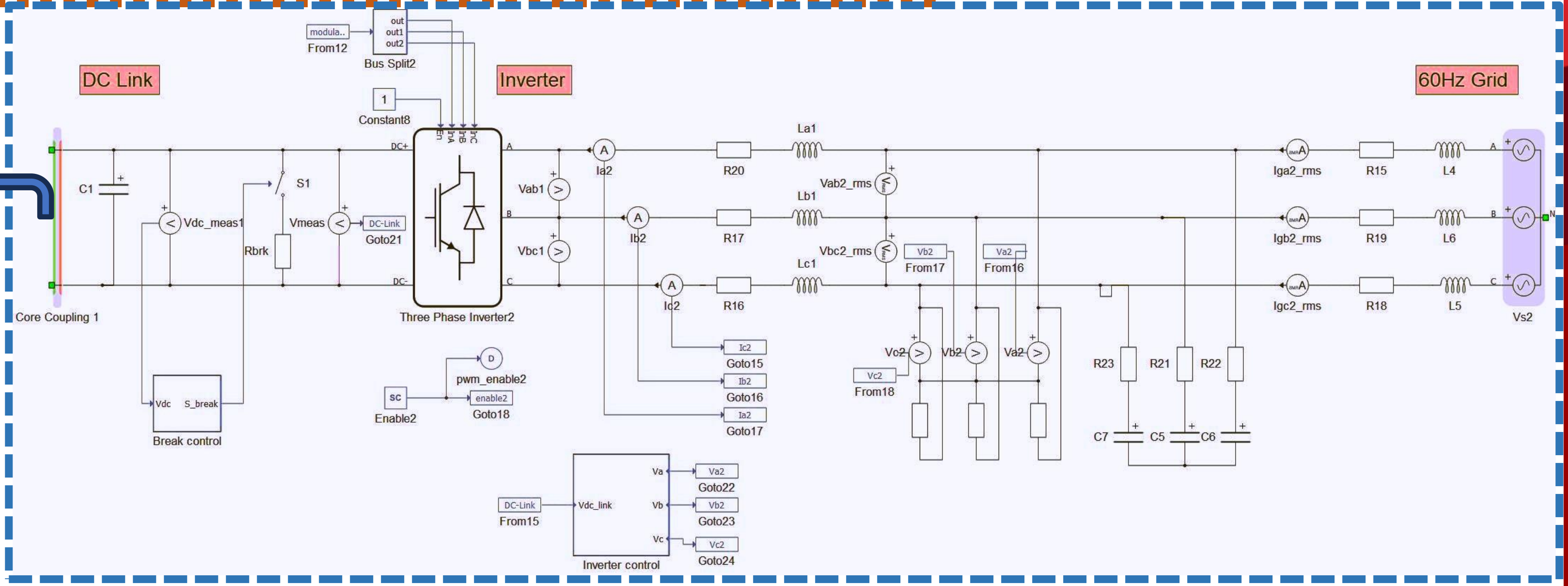



D. Singh, A. Zhou, A. Muneeb, A. B. Mirza and F. Luo, "Modeling and Performance Enhancement of Grid Tied Tidal Energy System with Fractional Order Integral Based Incremental Conductance," 2023 IEEE Energy Conversion Congress and Exposition (ECCE), Nashville, TN, USA, 2023, pp. 685-691, doi: 10.1109/ECCE53617.2023.10362730.

# Modeling and Control of Grid Tied Tidal Energy System




**FOMCON:**MATLAB toolbox is used to design Fractional controller.




**Circuit Partitioning**

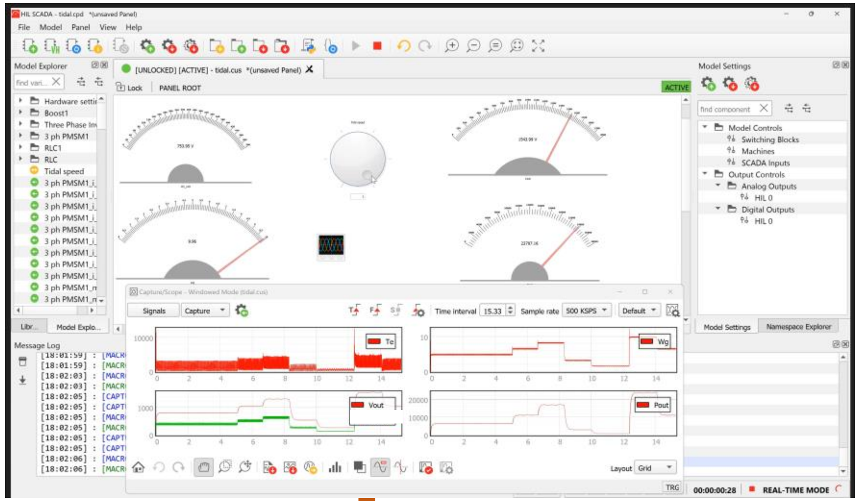
**Reason:** Too many Converter

**Solution:** Core Coupling Components

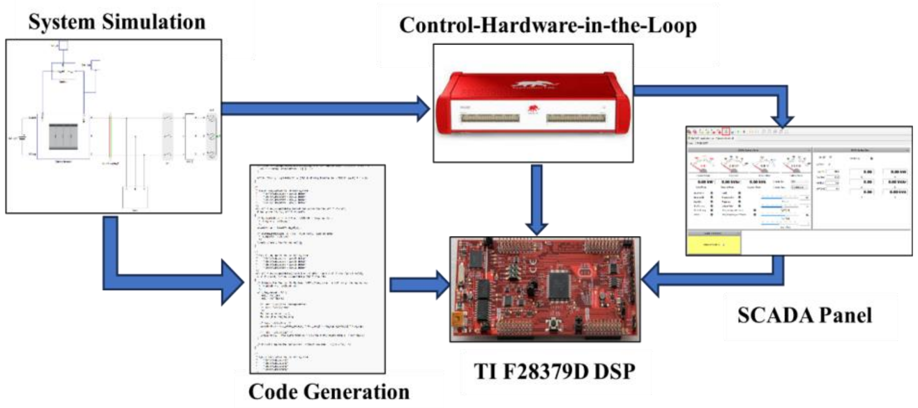
- ➢ Divide the circuit into sub-circuits.
- ➢ Each simulated on separate cores.

# Controller Hardware-in-the-Loop (CHIL)

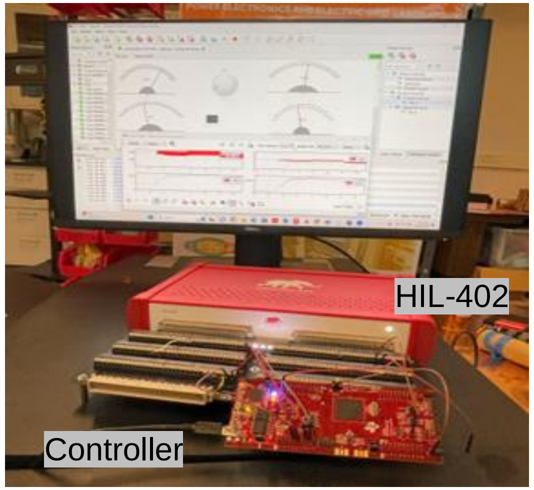
## Testing Methodologies



## Flow Diagram for Real-Time Testing




## CHIL Platform




**User-Friendly Interface:** Create custom real-time interfaces.

- ❖ **Control & Observe:** Manage HIL simulations and external devices. **Real time validation of developed control algorithms for tidal energy conversion system(TECS).**
- ✓ Validation of developed MPPT and output voltage control algorithms for TECS on C-HIL testbed.
- ✓ The output voltage control algorithm is implemented on the TIF28379D DSP controller.
- ✓ An UART communication channel is established for seamless communication between the Typhoon HIL control panel (SCADA) and the DSP.
- ✓ The system's response to varying tidal conditions (tidal speed is varied between 0.5-3 m/s) and load changes is evaluated to assess the performance of the control strategy.

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# Extension of Resiliency/ Power Quality analysis for TECS

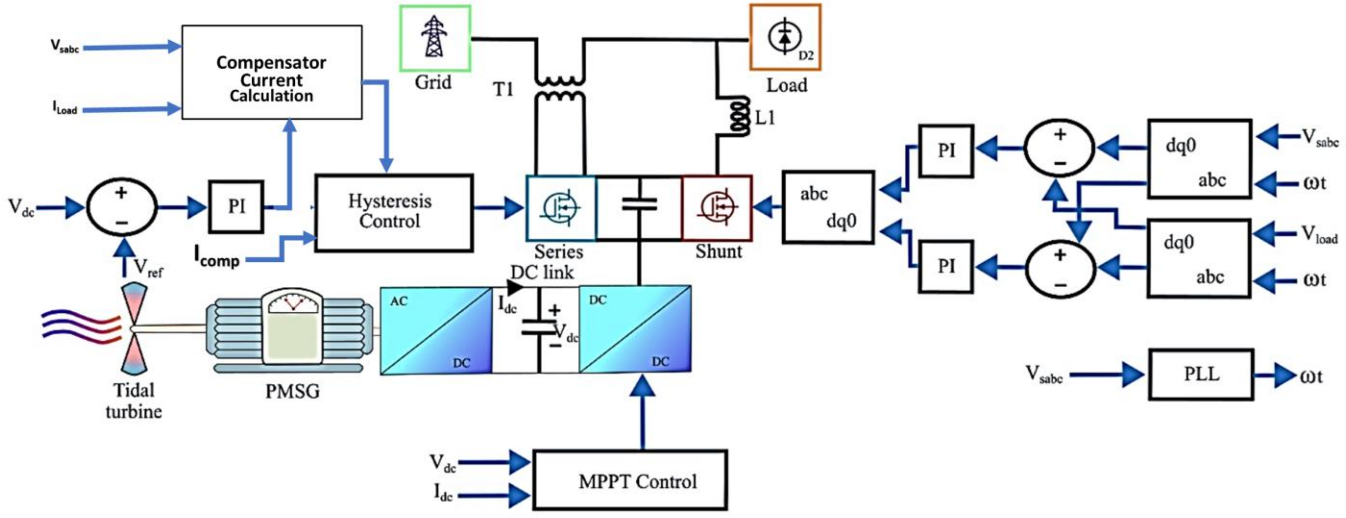
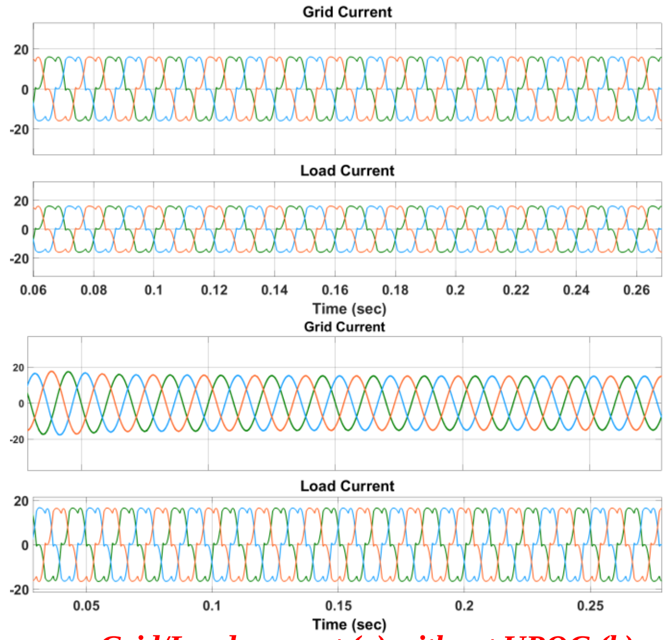



**Fig. 1. Power conversion architecture of PMSG based direct drive grid tied tidal energy with control.**

| PQ Issues | Duration |
|---|---|
| Voltage Sag | t= 1-1.2 sec |
| Voltage Swell | t= 1.4-1.6 sec |
| Current Harmonics | t= 0.15-0.3 sec |
| Interruption | t= 0.5-0.7 sec |
| Source Variation | t= 0-0.5 sec |




*Grid/Load current (a) without UPQC (b) with UPQC*

## Custom Power Devices analyzed

- ➢ D-STATCOM (Shunt)
- ➢ DVR (Series)
- ➢ UPQC (Hybrid)

**Conclusion:** UPQC is emerging as an attractive solution

➢Due to its flexibility and ability to provide comprehensive PQ mitigation.

➢ It can deal with both voltage and current quality concerns simultaneously.

**Assessing and Mitigating Power Quality Issues in Tidal Energy Integrated Distributed Networks: A Comparative Analysis of Custom Power Devices, UMERC 2023.**

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# HVDC Offshore Wind (OSW) Energy Integration

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**Technical** → **Research Tasks**

- **Comparative Study: OSW HVDC Architectures**
  - **Understanding constraints on selection of**
    1. Power topology
    2. Connection architecture
    3. Modeling constraints
    4. Control Strategy
- **Extended Bandwidth Model**
  - **Understanding type of modeling requirements**
    1. Average Model
    2. Detailed Model
    3. Phasor Model
    4. Aggregate Model
- **Benchmarking in Software and HIL Platforms**
  - Developing standard **hardware-in-loop setup** for facilitating analysis of OSW dynamics and intermittency
- **Cross-Platform Networked Simulation**
  - Analyzing **multi-physics impacts of OSW intermittency** on a multi-microgrid or a grid integrated system

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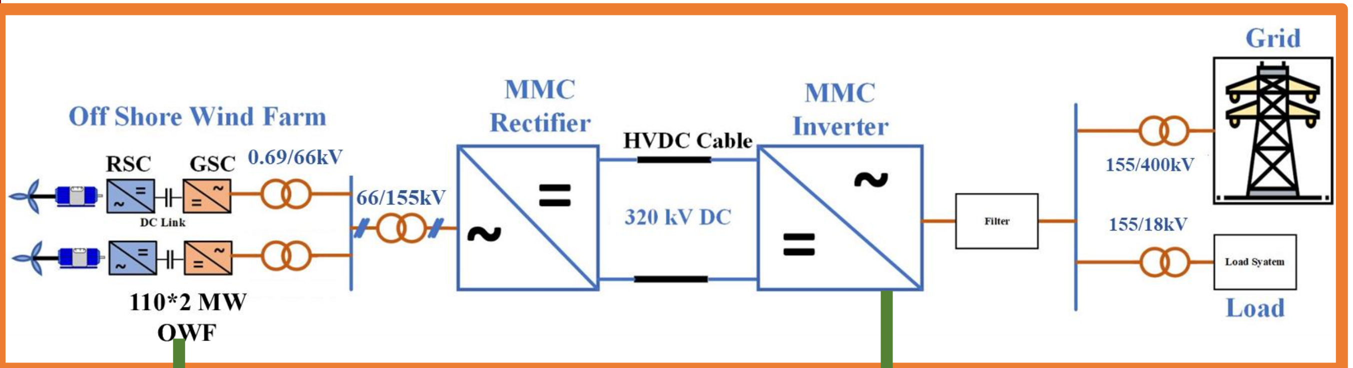
# Challenges of OSW Farms Integration

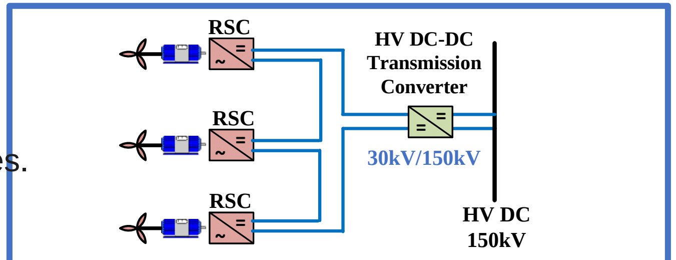



Connection and transmission grid architectures and their challenges

MMC converter and different FRT/LVRT enhancement control techniques

The series architecture has two challenges.

- Insulation
- Reliability of the large system .




(b) Centralized Single Stage Series Connected DC System

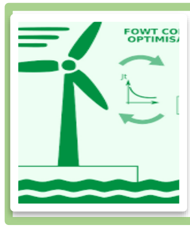
**Explore the economic feasibility and implementation of new technologies for large OWF integration:**

All-DC, DR-HVDC

**Assess power electronics' influence on AC grid stability thoroughly:**

1.Future developments: MMC integration, and improved system stability.

2.Investigate AC grid stability, frequency control, and voltage performance.



**Novel modeling techniques to precisely represent power electronics' fast dynamics with lower computational costs than EMT.**

**Real-Time Simulation platform to investigate system dynamics under variable conditions**

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# Modeling Approach

**The choice of modeling approach depends on:**

1. The analysis goals
2. System complexity
3. Available computational resources

**Detailed modeling is suitable for:**

1. Accurate analysis
2. Optimization of specific converter topologies.

**Average modeling is used for:**

1. Initial design exploration
2. Control system design.

**Aggregate modeling is preferred for:**

1. System-level studies
2. Transient analysis involving multiple converters.

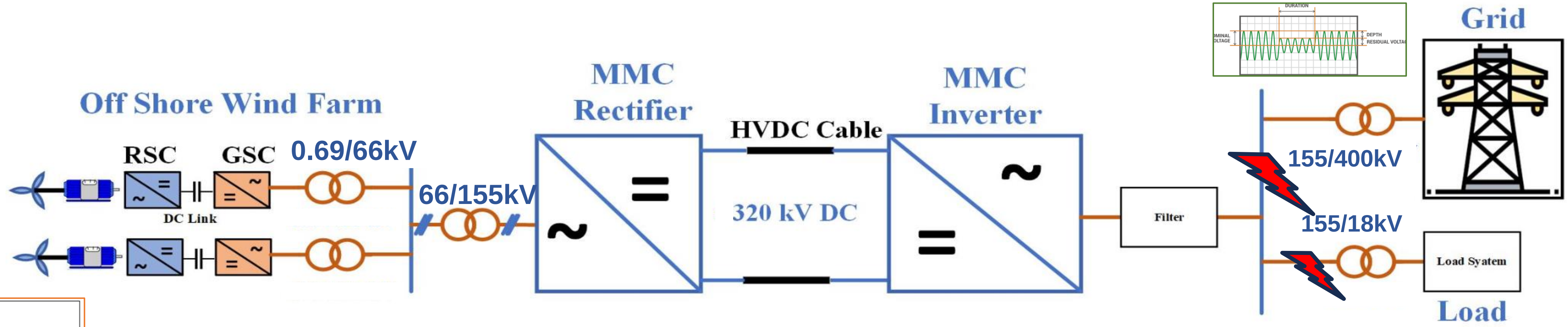
**Phasor modeling is employed in:**

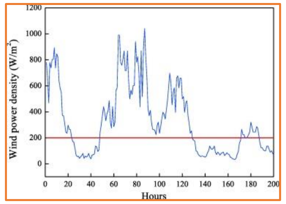
1. Steady-state power flow analysis
2. Real-time monitoring
3. Stability assessment in large power systems.

**Co-Simulation/Hybrid:**

1. Comprehensive analysis
2. Optimized resource usage

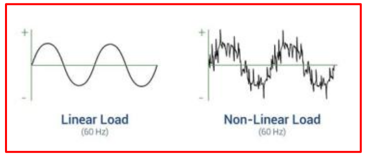
# HVDC –MMC System Benchmarking




**110*2 MW OWF**

Fig.1 Off-shore Permanent Magnet Synchronous Generator (PMSG) wind farm with HVDC-MMC.




| Parameter | Name | Value |
|---|---|---|
| R_rotor | Rotor radius | 42 m |
| lambda_opt | Optimal tip-speed ratio | 7.1 |
| Vspeed_nom | Nominal wind speed | 11 m/s |
| U_rated | Phase-to-phase rated voltage | 690 V |
| P_rated | Rated active power | 2 MW |
| f_switching | PWM carrier-freq. | 2000 Hz |
| Vdc_ref | Reference voltage value | 1250 V |
| N | No. of Wind Turbine | 110 |

| Parameter | Value |
|---|---|
| Rated DC Voltage (Vdc_nom) | 320 kV |
| **Submodule Parameters** | |
| Number of Submodules per Arm (Rectifier) | 118 |
| Number of Submodules per Arm (Inverter) | 118 |
| Submodule Capacitor Capacitance (C_pm) | 10.48e-3 |
| Arm Resistance (R_arm) | 0.03 |
| Arm Inductance in Per-unit (L_arm_pu) | 0.15 |

| Parameter | Value |
|---|---|
| Grid Frequency (F_grid) | 60 Hz |
| Grid Voltage (V_grid) | 400 kV |
| **Load Parameters** | |
| Nominal Power of Converters (P_nom) | 220 MW |
| Nominal Apparent Power (S_nom) | 220 MVA |
| Load Active Power Nominal (P_load) | 200 MW |
| Load Reactive Power Nominal (Q_load) | 0 MW |
| Non-ideal Load Active Power (P_DynLoad) | 200 MW |
| Non-ideal Load Reactive Power (Q_DynLoad) | 150 MW |

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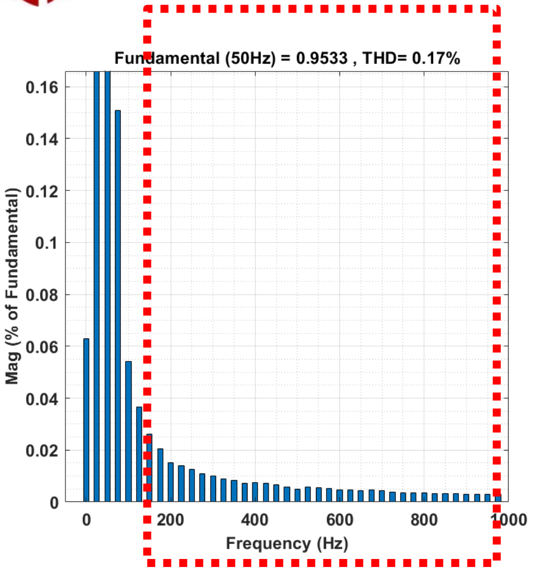
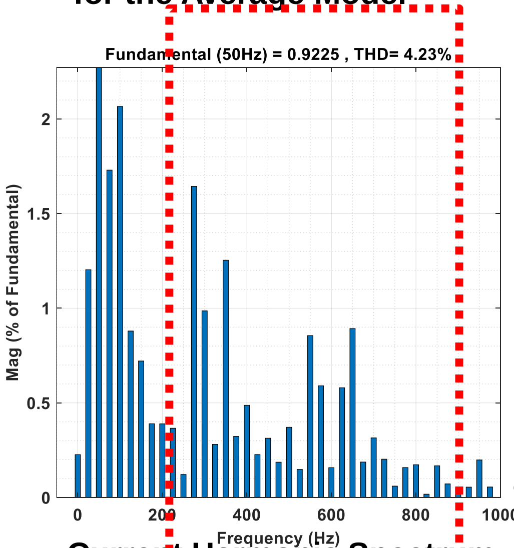
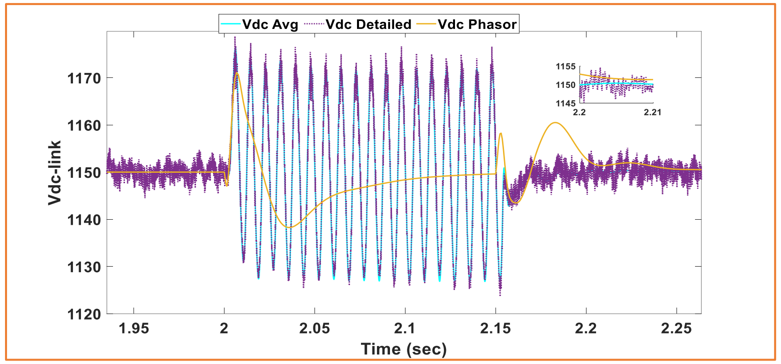
# HVDC System Benchmarking to Compare Modeling Techniques

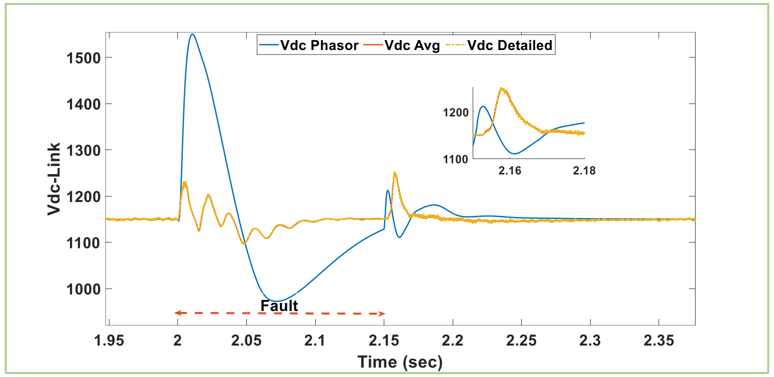



Current Harmonic Spectrum for the Average Model

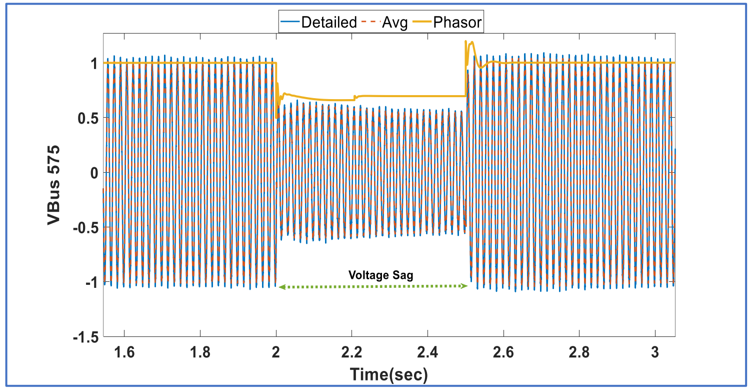


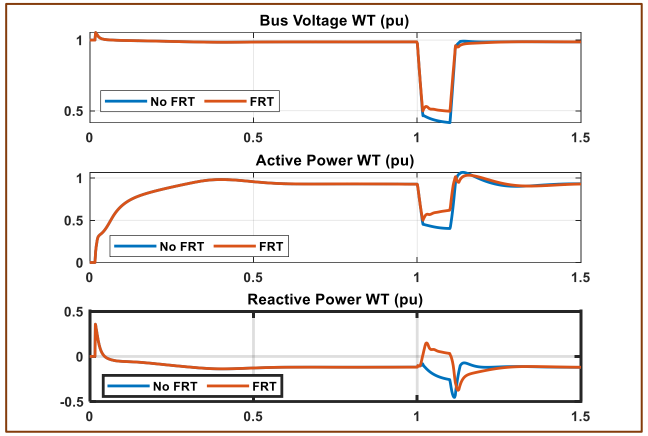

Current Harmonic Spectrum for the Detailed Model




DC-Link Voltage Under faults (a) Unsymmetrical (b) Symmetrical




Simulation Results under Voltage Sag

- Detailed Model: Simulated a 126*1.5 MW wind farm for 0.2 seconds over approximately 3 hours.
- Aggregate Model: Simulated a 126*1.5 MW wind farm for 0.2 seconds over approximately 4.05 minutes.
- Co-simulation/Hybrid Model: Simulated a 126*1.5 MW wind farm for 0.2 seconds over approximately 2.86 minutes.



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# Digital Twin: Real Time Condition Monitoring

$$\textbf{minimize}: \left(f_{obj}\right) \quad f_{obj} = \alpha f_{obj2} + ß f_{obj2}$$

$(L, C, RDSON, Rc, RL)$

$$f_{obj1} = \sum_{k=1}^{n} \left(i_{L,M}{}^{k} - i_{L,A}{}^{k}\right)^2 \qquad f_{obj2} = \sum_{k=1}^{n} \left(V_{C,M}{}^{k} - V_{C,A}{}^{k}\right)^2$$

$$\textbf{variables}: \quad V_{C,M} = f(L, C, RDSON, Rc, RL)$$

$$i_{L,M} = f(L, C, RDSON, Rc, RL)$$

- $V_{C,M}$: Computed
- $i_{L,M}$: Sensor Data
- $V'_{C,A}$: Computed
- $i'_{L,A}$: Sensor Data

**subject to**:

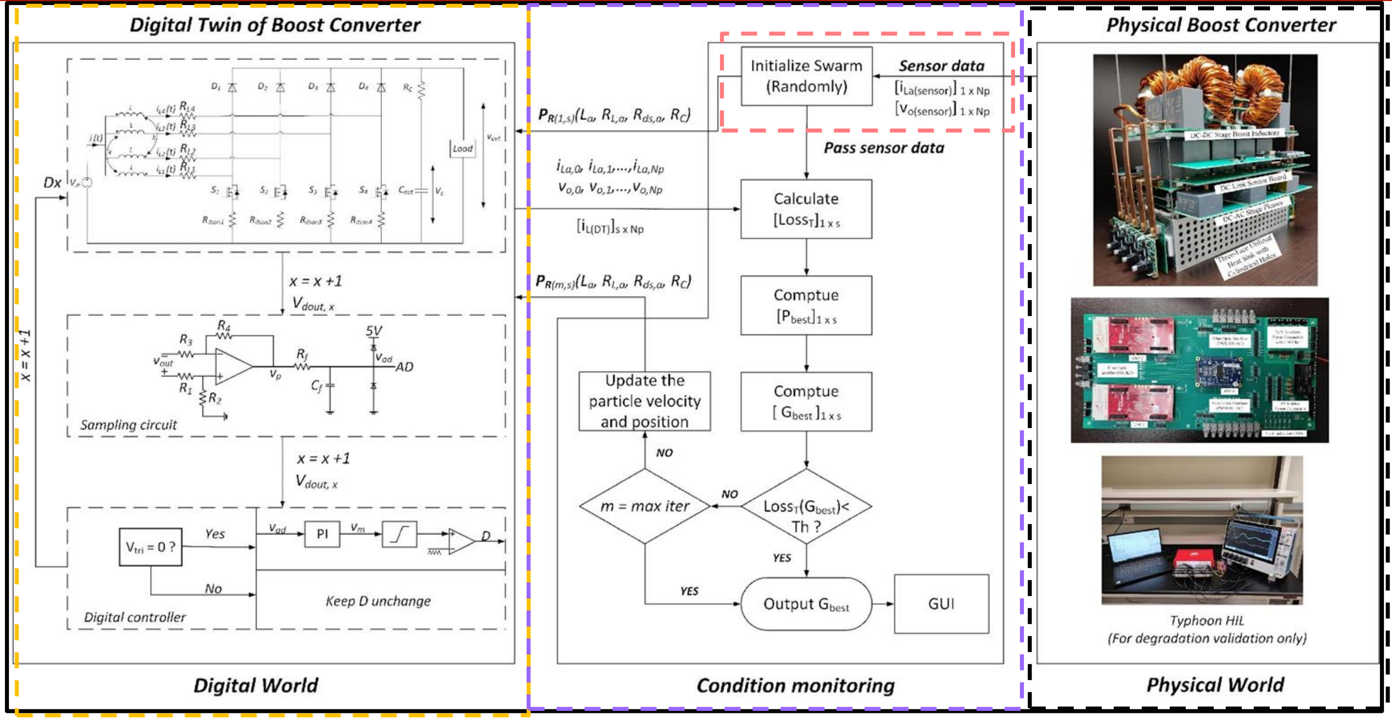
$$L_{min} < L \leq Lmax$$

$$C_{min} < C \leq Cmax$$

$$R_{DSON,min} < R_{DSON} \leq R_{DSON,max}$$

$$R_{L,min} < R_L \leq R_{L,max}$$

$$R_{c,min} < R_c \leq R_{c,max}$$




**Health and Fault Monitoring validation at 75kW Boost Converter**

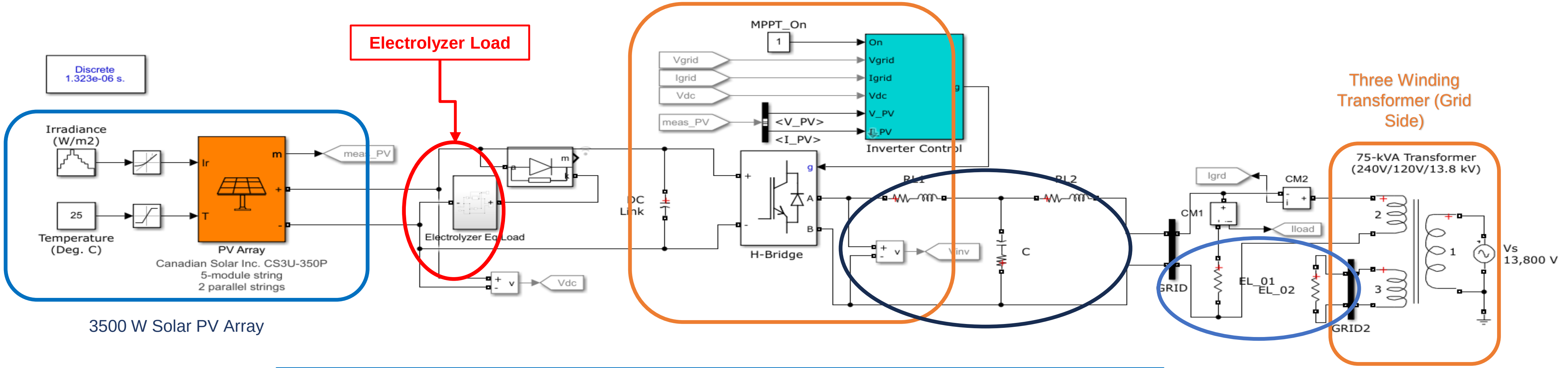
- **Metaheuristic approach for boost converter condition monitoring**
- **Experimental validation on 75 kW Boost Converter**
- **Robustness observed under varied components using a HIL platform**
- **Estimation accuracy up to 95.3% for C and as low as 71.2% for RON with 15% component variation**
- Two solutions proposed for improving RON estimation: averaged and decoupling approaches
- Hybrid condition monitoring solutions proposed to reduce time complexity at the expense of accuracy

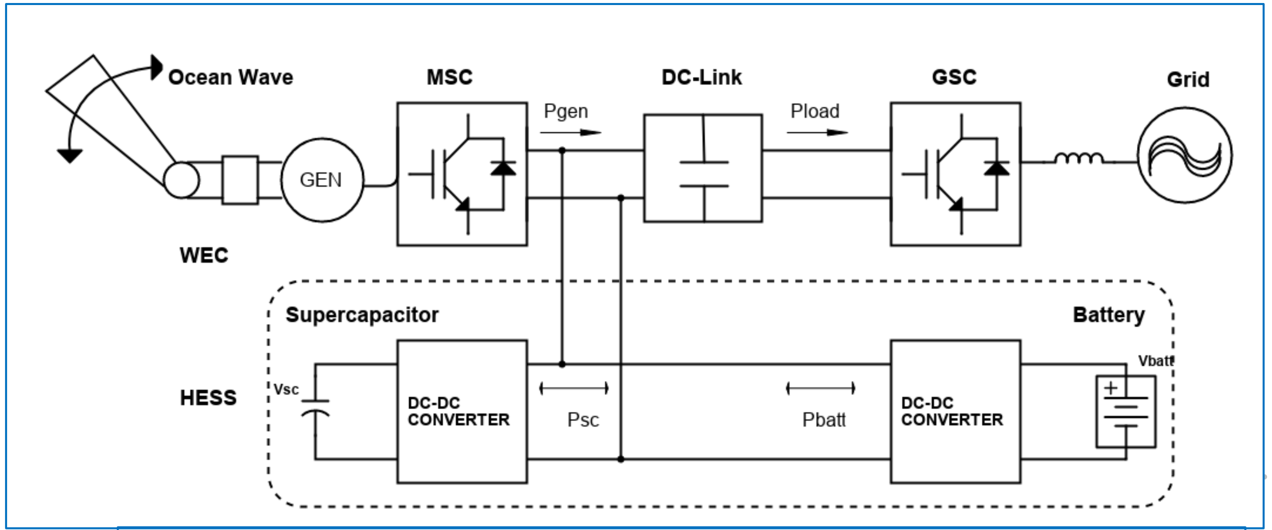

K. Choksi, A. B. Mirza, A. Zhou, D. Singh, M. Hijikata and F. Luo, "Self-Evolving Digital Twin-Based Online Health Monitoring of Multiphase Boost Converters," in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 16100-16117, Dec. 2023, doi: 10.1109/TPEL.2023.3311710

Stony Brook University

# Hybrid Energy Storage System

## Simulink Model of 1-Phase Grid Connected Solar PV




Marine renewable energy converter with HESS

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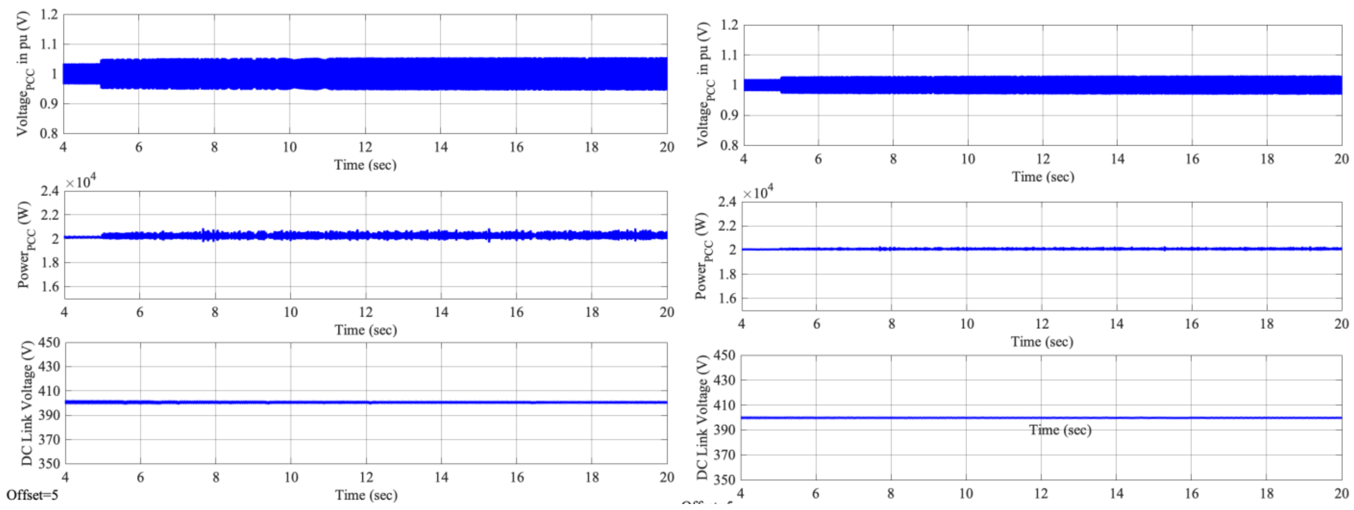
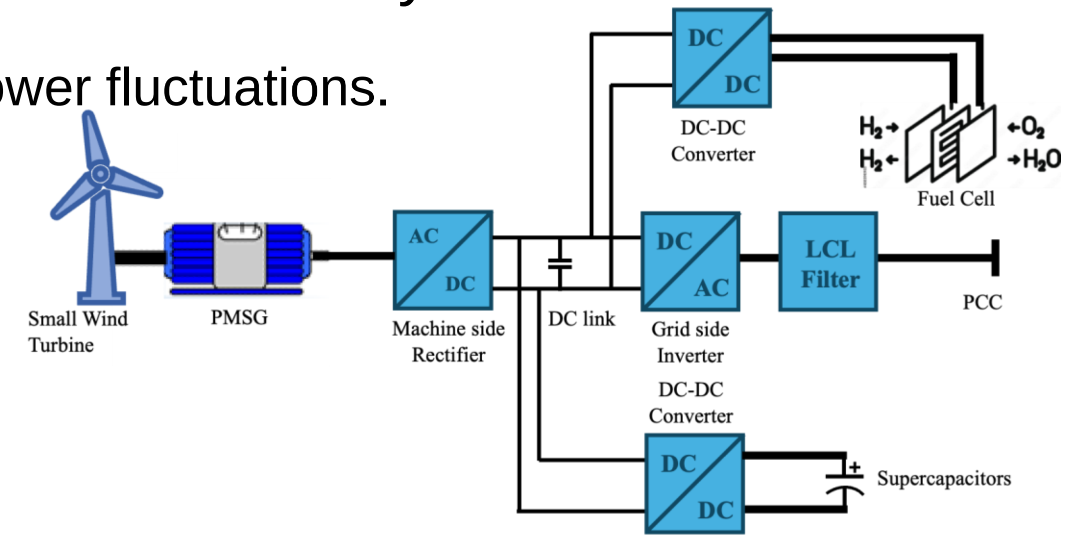
# HFC and Supercapacitor Combination

- Integrating supercapacitors with HFCs addresses the slow dynamics issue.
  - The hybrid system effectively mitigates voltage and power fluctuations.
  - It performs comparably to using a battery.




a) b)

**Wind Turbine Output With HFC with (a) Single String (b) 10 Strings of Supercapacitor as Energy Storage System.**




**Schematic of the Test System.**

| Parameters | Values |
|---|---|
| Number of Supercapacitors in a String | 10 |
| Case 1: | 1 String of supercapacitors |
| Case 2: | 10 String of supercapacitors |

# Thank You!