U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Understanding the Role of Short-Term Energy Storage and Large Motor Loads for Active Power Controls by Wind Power

Project ID #M9

Vahan Gevorgian

NREL

FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

Technology Development	Market Acceleration & Deployment
Atmosphere to Electrons	Stakeholder Engagement, Workforce Development, and Human Use Considerations
Offshore Wind	Environmental Research
Distributed Wind	Grid Integration
Testing Infrastructure	Regulatory and Siting
Standards Support and International Engagement	
Advanced Components, Reliability, and Manufacturing	

Analysis and Modeling (cross-cutting)

Project Overview

M9: Understanding the Role of Short-Term Energy Storage and Large Motor Loads for Active Power Controls by Wind Power

Project Summary

- This project is aimed to develop and validate coordinated active power controls (APC) by wind generation, short-term energy storage, and large industrial motor drives for providing various types of ancillary services to the grid.

Project Objective & Impact

- It was demonstrated that the symbiosis of frequency responsive technologies can notably improve the frequency performance of power systems.
- Wind generation, energy storage, and pumping stations can provide a significant amount of synthetic frequency response to power systems. These technologies have been furnished with control loops that respond in proportion to the rate of change of frequency (ROCOF).
- These assets can reliably emulate the inertial response of synchronous machines to frequency events.

Project Attributes

Project Principal Investigator(s)
Vahan Gevorgian, NREL
DOE Lead
Charlton Clark
Project Partners/Subs
Rob Hovsapian, former INL Jesse Leonard, Clemson University Nick Miller, GE David Gao, University of Denver
Project Duration
April 2016 - April 2018

Project Roles

NREL

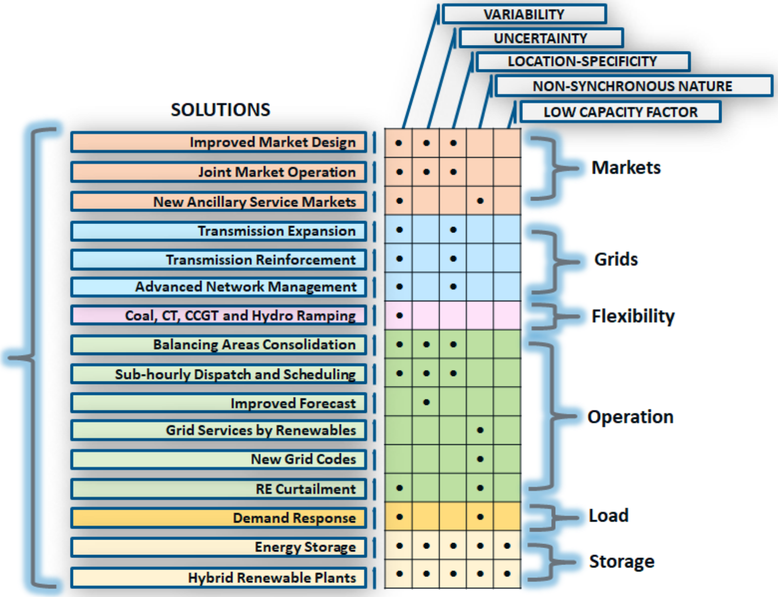
- Development of Power-hardware-in-the-loop (PHIL) system using NREL Controllable Grid Interface (CGI) for testing and demonstrating of active power controls (APC) by wind power
- Conduct testing and analysis to understand impacts of short-term energy storage and loads on enhancing the APC services by wind power

INL

- Development of Geographically Distributed Real-Time Simulations simulation (GD RTS) technique using remote link and lab assets
- Real-time co-simulations, integrated testing using NREL-INL link

Technical Merit and Relevance

- The ability of wind power to provide active power control services has been recognized as an important contributor to the grid in many studies. The coordination among the ancillary service providers (wind, PV, storage, etc.) within a balancing area is an important aspect of the investigation to ensure that the response will not be overly aggressive as to cause overshoot, nor too slow nor too small to make a significant impact in restoring to normal condition within an allowable time.

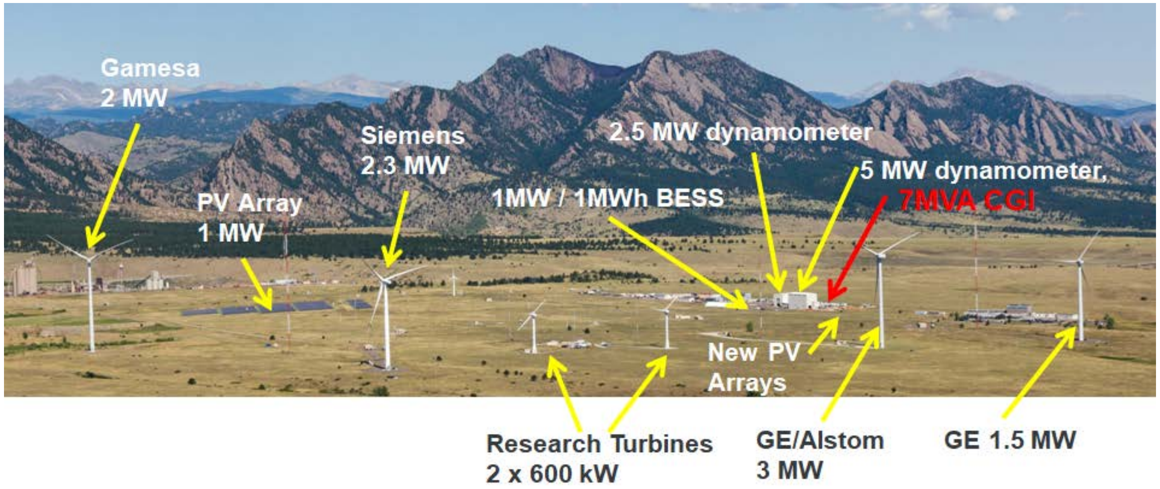


- NERC's Integration of Variable Generation Task Force recommendations on requirements for variable generation to provide their share of essential reliability services, including active power control (APC) capabilities

- The project focused on a broad problem of active power control by wind using enhancing technologies at NWTC that have been developed based on previous DOE investments.

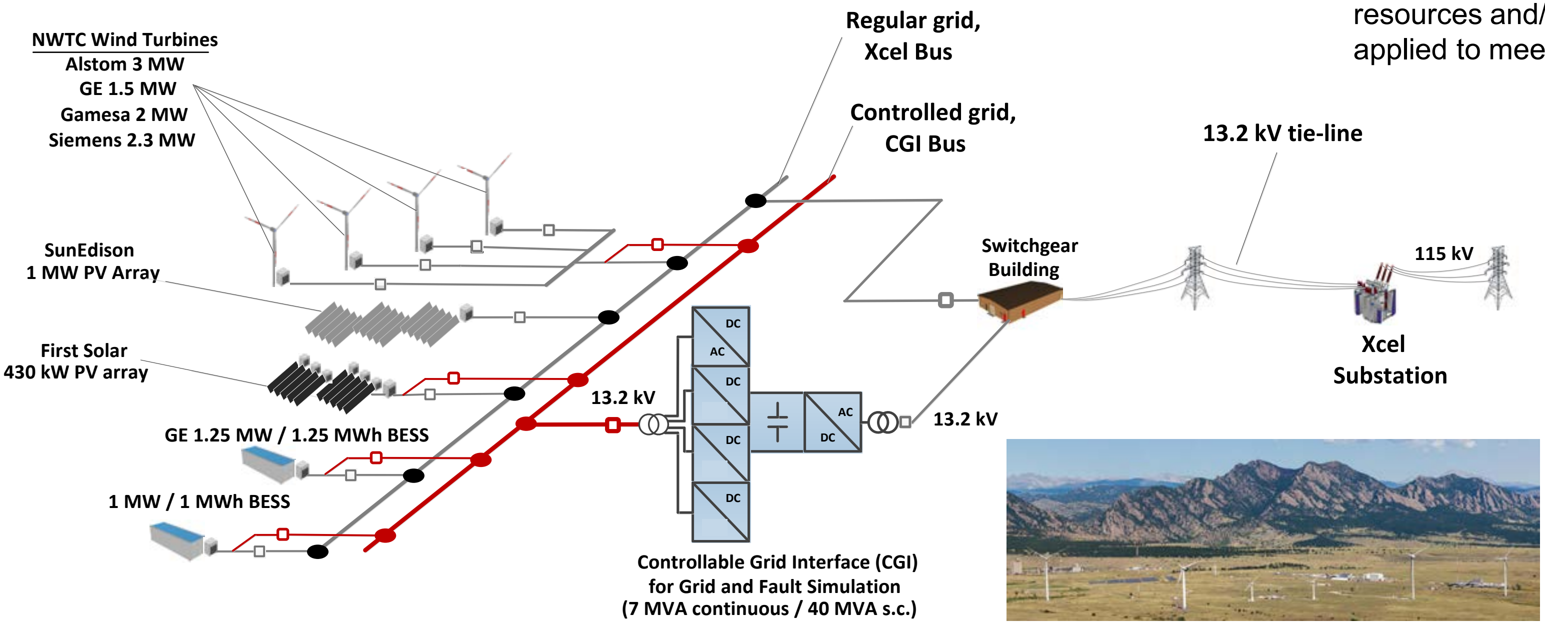
- This work uses state-of-the-art capabilities that have been developed at NREL during the past several years

Approach and Methodology



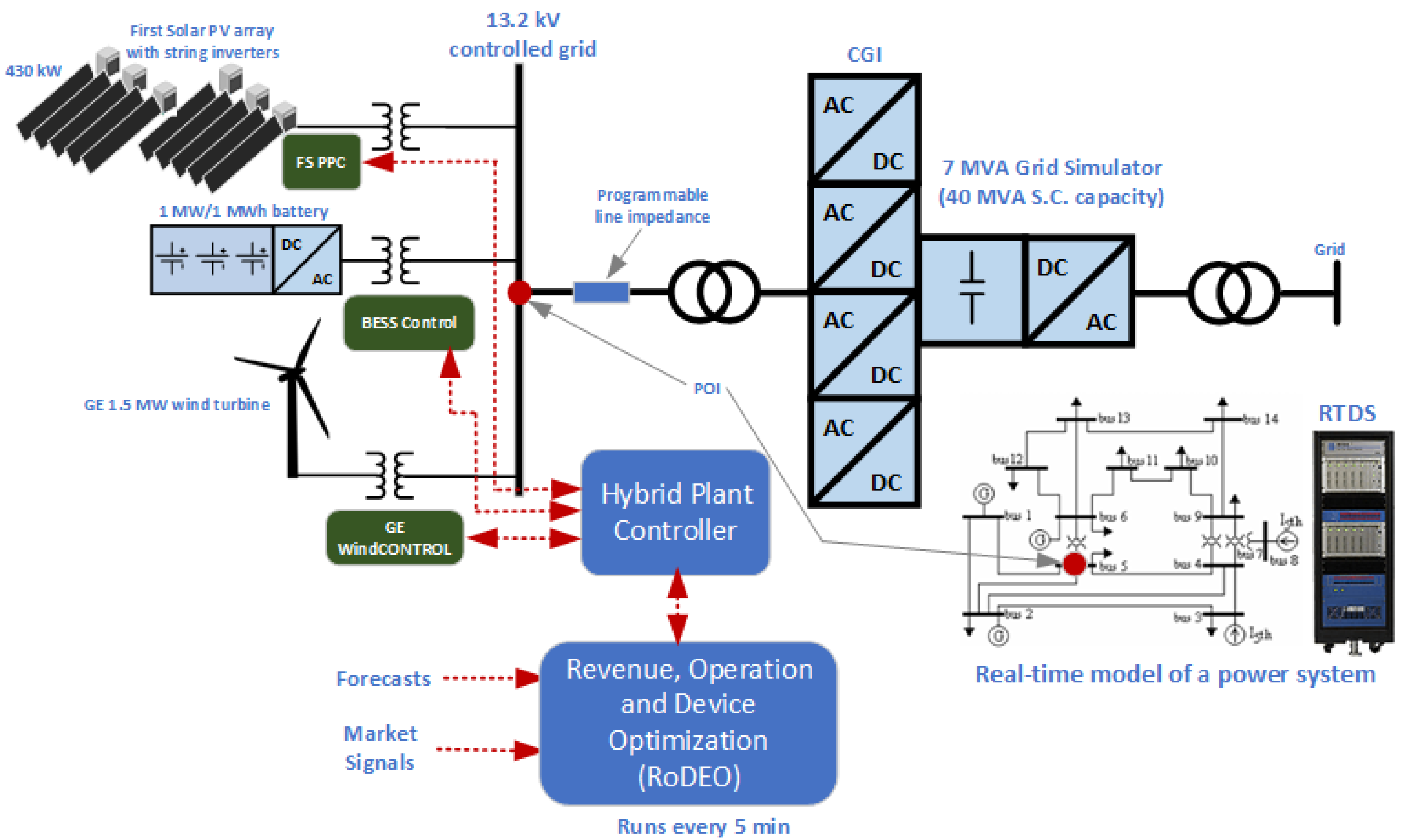
The project:

- Is based on a cohesive and realistic strategy including research plan, critical path items, risk mitigation, and timeline to achieving desired outcomes
- Is based on sound technical principles, with a credible pathway to technical success and/or meeting the other stated goals of the project
- Demonstrates a high degree of scientific rigor in research, testing and other key tasks
- Where feasible, includes collaboration with other commercial or research organizations to increase the available resources and/or knowledge base applied to meeting the project goals

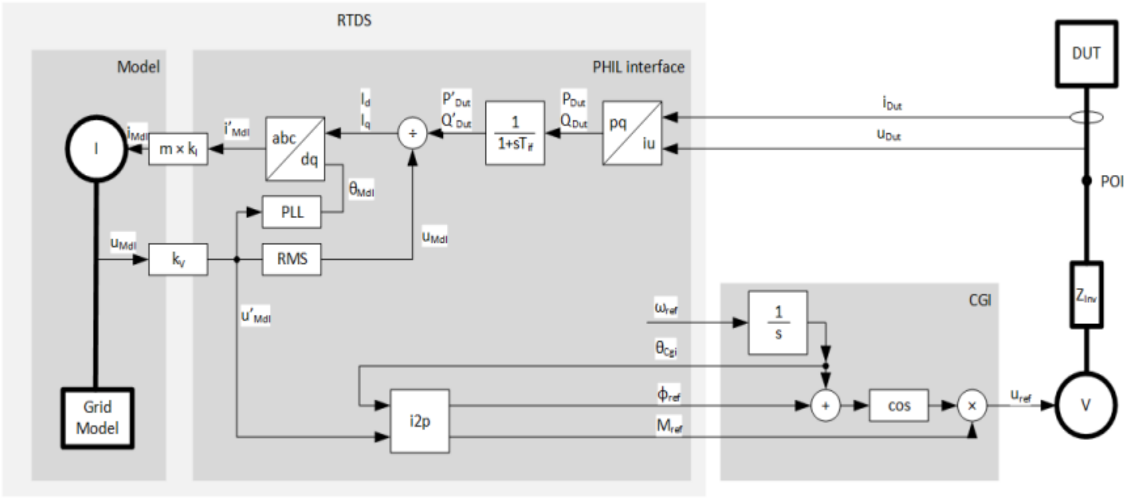


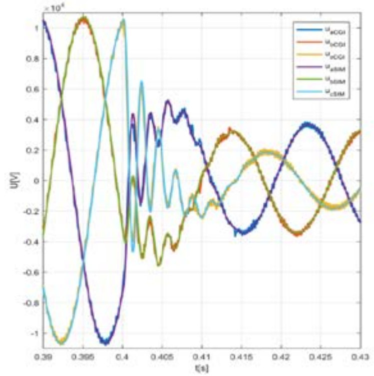
Approach and Meteorology: Validation Platform

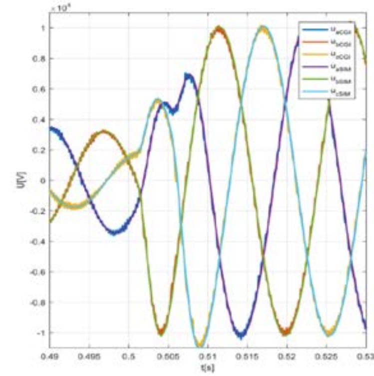
Multi-technology / Multi-MW / PHIL Experiment Setup

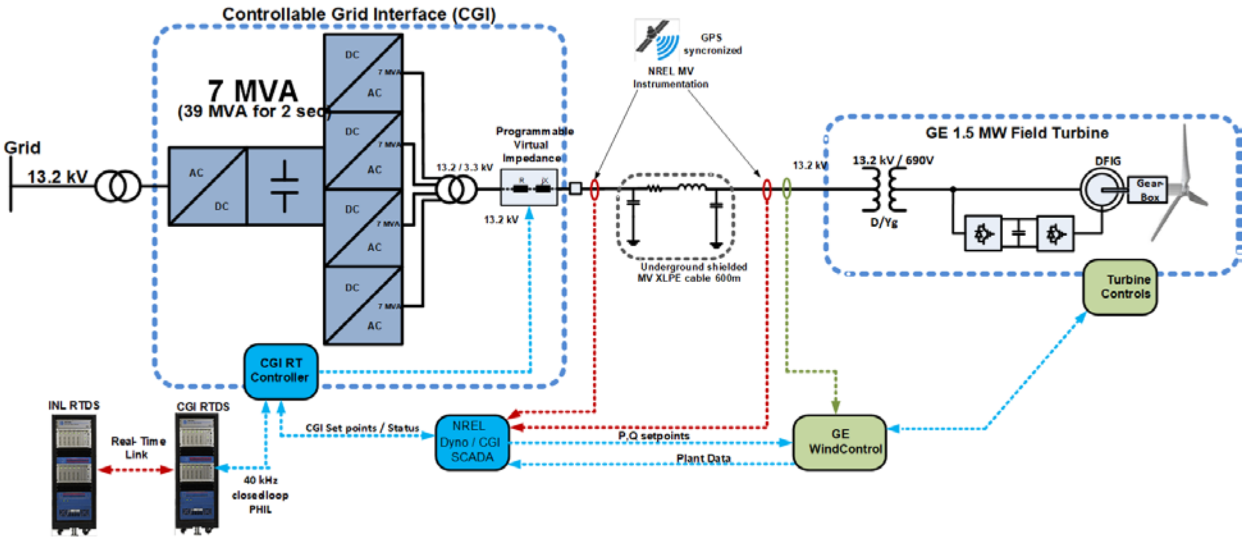


Development of PHIL Interface







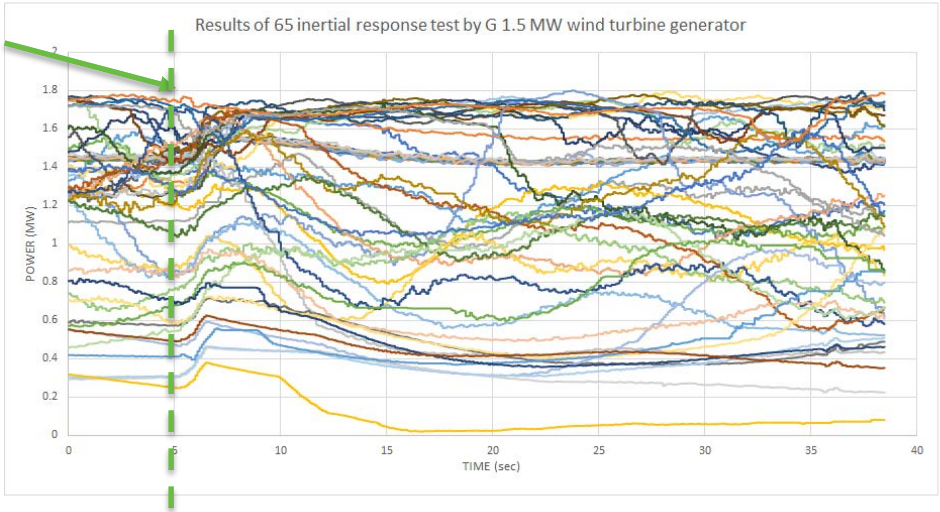


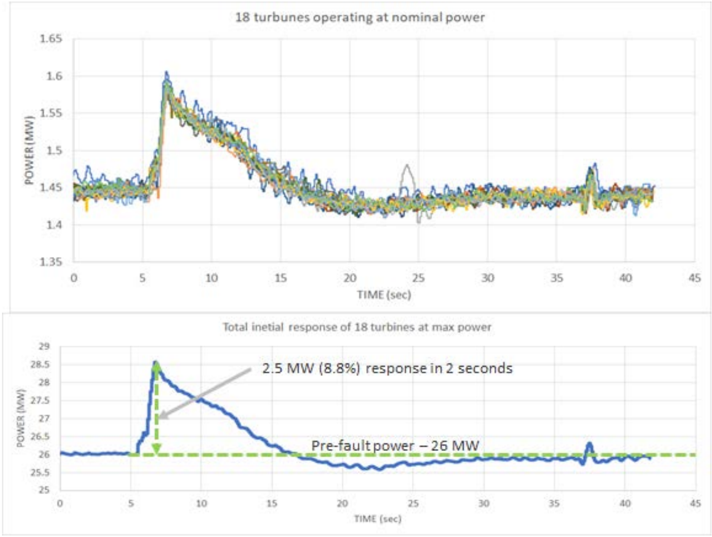
- Most advanced PHIL system in the world for WTG testing
- Accurate, low-latency, instantaneous voltage tracking
- Accurate tracking of positive, negative, and zero sequence components of modelled voltage
- Accurate tracking of actual WTG active and reactive power

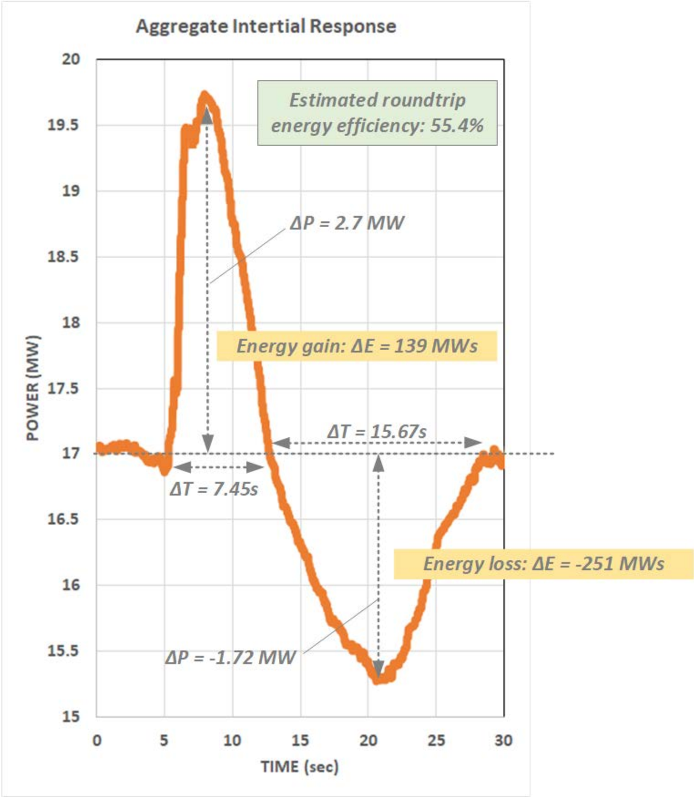
Accomplishments and Progress: Wind Inertia

Emulated Inertial Responses Individual Wind Turbines in a 150 MW wind power plant

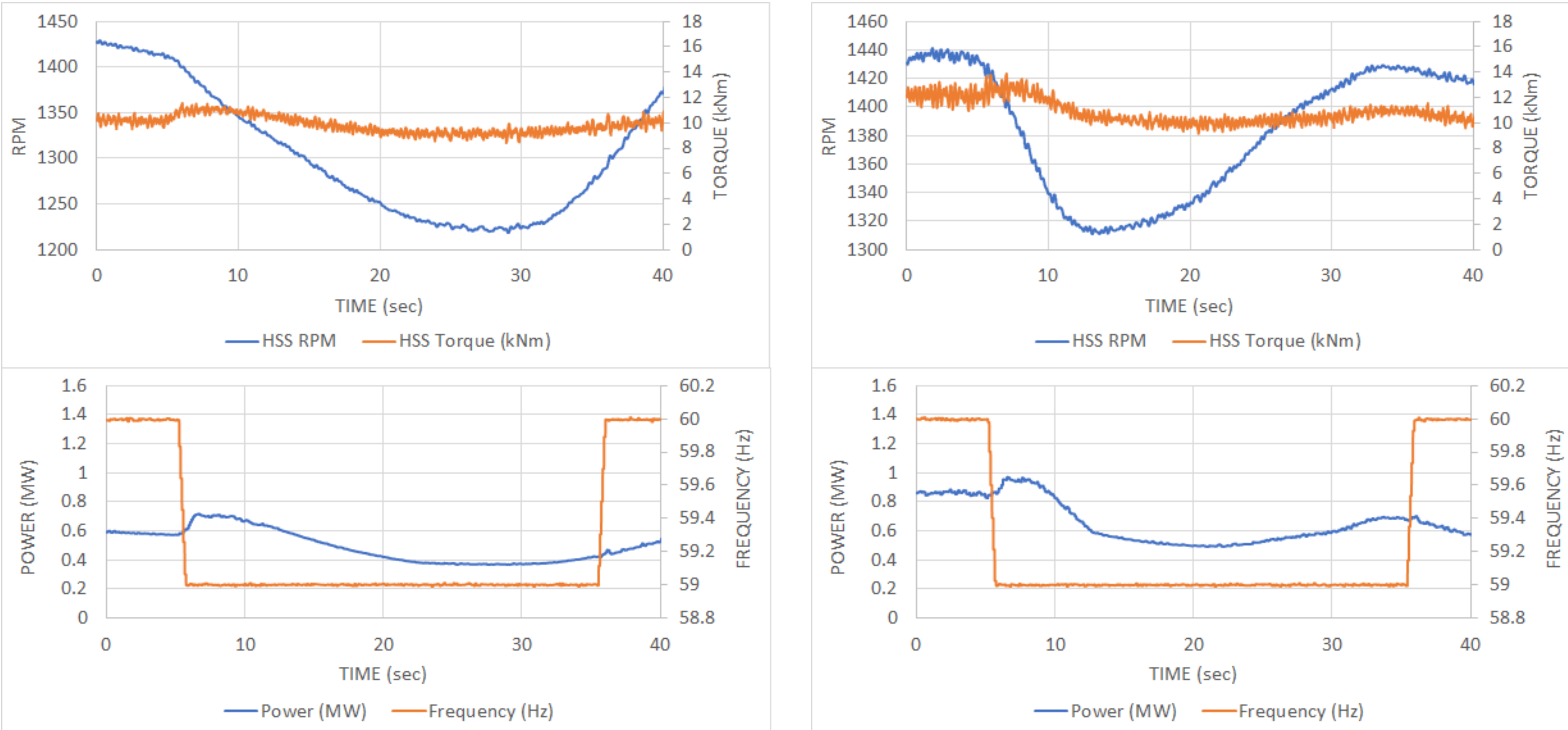
Frequency event emulated by CGI – 1Hz/sec ROCOF







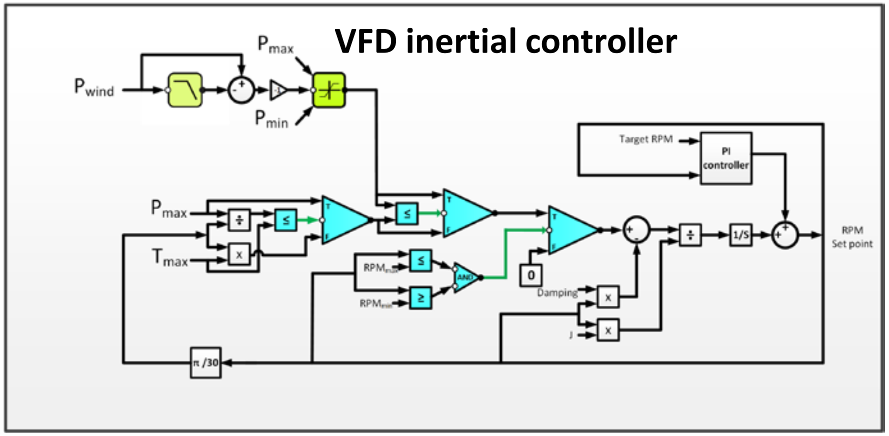
Wind Inertia and Mechanical Loading

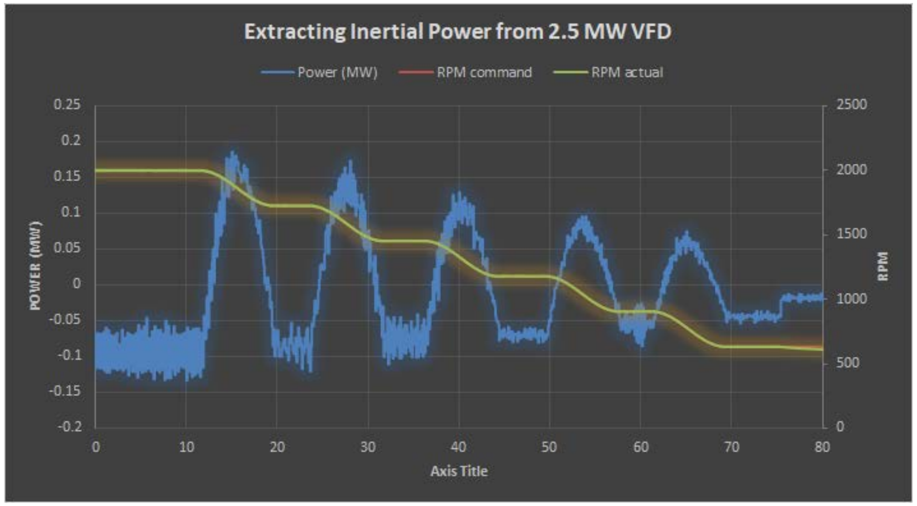


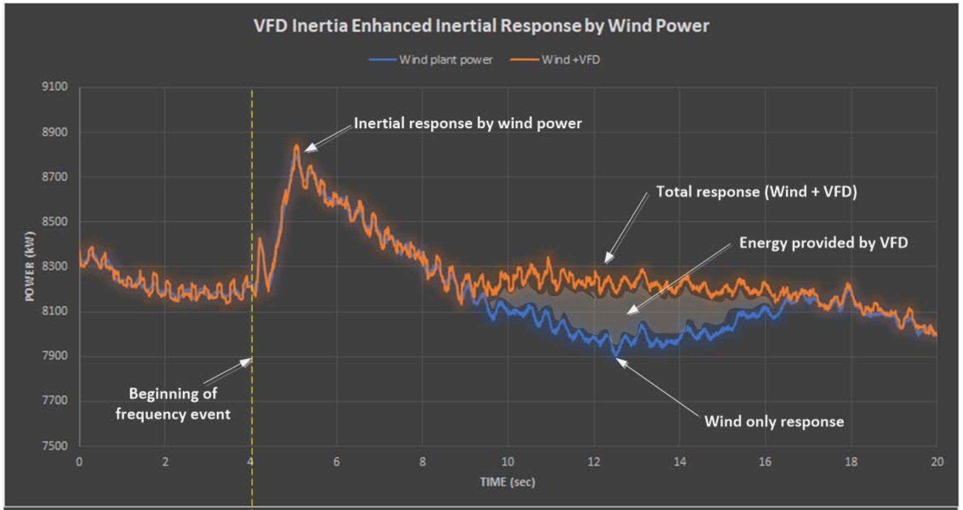
- WTG exposed to high ROCOFs
- Measured turbine active power, high-speed shaft torque and speed
- Did not observe any significant impacts of inertial control on the gearbox loading
- In fact, any high-speed shaft torque changes during inertial response do not seem to be any more “severe” than torque variations caused by wind speed turbulence conditions at the NWTC

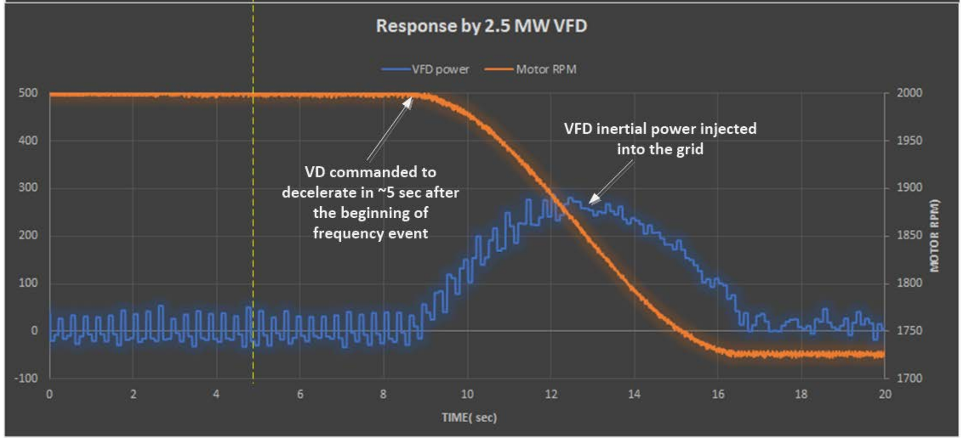
Wind + VFD Inertial Response

VFD Enhancing Inertial Response by Wind Power

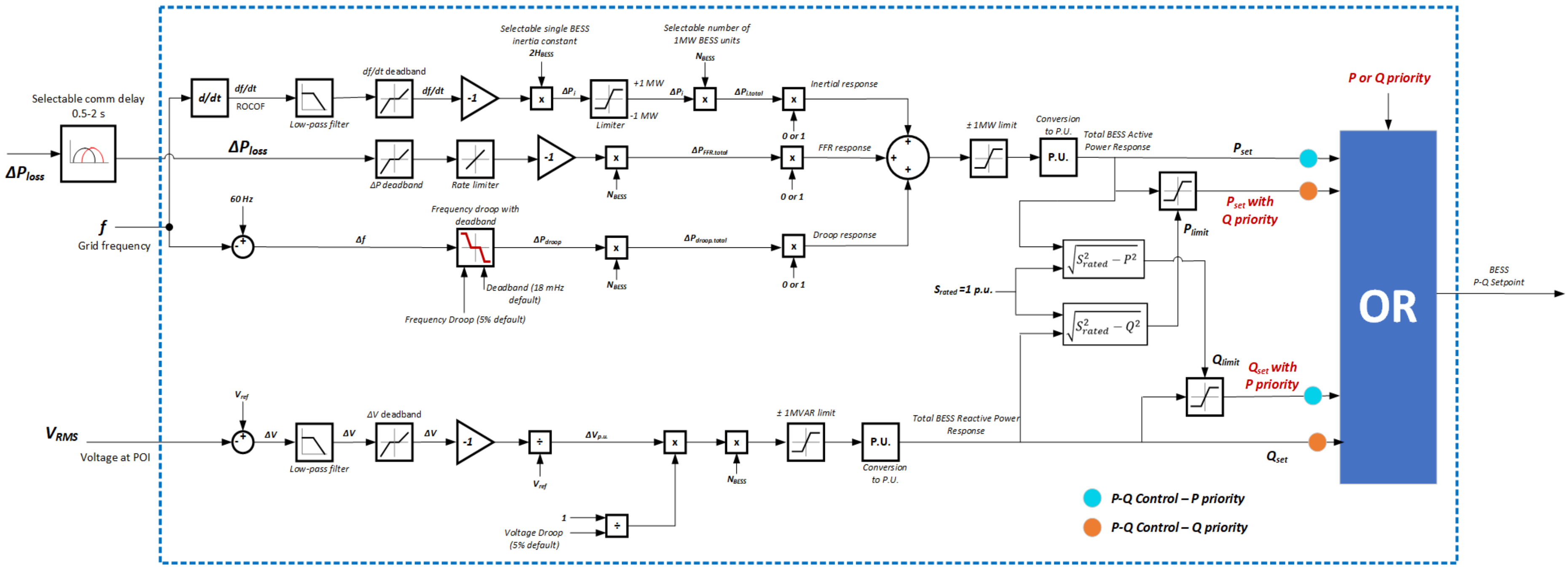


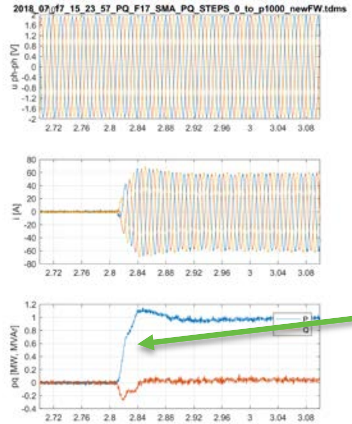






Development of Battery Energy Storage Systems (BESS) Controls

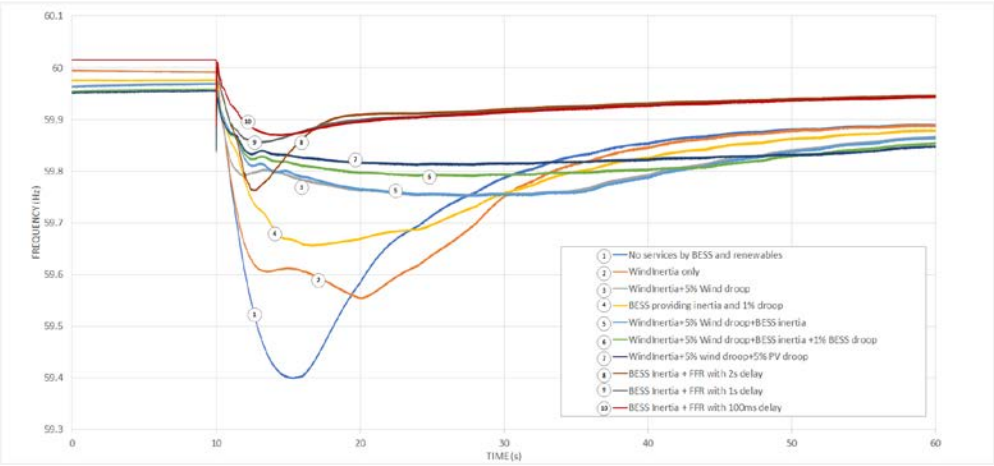


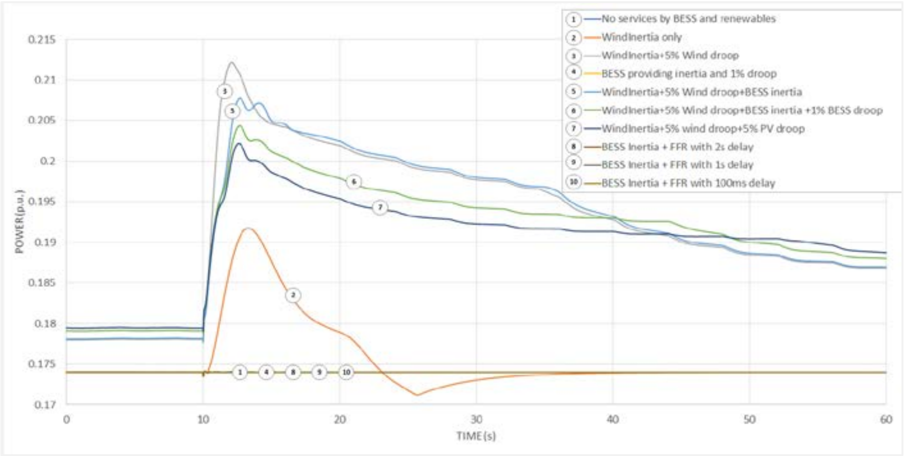


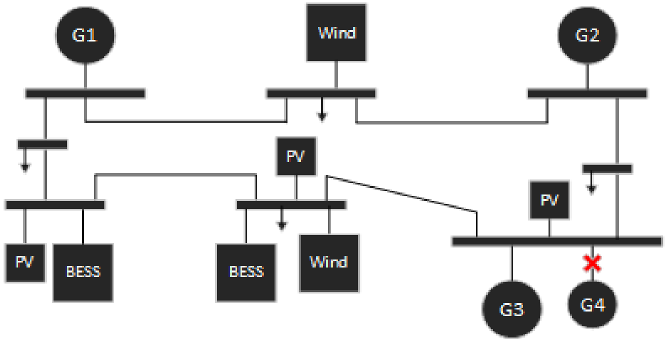
- BESS controller deployed on SEL RTAC
- This portion of work was combined with CA EPIC funded project with PG&E
- Collaboration with SMA
- Achieved **20 ms** response by BESS

PHIL Testing of Frequency Responsive Services by Wind and BESS

30% case

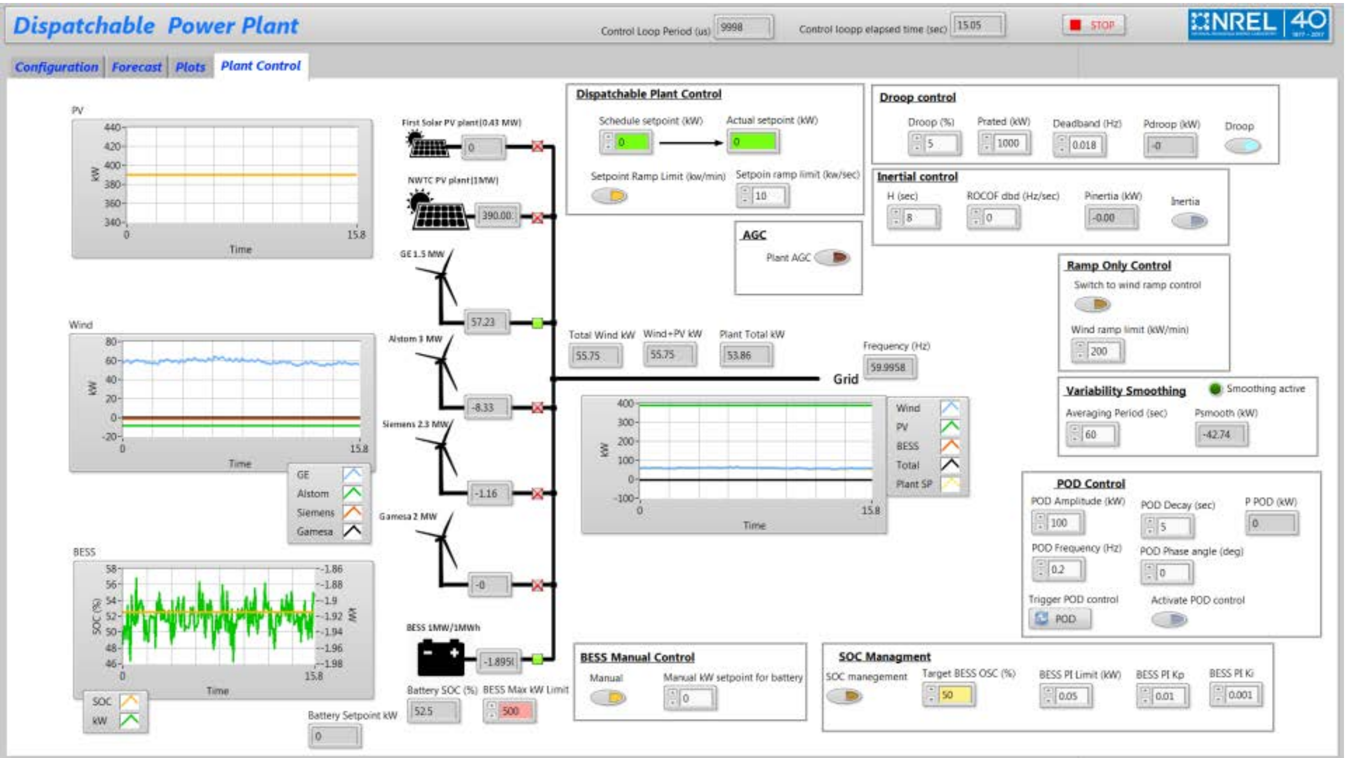






- Rate of Change of Frequency (ROCOF) similar to Western Interconnection
- Various penetration cases tested – 20-60%
- Different wind and BESS control strategies tested:
  - WindInertia only
  - WIndInertia + wind droop
  - BESS Inertia and droop
  - Wind + BESS combined services

Development of Hybrid Plant Controls



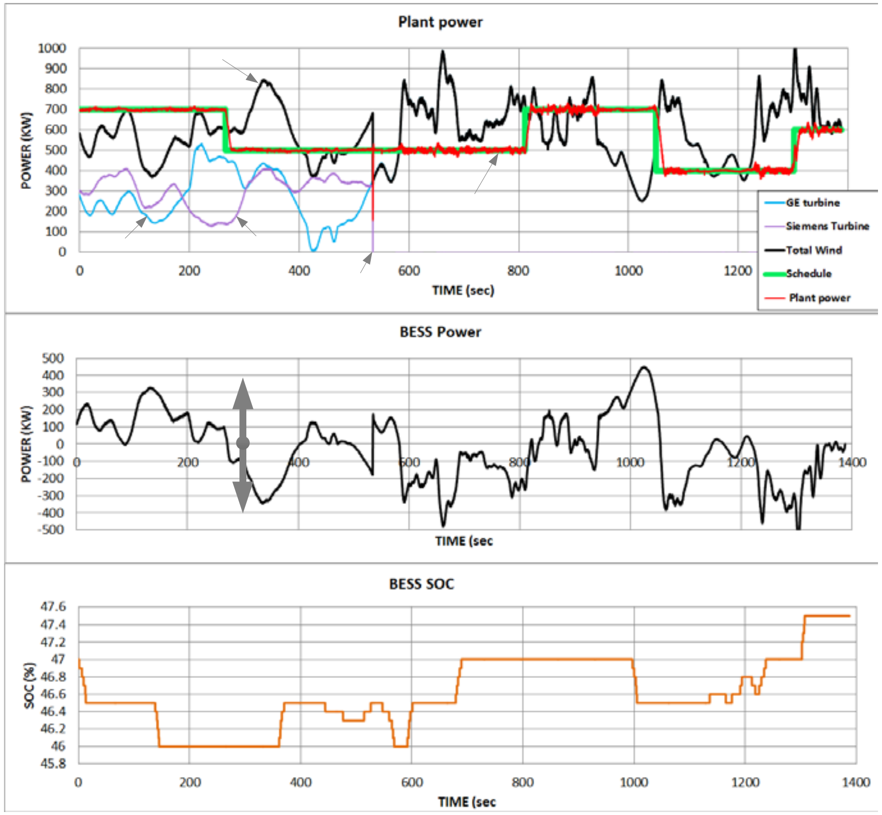
- Dispatchable renewable plant operation:
  - Ability to operate at active and reactive power external set points received from system operator
- Ramp limiting, variability smoothing, cloud-impact mitigation
- Provision of spinning reserve
- AGC functionality
- PFR (programmable droop control)
- FFR
- Inertial response:
  - programmable synthetic inertia for a wide range of H constants emulated by BESS
- Reactive power/voltage control
- Advanced controls: ability of the plant to modulate its output for provision of power system oscillations damping services was tested
- Stacked services (ability to provide several services at the same time)
- Battery SOC management controls

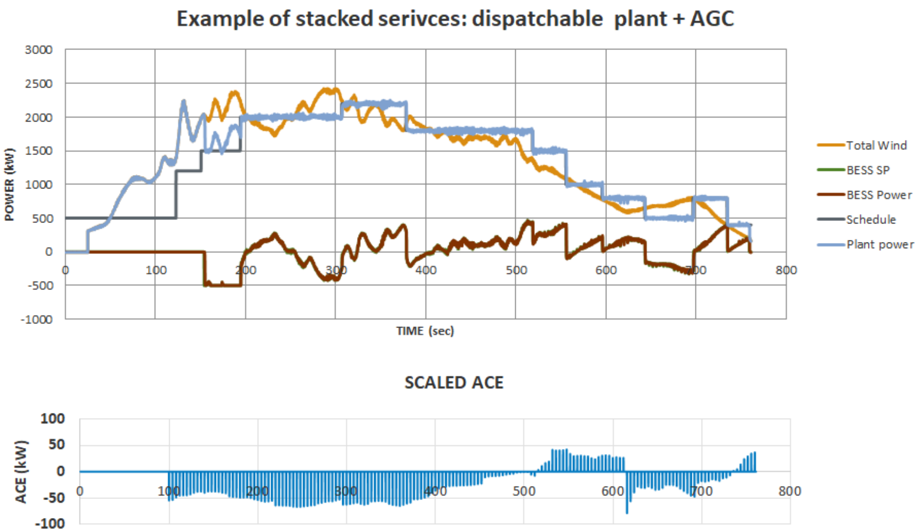
Dispatch setpoint | **Synthetic inertia** | **Primary frequency response** | **AGC participation**

$$P_{bess}(t) = P_0 - 2H\frac{df}{dt} - \frac{\Delta f}{droop} + K_P \cdot \mathrm{ACE}$$

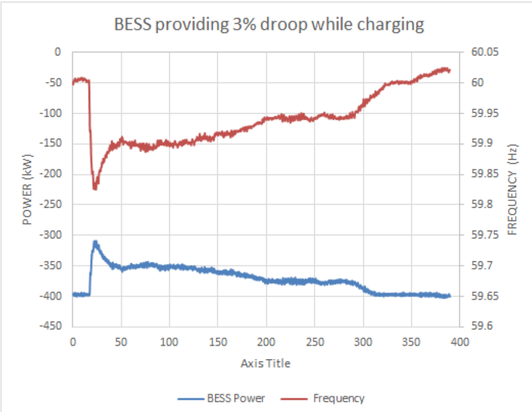
Dispatchable Operation with Inertial Response

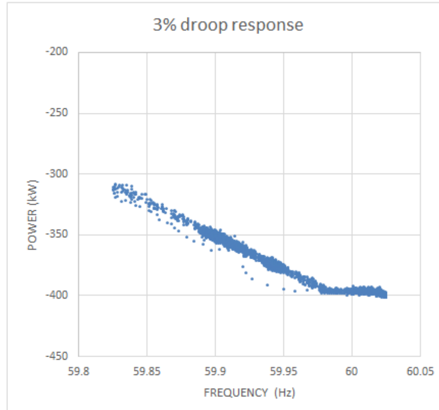
Dispatchable Wind Power plant

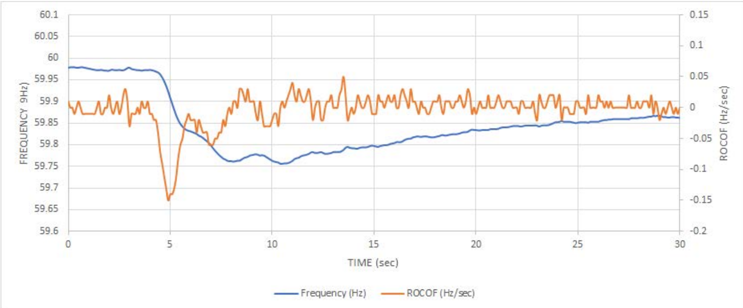


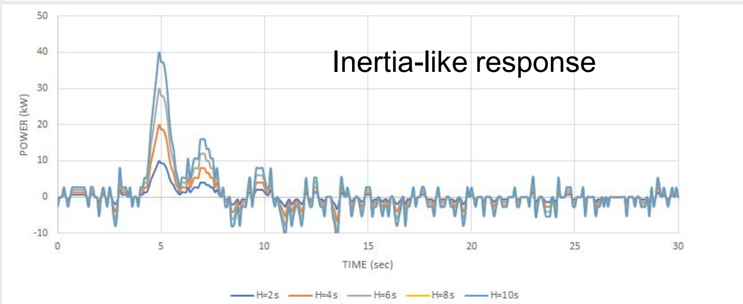


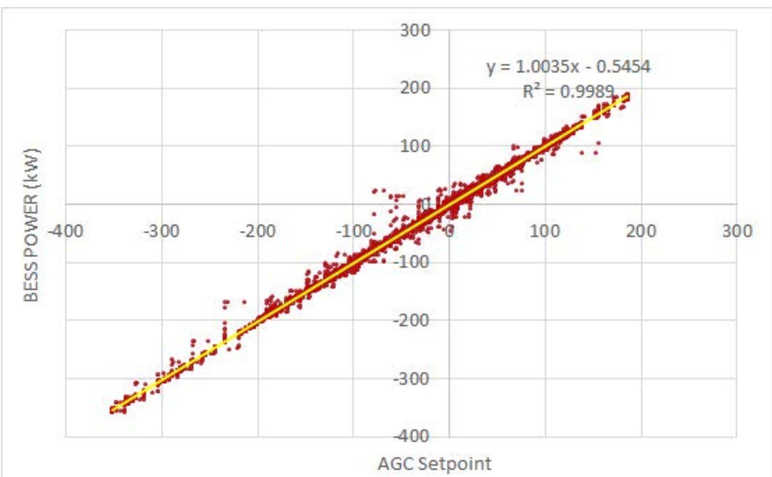
BESS Providing Inertial Response, Primary Frequency Response (PFR) and participating in Automatic Generation Control (AGC)

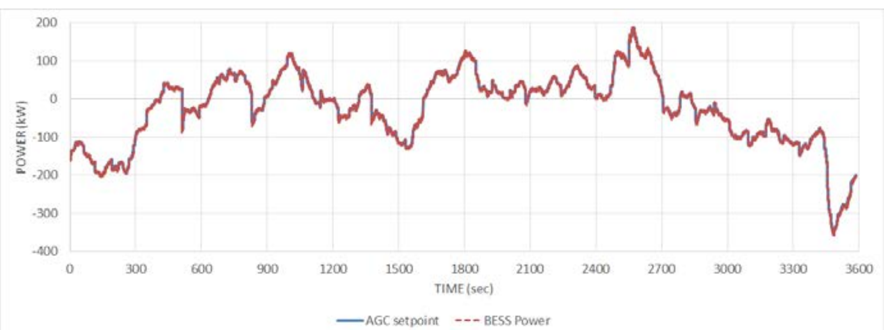


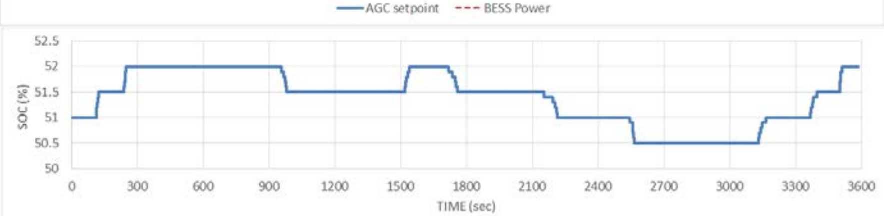






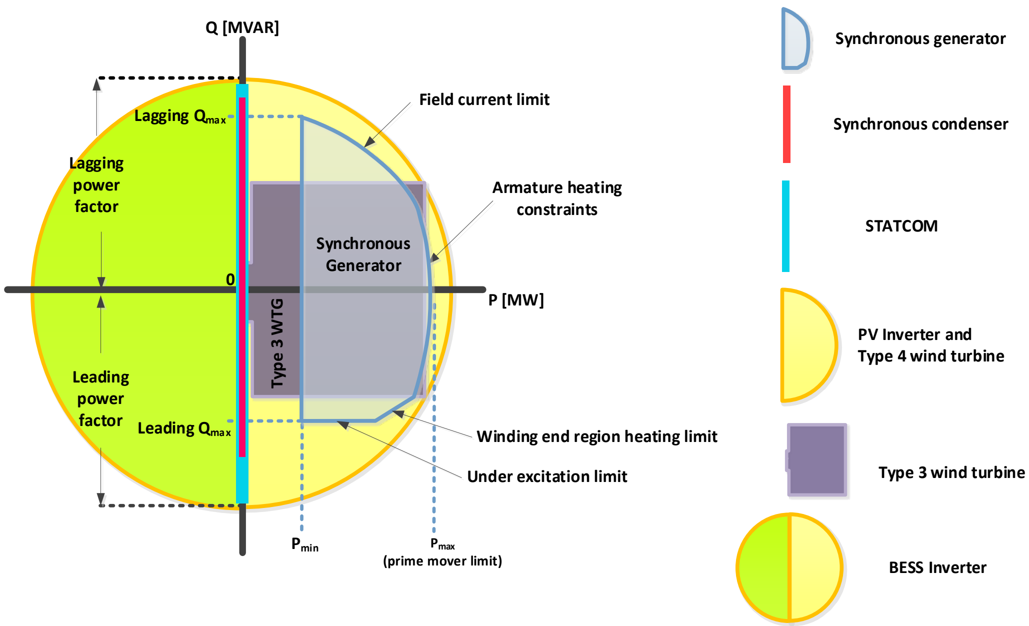




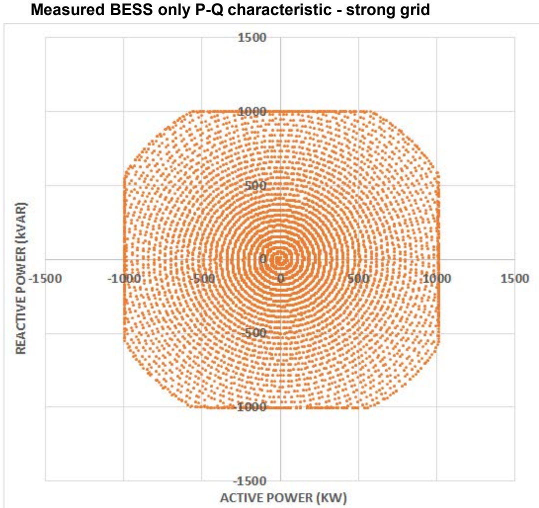


- PSCO historic ACE time series (updated every 4 sec)
- ACE is scaled down to match BESS rating

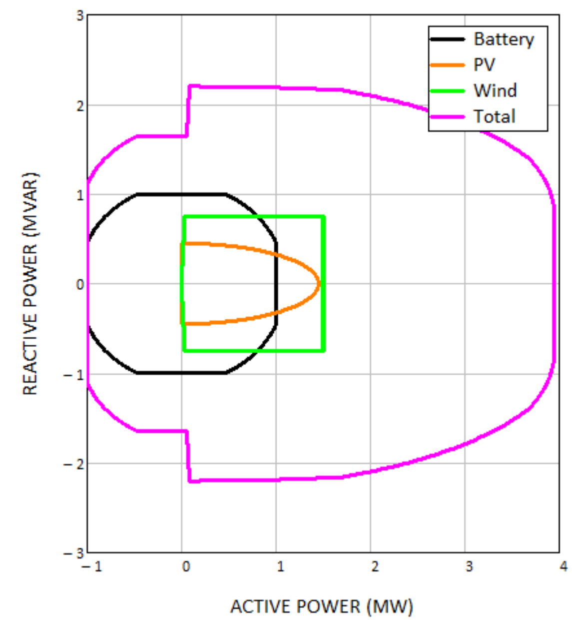
Reactive Power Capabilities



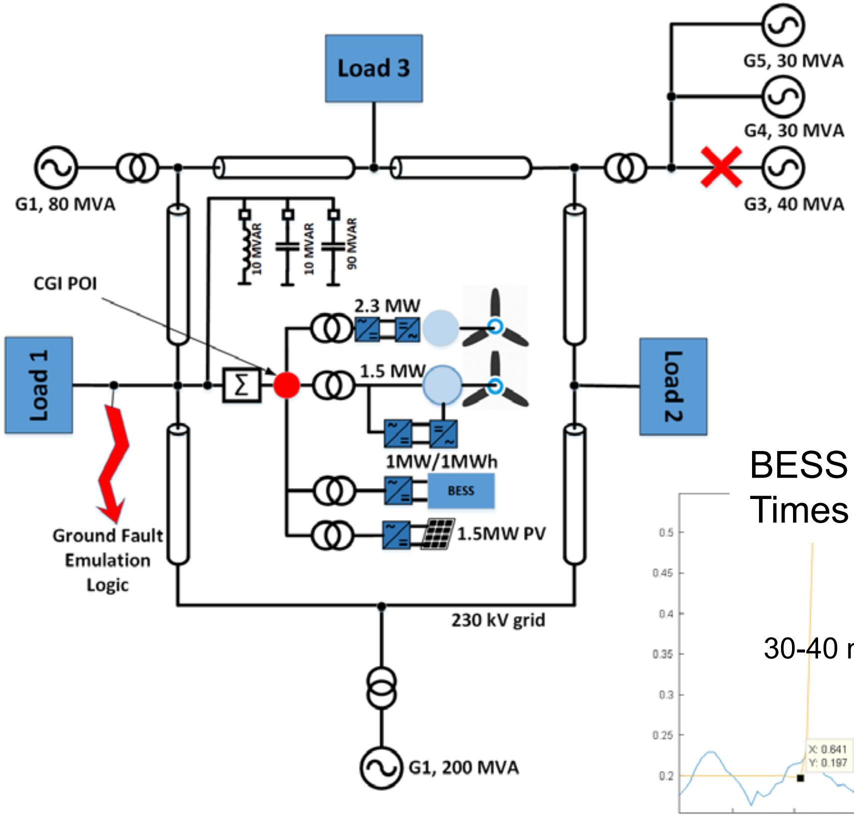
Measured BESS only P-Q characteristic - strong grid

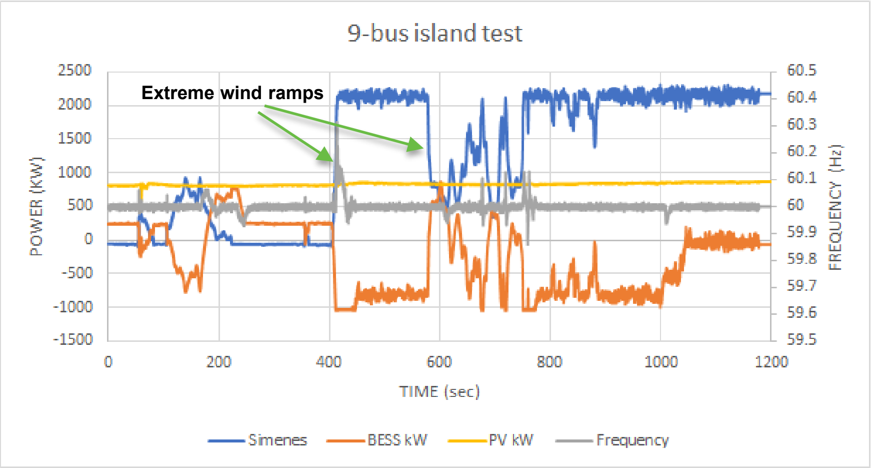


Combined P-Q characteristic:
1.5 MW PV + 1.5 MW wind + 1 MW BESS
Strong gird conditions

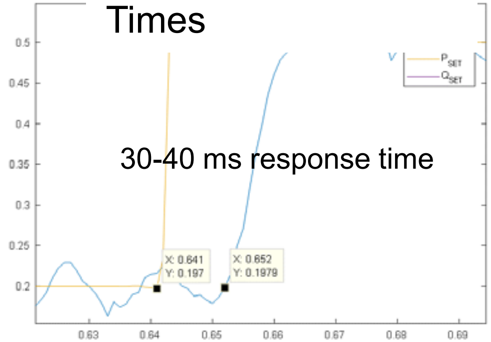


Island Power System Model in RTDS (IEEE – 9 bus)

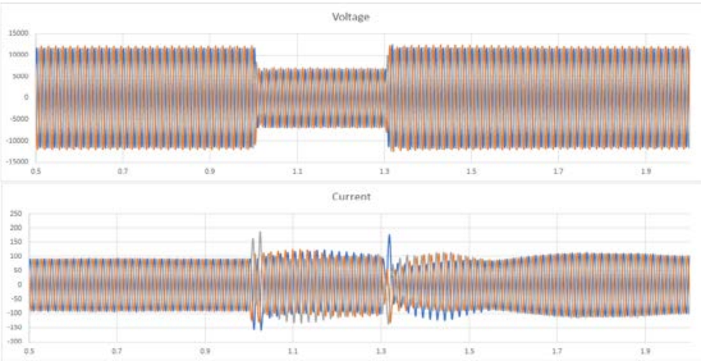




BESS Response Times

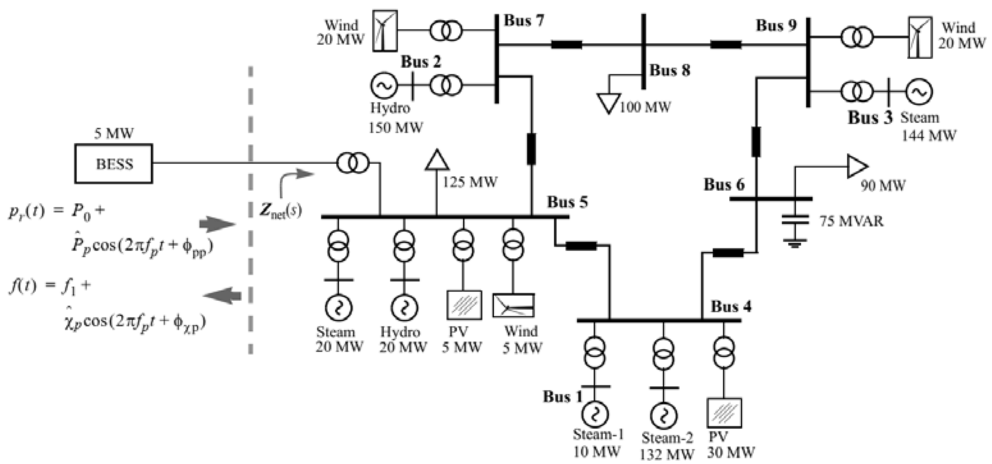


Hybrid Plant Voltage FRT Test



Development of Impedance-based Characterization Methods for Wind-BESS Systems

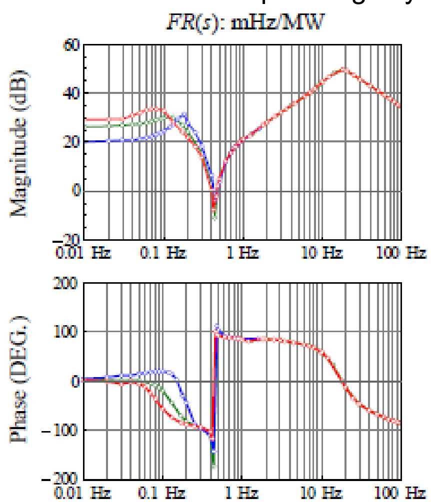
- Transfer Function from Active Power to Frequency at PCC



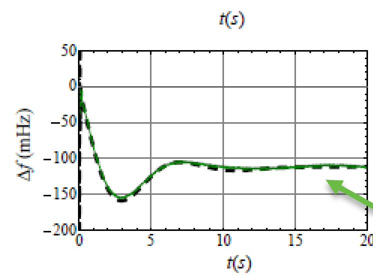
Ratings of conventional generators

Generator	Rating, S (MVA)	Active Power O/P, P_o (MW)	Inertia Constant, H (s)	Nominal Droop Constant (R_p)
Hydro @ Bus-7	150	59.18	6.0	0.05
Hydro @ Bus-5	20	10.48	6.0	0.05
Steam @ Bus-5	20	11.49	3.12	0.20
Steam-1 @ Bus-4	10	5.70	3.12	0.20
Steam-2 @Bus-4	132	75.78	3.12	0.20
Steam @ Bus-9	144	82.66	3.12	0.20
Total	476	245.29	4.15 s	–

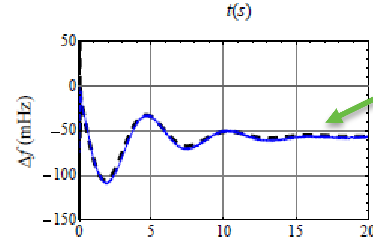
FR(s) for three different droop settings by SPP:



10% droop



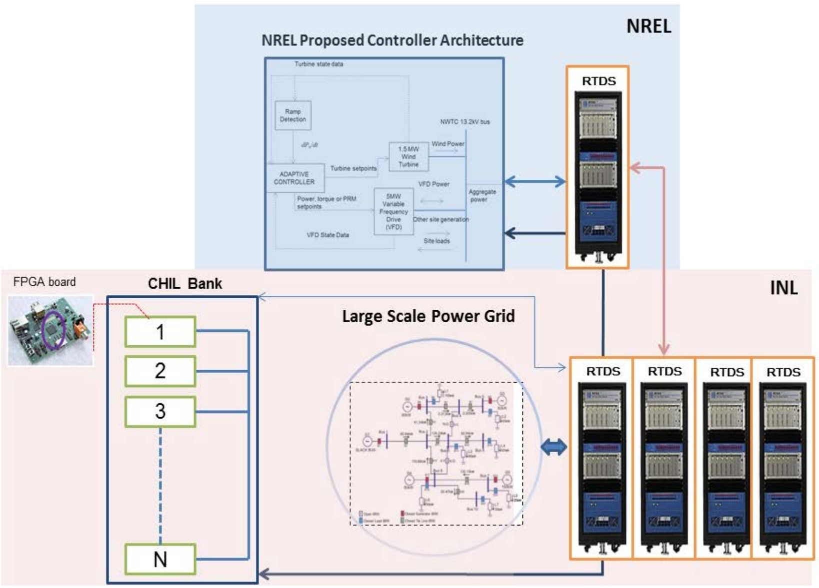
5% droop

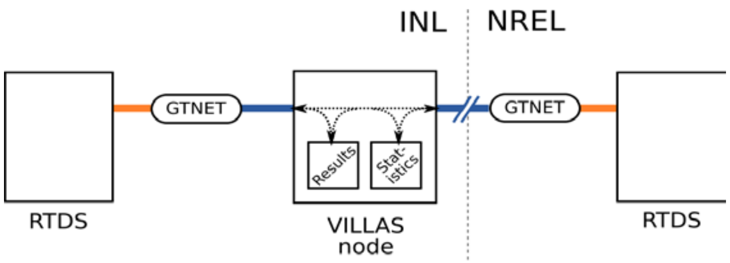


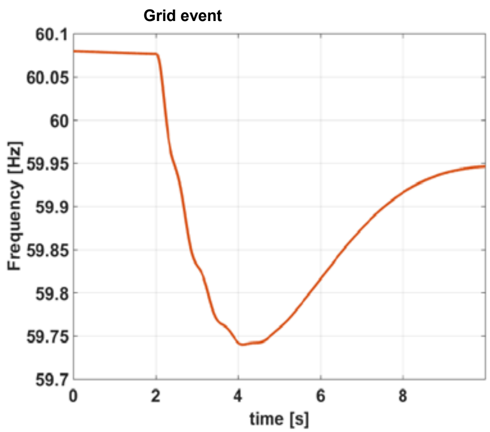
Accurate prediction of PFR, nadir and ROCOF

INL task: Distributed Real-Time Simulations Setup

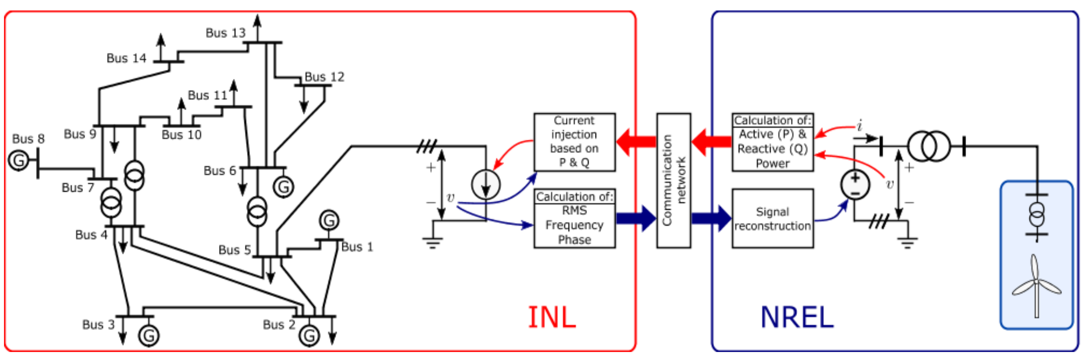
Geographically Distributed RTS between NREL and INL to characterize the APC with large-scale power systems

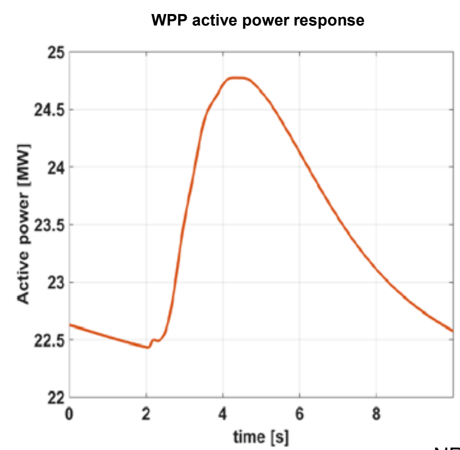






Geographically Distributed RTS setup for performing the integrated testing to enable wind turbine testing and characterization of the APC





INL task: Global Real-Time Super Lab

A Global Real-Time Superlab

Enabling high penetration of power electronics in the electric grid

by Antonello Monti, Marija Stevic, Steffen Vogel, Rik W. De Doncker, Ettore Bompard, Abouzar Estebsari, Francesco Profumo, Rob Hovsapian, Manish Mohanpurkar, Jack David Flicker, Vahan Gevorgian, Siddharth Suryanarayanan, Anurag K. Srivastava, and Andrea Benigni

The Global Real-Time Superlaboratory (Global RT Superlab) represents a vendor-neutral distributed platform based on the virtual interconnection of digital real-time simulators (DRTSs) and hardware-in-the-loop (HIL) setups hosted at eight geographically distributed laboratories in the United States and Europe (Figure 1). This article describes the efforts toward the realization of this large-scale virtual infrastructure and explains a demonstration of the multilab setup for simulation and testing of next-generation global power grids.

The Emerging Global Grid

The electric grid is changing. In particular, power electronics is significantly transforming power systems all around the world. This change is driven by the progressive installation of distributed energy resources (DERs), which are typically based on a power electronics interface, and it is creating a completely new power electronics-run, low-inertia grid. As described in [1], this future is closer than we think.

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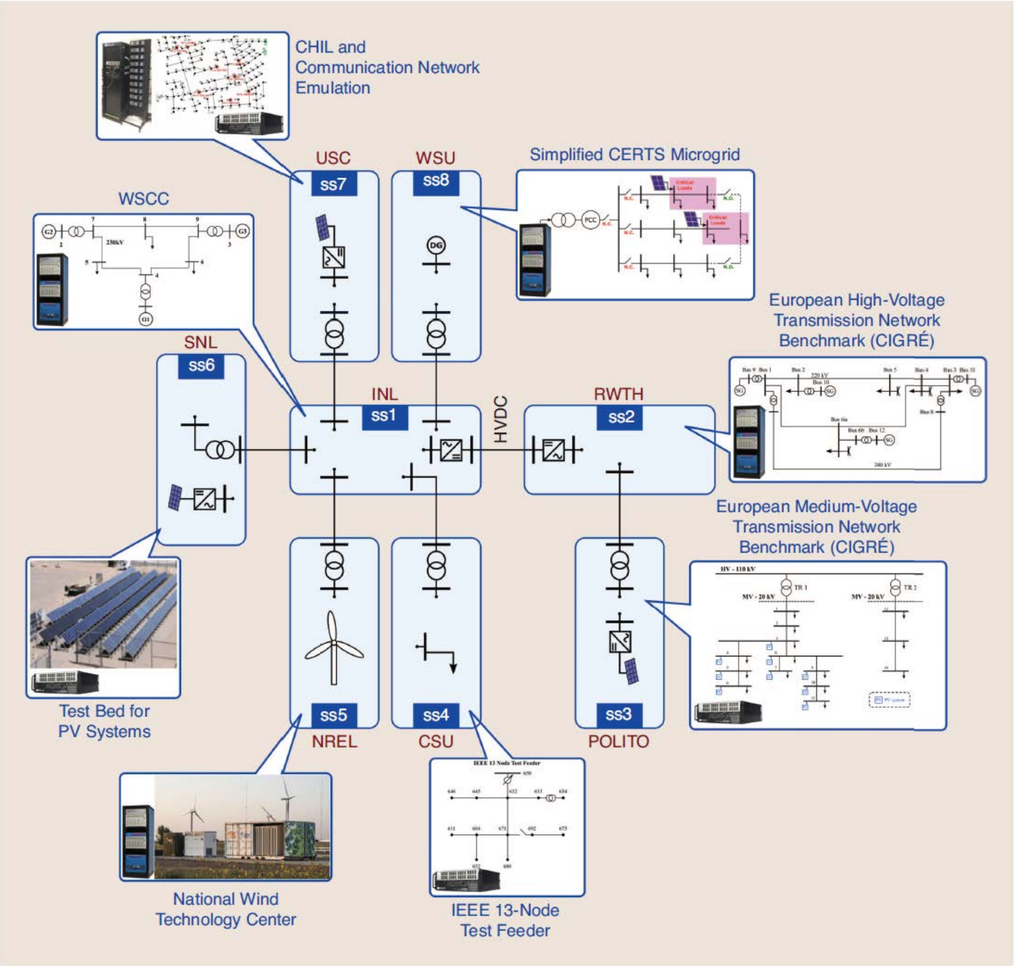

Milestones and Achievements

All milestones were completed

Organization	FY2017	FY2018
Quarter One	Controller Design - develop controller architecture	Conduct demonstration of NREL-INL PHIL/RTDS with multi-area power system model
Quarter Two	Controller in Simulink: develop controller in Matlab Simulink environment for concept testing	Demonstrate controllable power plant on a real-time platform
Quarter Three	Implement controller in real-time platform	Conduct test scenarios with controllable power plant providing essential reliability services
Quarter Four	Conduct testing and demonstration of the controller	Operate controllable power plant real-time as PHIL for a balancing area or islanded power system modeled with RTDS and provide report summarizing project

Additional achievements:

- 12 publications and conference presentations
- This work led to 5 new strategic industry collaborations (First Solar, PG&E, GE, RES, TEPCO-Japan)
- Results of this work are used in DOE grid modernization efforts for Puerto Rico