Overview of ARIES Research Projects Involving Inverter-Based Resources

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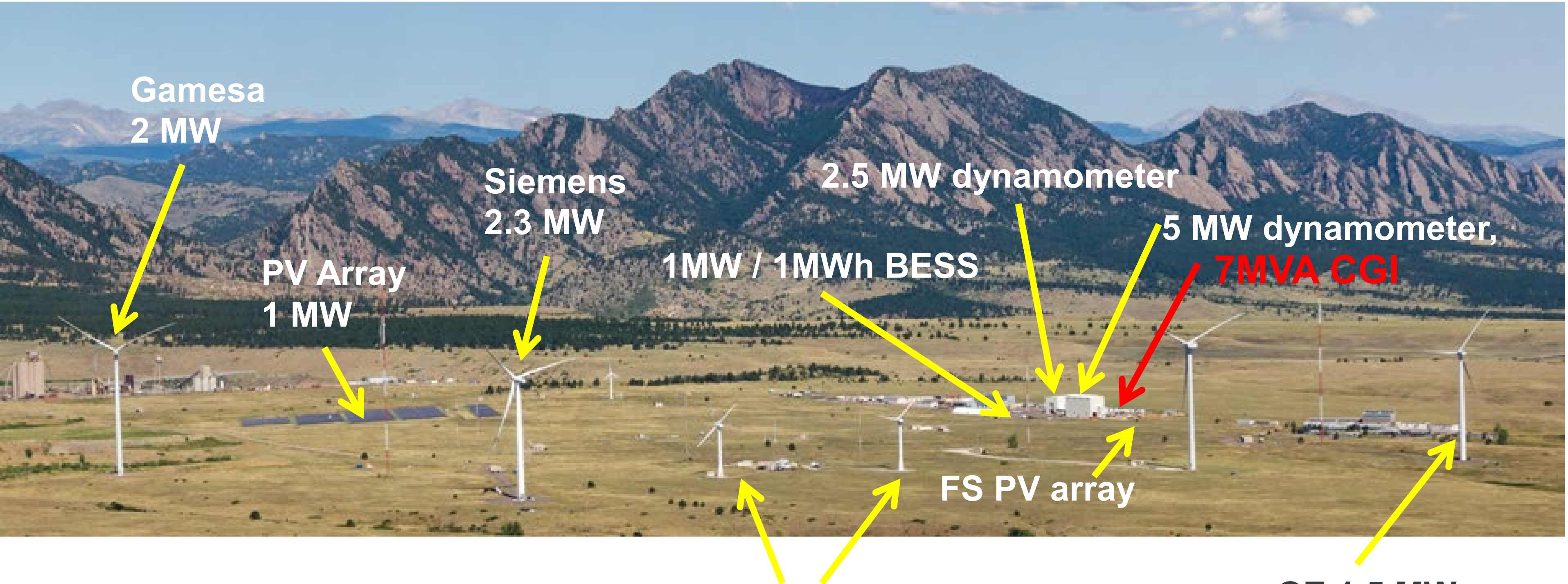
Power Electronic Grid Interface (PEGI) Platform Workshop

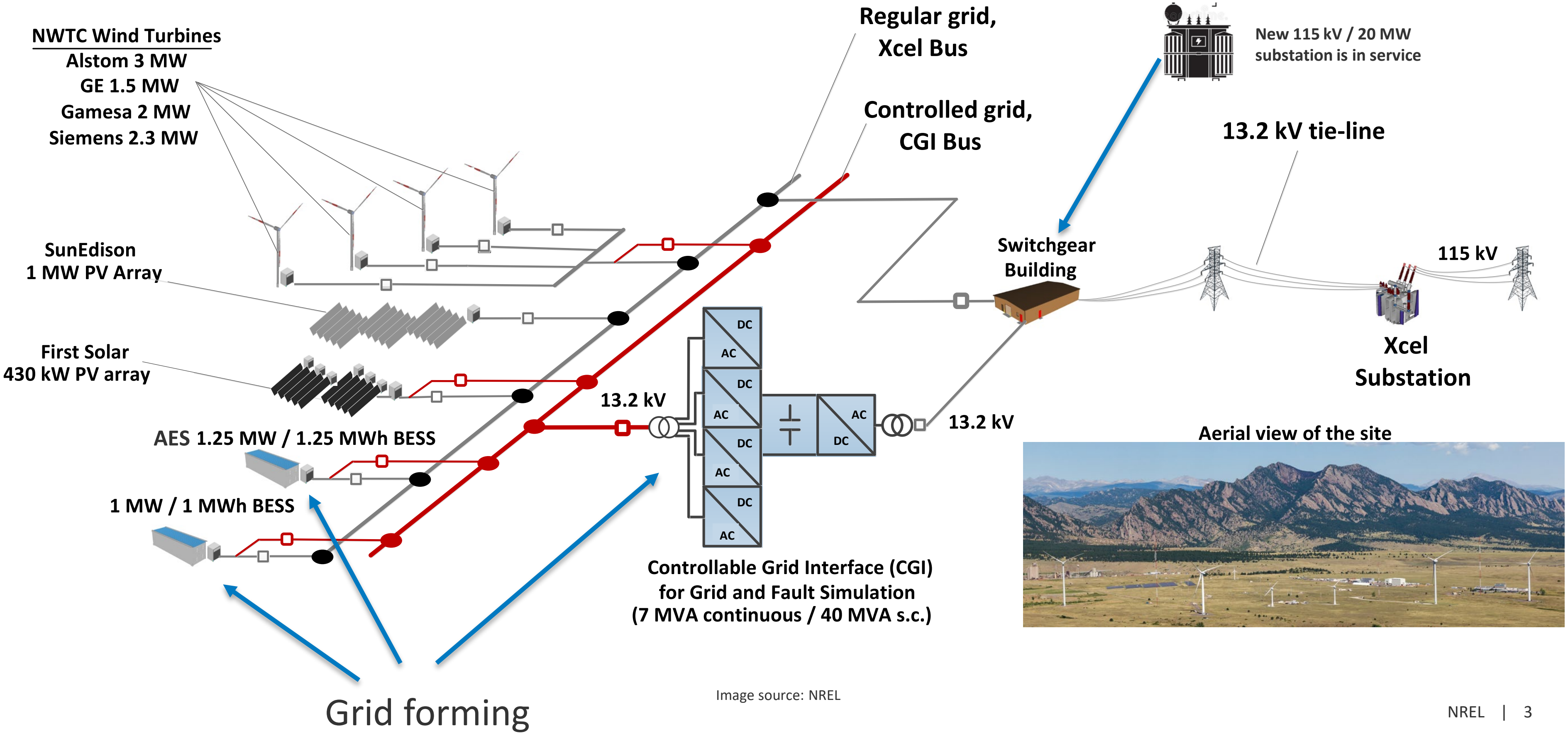
October 13th, 2020

NREL Flatirons Campus

- *Total of 12+ MW variable renewable generation currently*
- *7 MVA Controllable Grid Interface (CGI)*
- *Multi-MW energy storage test facility*
- *2.5MW and 5 MW dynamometers (industrial motor drives)*
- *13.2 kV medium voltage grid*
- *1.5 MW total PV capacity*



NWTC Controllable Grid Platform



Aerial view of the site

Image source: NREL

Main Engineering Challenges for Grids with High Shares of IBRs

- Lowering of system inertia, degrading frequency stability with increasing penetration
- Degrading grid strength, stability in weaker grids
- New protection methods at any level in the grid (low short-circuit current)
- Who and how will be providing grid forming? Why can't we operate all inverters as grid forming? Do we still need grid following? New black-start paradigm? Inrush current issue?
- New stability challenges in inverter dominated grids – control interactions and resonances. New stability evaluation methods (impedance-based stability analysis, etc.).
- How to control new transmission technologies – FACTS, HVDC, multi-terminal HVDC? New roles for synchronous condensers?
- Frequency stability in future inverter–dominated grids and in 100% grids:
  - Future 1: everything is inverter coupled (even hydro), no synchronizing torque, classic frequency stability becomes irrelevant
  - Future 2: We still have some synch generation at 100% (hydro, CSP, etc.), so classic frequency stability still matters.
- Reliability and resiliency of decentralized and autonomous grids, MVDC/LVDC grids
- High fidelity sensing and new data driven state estimation, control and protection methods
- Cyber security in inverter dominated grids

Ongoing Research Projects at FC

7 MVA Controllable Grid Interface #1

Power rating

- 7 MVA continuous
- 39 MVA short circuit capacity (for 2 sec)
- 4-wire, 13.2 kV

Possible test articles

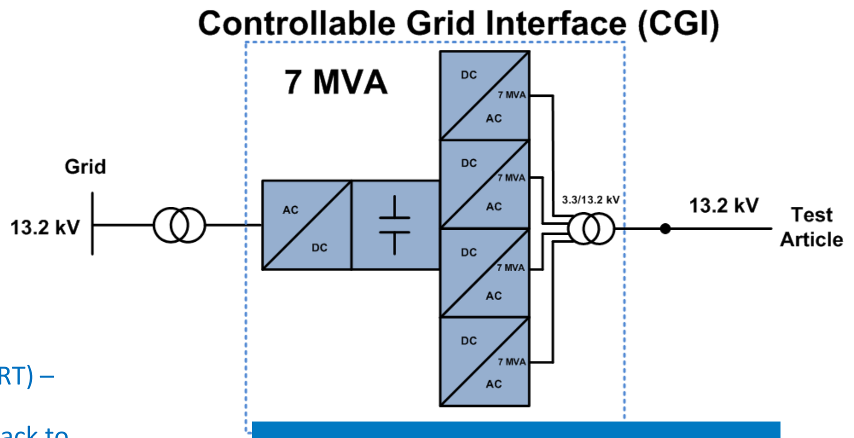
- Types 1, 2, 3 and 4 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies

Voltage control (no load THD <1%)

- Balanced and un-balanced voltage fault conditions (ZVRT and 140% HVRT) – independent voltage control for each phase on 13.2 kV terminals
- Response time – 1 millisecond (from full voltage to zero, or from zero back to full voltage)
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0-10 Hz) – SSR conditions
- Programmable impedance (strong and weak grids)
- Programmable distortions (lower harmonics 3, 5, 7)
- Impedance characterization of inverter-coupled generation
- Full STATCOM functionality

Frequency control

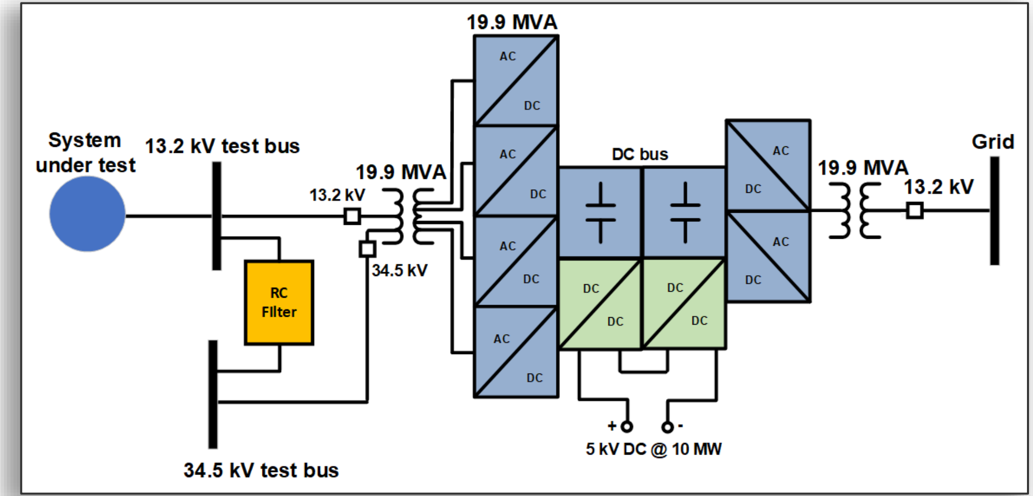
- Fast output frequency control (3 Hz/sec) within 45-65 Hz range
- 50/60 Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (coupled with RTDS, Opal-RT, etc.)
- Test-bed for PMU-based wide-area stability controls



Capabilities

- Balanced and unbalanced over and under voltage fault ride-through tests
- Frequency response tests
- Continuous operation under unbalanced voltage conditions
- Grid condition simulation (strong and weak)
- Reactive power, power factor, voltage control testing
- Protection system testing (over and under voltage and frequency limits)
- Islanding operation
- Sub-synchronous resonance conditions
- 50 Hz tests

20 MVA Controllable Grid Interface



Power rating
- Continuous AC rating - 19.9 MVA at 13.2kV and 34.5 KV
- Overcurrent capability (x5.7 for 3 sec, x7.3 for 0.5 sec)
- 4-wire 13.2 kV or 35.4 kV taps
- Continuous operational AC voltage range: 0 - 40 kVAC
- Continuous DC rating – 10 MW at 5 kVDC

Possible test articles
- Types 1, 2, 3 and 4 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies / hybrid systems
- Responsive loads

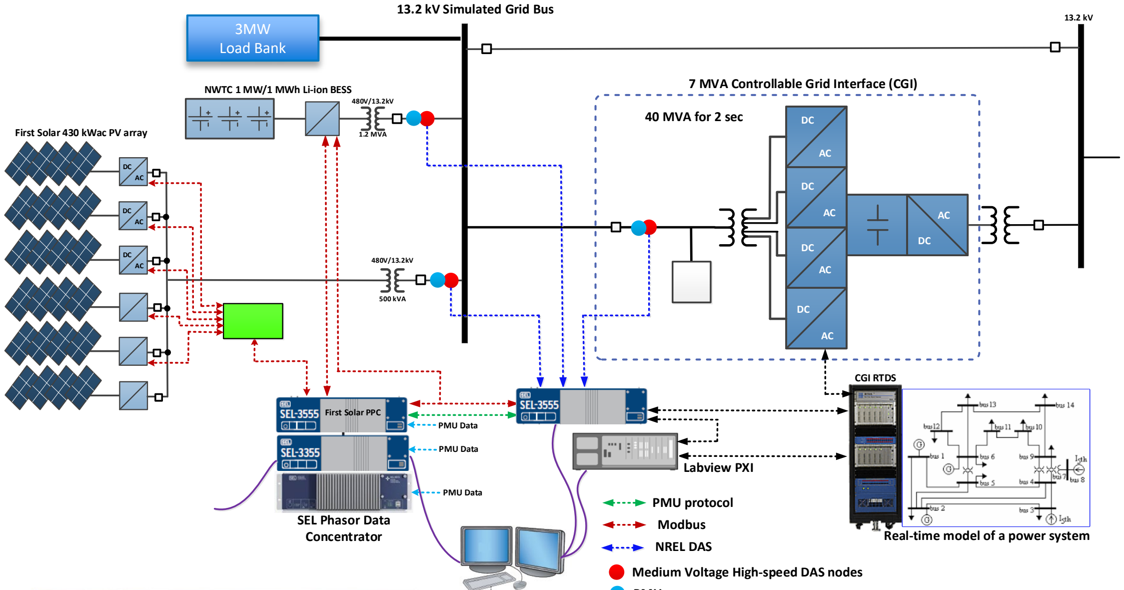
Voltage control (no load THD <1%)
- Balanced and unbalanced voltage fault conditions (ZVRT, LVRT and 140% HVRT) – independent voltage control for each phase on 13.2 kV and 34.5 kV terminals
- Response time – less than 1 millisecond (from full voltage to zero, or from zero back to full voltage)
- Programmable injection of positive, negative and zero sequence components
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0-10 Hz) – SSR conditions
- Programmable impedance (strong and weak grids, wide SCR range corresponding to a POI with up to 250 MVA of short circuit apparent power)
- Injection of controlled voltage distortions
- Wide-spectrum (0-2kHz) impedance characterization of inverter-coupled generation and loads
- All-quadrant reactive power capability characterization of any system

Frequency control
- Fast output frequency control (3 Hz/sec) within 45-65 Hz range
- 50/60 Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (can be coupled with RTDS, Opal-RT, Typhoon, etc.)
- Coupled with PMU-based wide-area stability controls validation platform

New features
- 5 kV MVDC grid simulator (PHIL capable)
- Voltage or current source operation
- Seamless transition between voltage and current source modes
- Emulation of full set of resiliency services:
    - Black start
    - Power system restoration schemes
    - Microgrids
- Flexible configurations are possible when combined with CGI#1:
    - Two independent experiments
    - Parallel operation
    - Back-to-back operation
    - Emulation of isolated, partially or fully grid-connected microgrids

SETO Project: PV-BESS Integration

NREL-First Solar Collaboration



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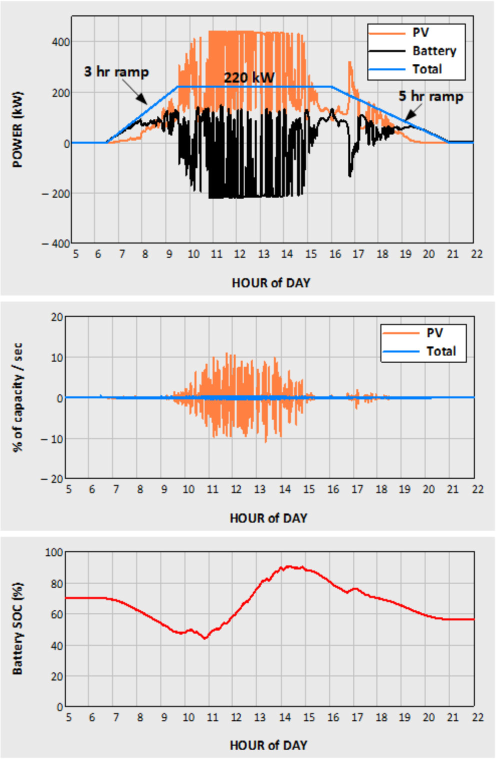


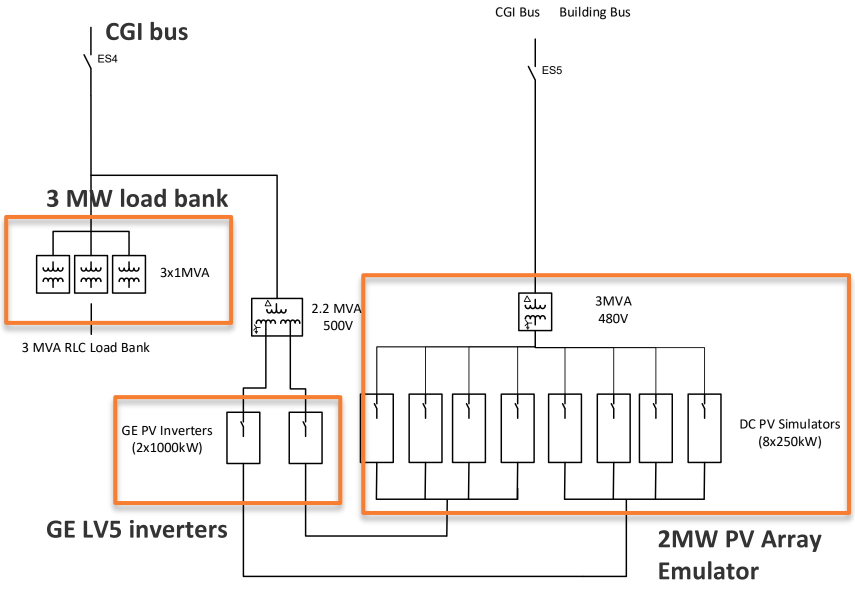
Developed and tested various controls for PV-BESS system:

- Dispatchability and flexibility
- Essential reliability services
- Advanced reliability and wide-area stability services
- Black start and islanded operation
- Impedance characterization of PV-BESS system in GFL and GFM modes

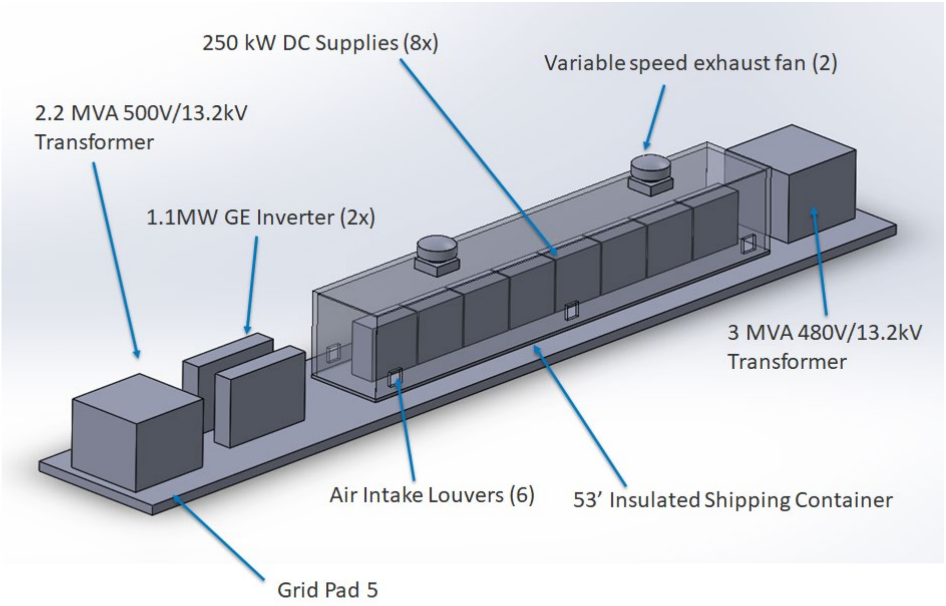
SETO Project: Grid Forming PV Inverters

NREL-GE Collaboration

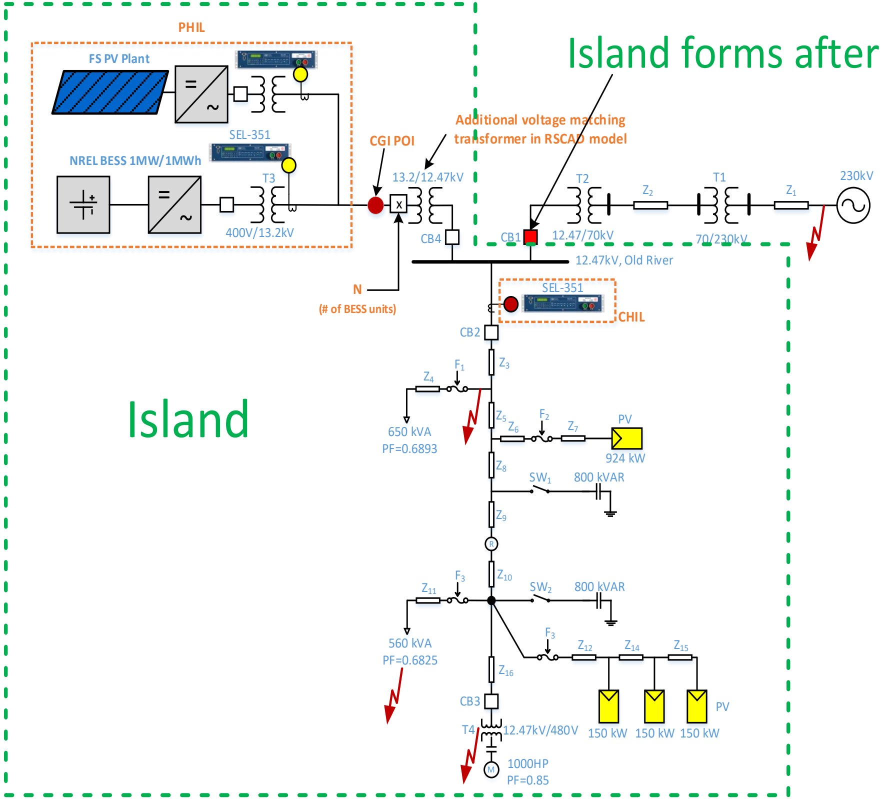
GE Grid Forming PV - Project Pad 5 Concept



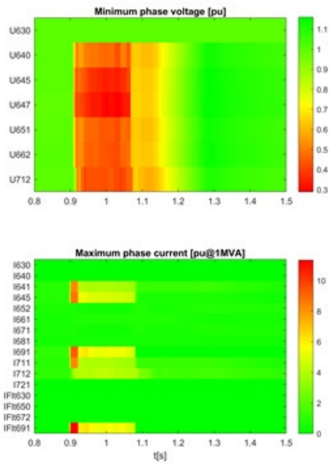
Objective: Develop and demonstrate grid forming controls by utility-scale PV inverters

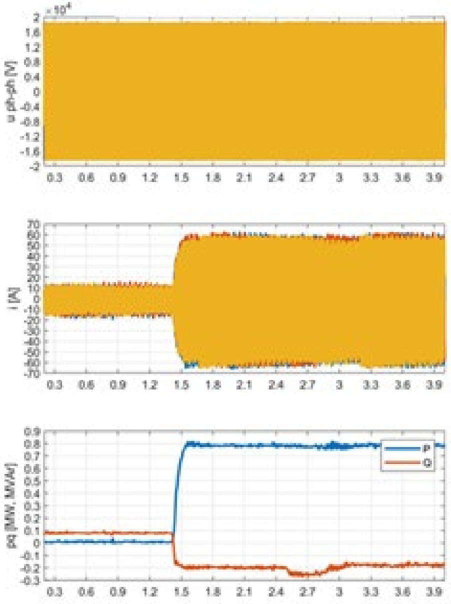


NREL-PG&E Project: GFM BESS Circuits to Enhance Reliance of Distribution Grids



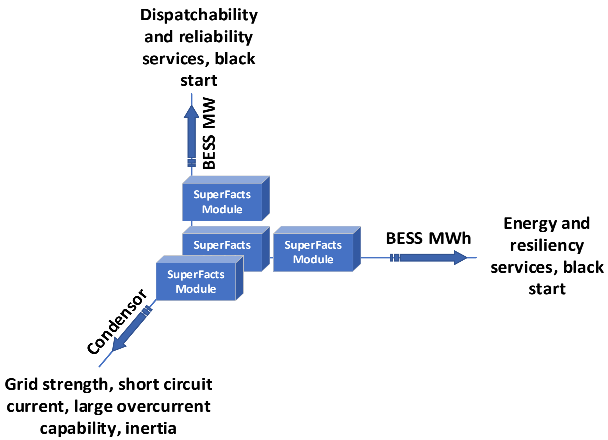
Island forms after CB1 trip

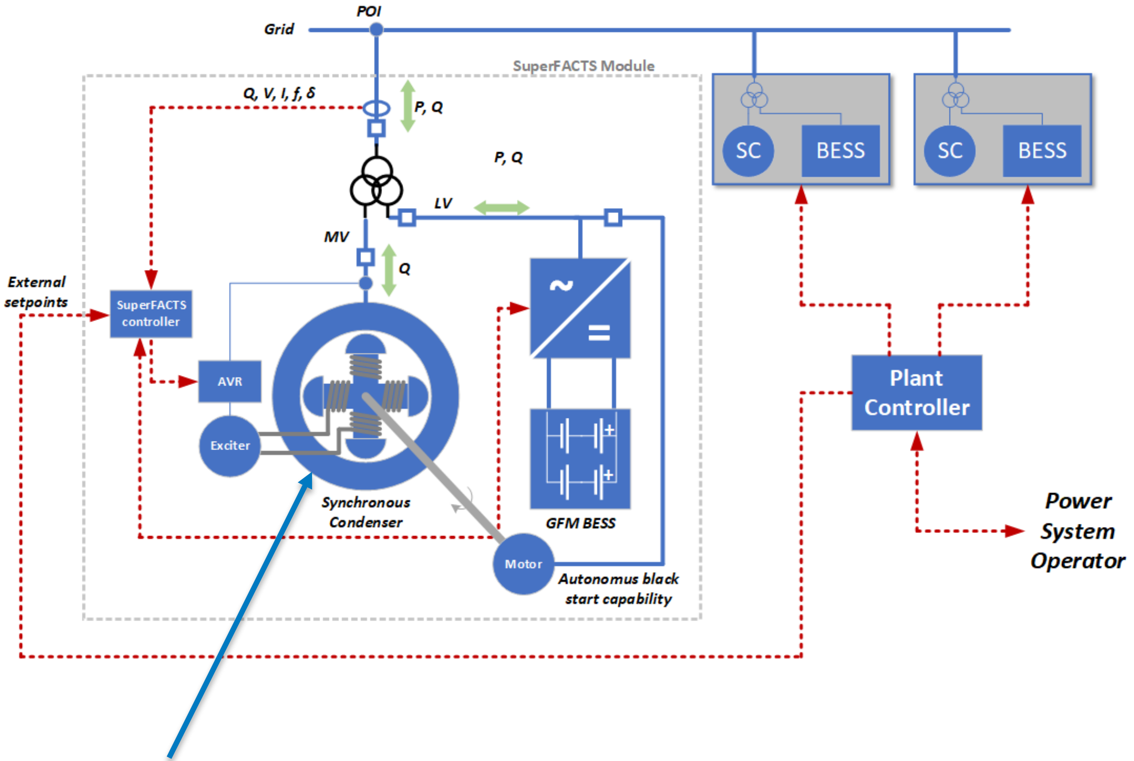




DOE OE Project: SuperFACTS

- Integrated Synchronous Condenser – GFM BESS system
- Scalable solution for transmission, subtransmission and islanded applications
- All types of grid services (market based, reliability and resiliency)
- Robust controls
- Grid strength enhancement
- Black start resource
- Fully scalable solution

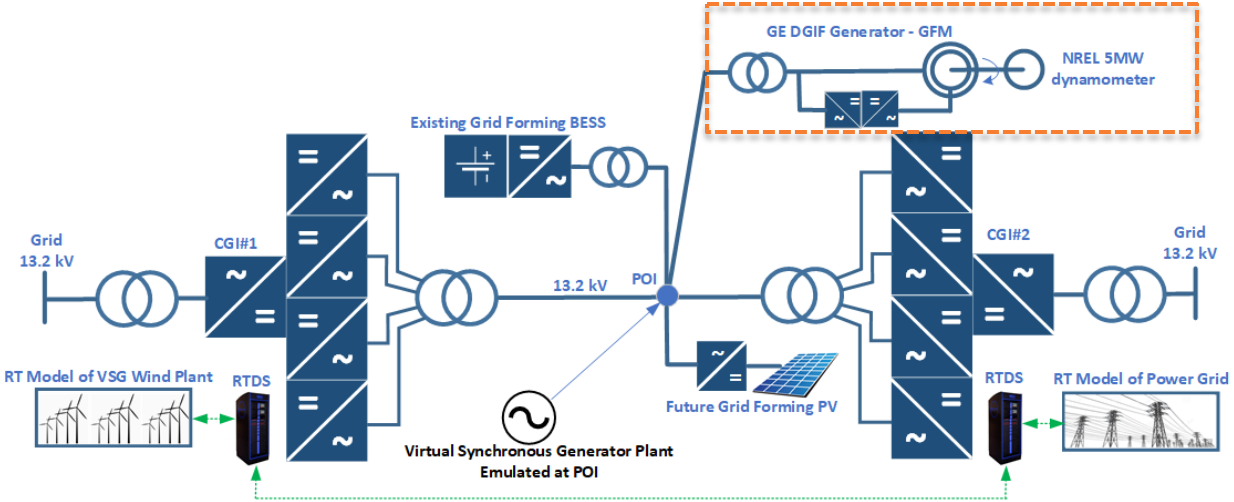




Will utilize PEGI 2 MVA synchronous generator

WETO Project: Wind as Virtual Synch Generator

Grid Forming GE 2.8 MW DFIG generator

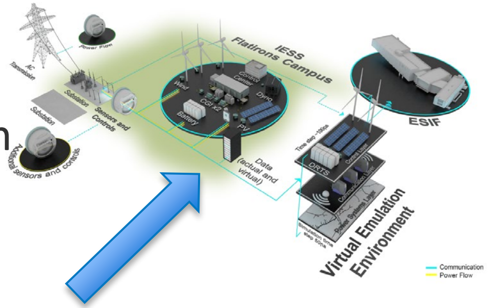


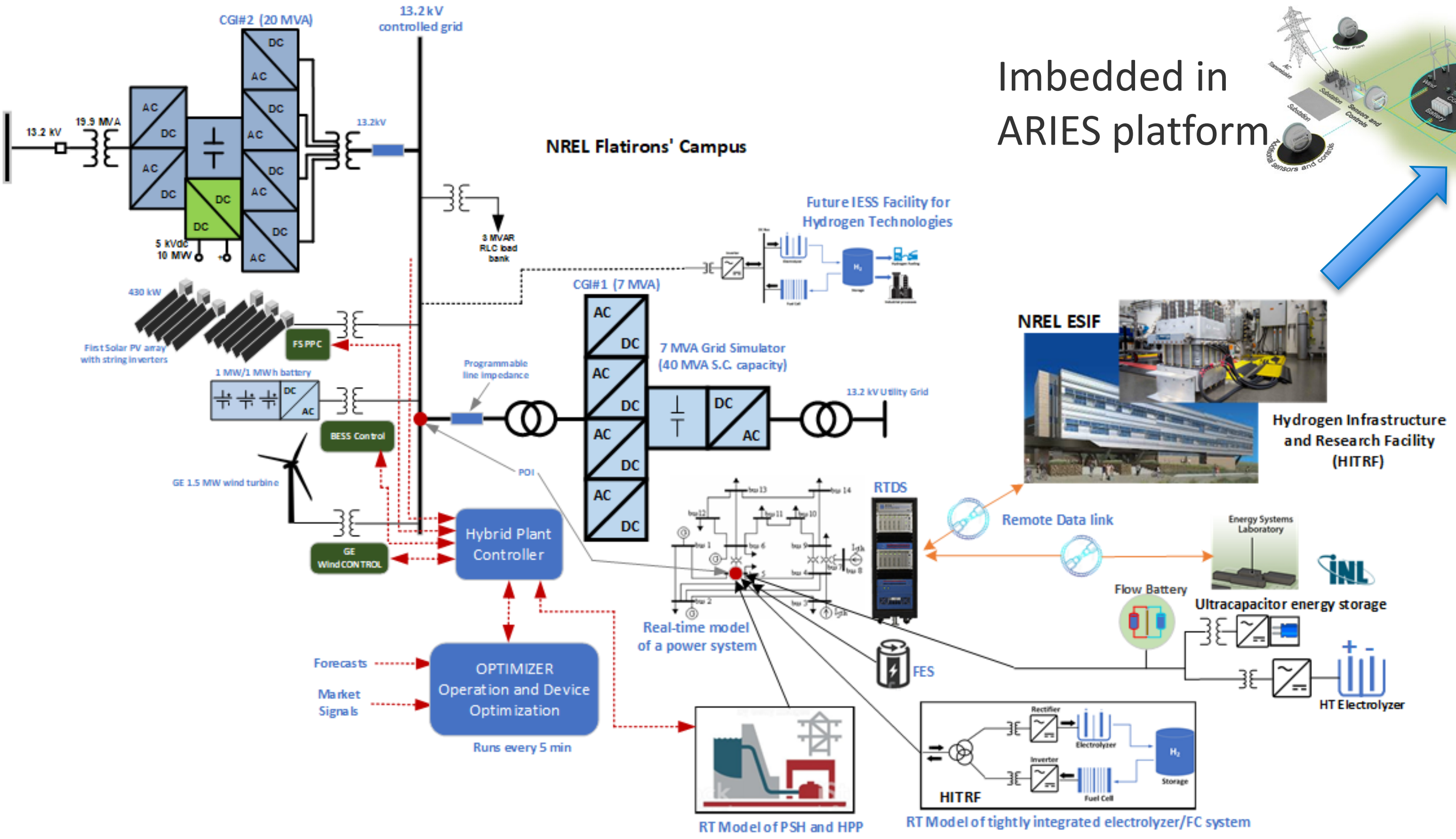
Main Objective: Development, implementation and validation of GFM controls using GE generator/converter platform with NREL's 5 MW dynamometer and Controllable Grid Interfaces

- Provision of reliability services by GFM wind power
- Transient performance by GFM wind power
- Black start and resilience services by GFM wind power

DOE GMLC: FlexPower Hybrid Plant Demonstration Platform

Imbedded in ARIES platform



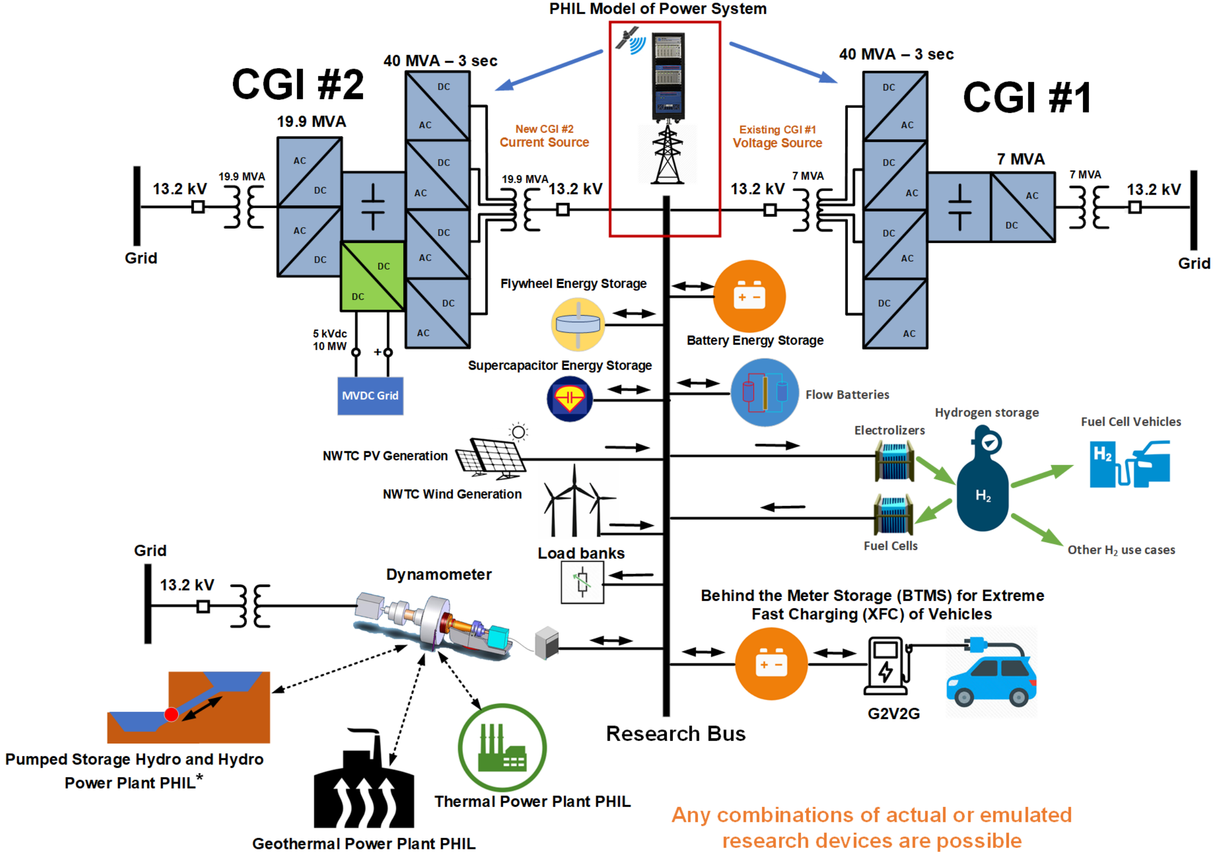


Additional assets:

- 20 MW CGI (2021)
- New RTDS
- New RTAC

Optimized Hybrid Energy Systems

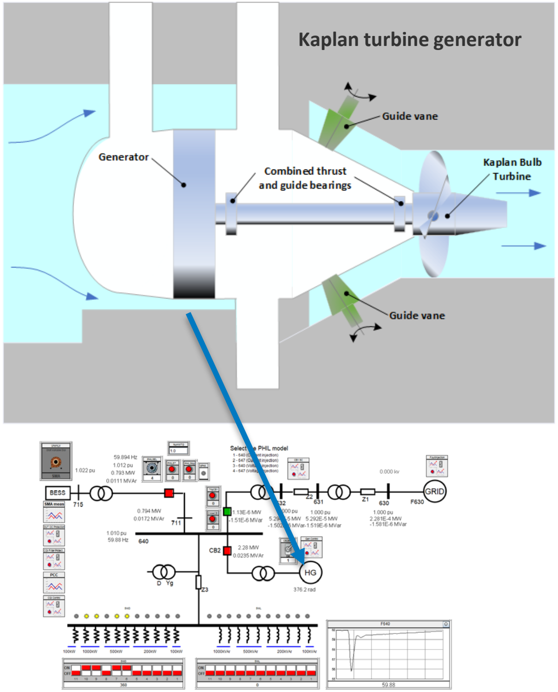
- Validation of design optimization tools and operational strategies for hybrid energy storage systems for provision of grid services at various time scales (ms-s-min-hr-day)
- Development and validation of optimized control theory for hybrid energy storage to provide essential reliability and resiliency services to the grid:
    - Optimal ratios between device level, plant level and system level controls
- Design and operation of hybrid renewable-storage plants for improved dispatchability, increased capacity factors and enhanced grid services
- Optimized storage technology mixes for microgrids and islanded systems



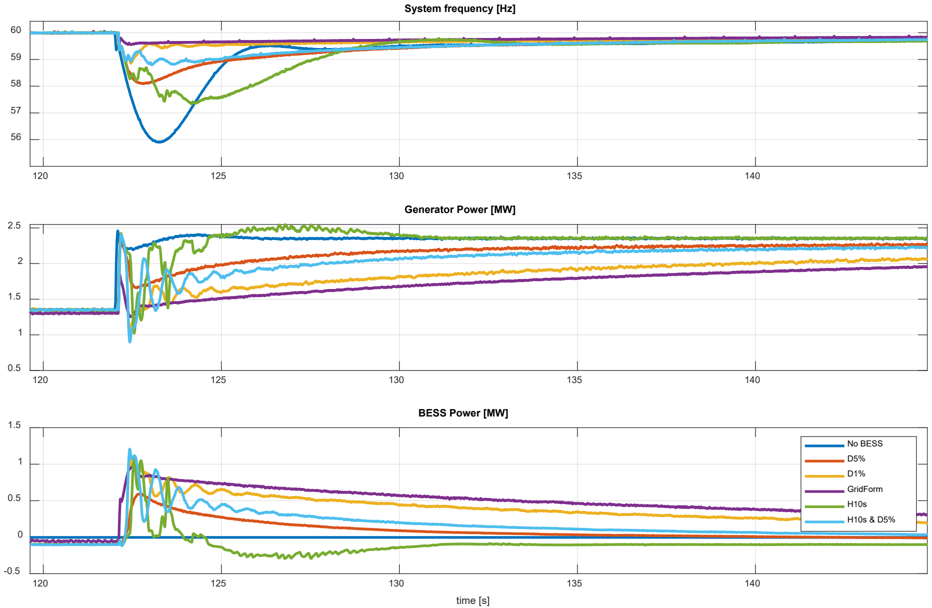
* PHIL: Power-Hardware-in-the-Loop

WPTO project: Integrated hydro- energy storage systems (INL, NREL, ANL)

PHIL Implementation of ROR Kaplan turbine generator operating with real BESS



PHIL emulation of different strategies for ROR HPP black start



Next step: Testing of developed black start controls on a real ROR plant in Idaho

Flatirons Campus microgrid operation

7am Sunday, 10/11/2020 – 8am Monday, 10/12/2020

Thank you

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Questions? Please, contact vahan.gevorgian@nrel.gov

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