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
- 2.5 MW and 5 MW dynamometers (industrial motor drives)
- 13.2 kV medium voltage grid
- 1.5 MW total PV capacity
NWTC Controllable Grid Platform

NWTC Wind Turbines
- Alstom 3 MW
- GE 1.5 MW
- Gamesa 2 MW
- Siemens 2.3 MW

SunEdison 1 MW PV Array

First Solar 430 kW PV array

AES 1.25 MW / 1.25 MWh BESS

1 MW / 1 MWh BESS

Controllable Grid Interface (CGI) for Grid and Fault Simulation (7 MVA continuous / 40 MVA s.c.)

Aerial view of the site

Image source: NREL

New 115 kV / 20 MW substation is in service

13.2 kV tie-line

115 kV

Regular grid, Xcel Bus

Controlled grid, CGI Bus

Switchgear Building

Xcel Substation

1 MW PV Array

GE 1.5 MW
Siemens 2.3 MW
Gamesa 2 MW
SunEdison
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
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

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

GE Grid Forming PV - Project Pad 5 Concept

250 kW DC Supplies (8x)
Variable speed exhaust fan (2)
2.2 MVA 500V/13.2kV Transformer
1.1MW GE Inverter (2x)
3 MVA 480V/13.2kV Transformer
Air Intake Louvers (6)
53’ Insulated Shipping Container

Grid Pad 5
NREL-PG&E Project: GFM BESS Circuits to Enhance Reliance of Distribution Grids

Island forms after CB1 trip

Island
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.
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
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

www.nrel.gov

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