Ultrafast Frequency Response of Converter-Dominant Grids Using PMUs

Presenter: V. Gevorgian
Team: H. Villegas, Iowa State University
      P. Koralewicz, E. Mendiola, S. Shah, R. Wallen, NREL

18th Wind Integration Workshop
Dublin, Ireland
October 17, 2019
What Is Fast Frequency Response?

- An alternative method to achieving faster compensation to load-generation imbalances resorts to detecting the amount of a disturbance that triggers a frequency transient.
- We propose a control strategy to deploy ultrafast frequency response (FFR) converter-based assets. The objective is to prevent relatively large frequency transients by counteracting the impact of sudden imbalances on an electric grid.
- FFR: tens of milliseconds.

\[
P_{\text{bess}}(t) = P_o(t) - 2H \frac{df(t)}{dt} + \Delta P_{\text{FFR}}(t) - \frac{f_o - f(t)}{\text{droop}} + \Delta P_{\text{AGC}}(t)
\]
This test was conducted with a commercial wind power plant controller. All plant-level and turbine-level control delays are real.
Battery energy storage system (BESS) active and reactive power in grid-following mode

BESS active and reactive power in grid-forming mode

20 ms ramp

1-MW/1-MWh BESS at NREL test site
Phasor Measurement Unit-Based Wide-Area Stability Control Concept
NREL Flatirons Campus

- Siemens 2.3 MW
- GE/Alstom 3 MW
- GE 1.5 MW
- Gamesa 2 MW
- Total of 12+ MW variable renewable generation currently
- 7-MVA controllable grid interface (CGI)
- Multimegawatt energy storage test facility
- 2.5-MW and 5-MW dynamometers (industrial motor drives)
- 13.2-kV medium-voltage grid
- 1.5-MW total photovoltaic (PV) capacity.

- PV array 1 MW
- 1-MW/1-MWh BESS
- 2.5-MW dynamometer
- FS PV array
- Research turbines 2 x 600 kW
- GE/Alstom 3 MW
- 5-MW dynamometer, 7-MVA CGI
- 1.5-MW total photovoltaic (PV) capacity.
Flexible test bed for many black-start schemes

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

Regular grid, Xcel Bus

Controlled grid, CGI Bus

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

Switchgear Building

13.2 kV tie-line

Xcel Substation

115 kV

Aerial view of the site

Image source: NREL

Photo by NREL
NREL’s Advanced Test Bed for Wide-Area Stability Controls Validation
Phasor Measurement Unit-Based System Characterization Test Setup

- GPS clock synchronization across all devices
- CGI voltage, angle, frequency perturbation injection through RTDS
- Perturbation captured on MVDAS and phasor measurement unit (PMU)
- Synchrophasor data paths
  - PMU to RTAC
  - PMU to PDC
  - PDC to RTAC.
- Time-align all synchrophasors to MVDAS capture.

50-kHz NREL-developed DAS for timing and measuring transfer functions of PMU-based networks

Controlled disturbances emulated by power-hardware-in-the-loop (PHIL)
Transfer Function: 5% Magnitude Injection
Transfer Function: 0.5-Hz Frequency Injection
Transfer Function: 0.1 Rad Angle Injection
Solution ensures that all positive-sequence bus voltages, and the currents leaving a bus, become available at a phasor data concentrator facility by direct measurement and/or estimation.
IEEE 39-bus test system

Load-generation disturbance detection dynamics

No PMU-based FFR controls

With PMU-based FFR controls
Fast Frequency Response and Backup Option

- FFR response is dispatched to participating wind and storage plants based on estimated generation or load loss $\Delta P$ from PMU-based algorithm.
- If accuracy of PMU-based measurements is compromised (communications loss or cyberattack), then local aggressive droop control will kick in as a backup response.
Results of PHIL Experiment Using Fast Frequency Response by Battery Energy Storage System
1.5-MW Wind Turbine Generator
Active Power Modulation (25 kW pk-to-pk)
Transfer Function Analysis

- Transfer function for active power has been identified
- Stable amplitude response up to 0.3 Hz
- Phase delay is declining with oscillation frequency
- For higher oscillation frequencies, compensation technique can be applied.
Testing of 1.5-MW Type 3 Wind Turbine Generator for Power System Oscillation Damping Services
Ability of DFIG Wind Turbine Generator to Provide Simultaneous Modulation of P and Q
Conclusions and Future Plans

- Inverter-coupled resources are capable of providing FFR.
- PMU-based estimation of needed system-level FFR response is possible, but:
  - How can it be done in an optimal way?
  - How can it address the curtailment issue?
  - What is the optimal ratio between FFR and conventional droop resources?
  - FFR by grid-forming resources—still needs to be studied.
- Curtailed inverter-coupled resources have the potential for the provision of wide-area stability services using PMU-based controls as well.
Thank you!

Go raibh maith agat!

www.nrel.gov

Vahan.Gevorgian@nrel.gov

NREL/PR-5D00-75259