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Wide Area Control Systems

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Wide Area Control Systems

David Schoenwald, Sandia National Labs
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Outline

Acknowledgements

Wide area control systems:
  ◦ High Voltage DC
  ◦ Energy storage
  ◦ Wind turbine
  ◦ Frequency Estimation
Acknowledgements

Work in wide area controls is performed with funding from:
- DOE Advanced Grid Modeling Program of the DOE Office of Electricity
- DOE Energy Storage Program of the DOE Office of Electricity
- DOE Transmission Reliability Program of the DOE Office of Electricity
- DOE Office of Energy Efficiency and Renewable Energy SunShot Program
- Bonneville Power Administration (BPA) Office of Technology Innovation

Project team includes:
- Ray Byrne, SNL
- Ricky Concepcion, SNL
- Ryan Elliott, SNL
- Jason Neely, SNL
- Brian Pierre, SNL
- Dave Schoenwald, SNL
- Felipe Wilches-Bernal, SNL
- Prof. Dan Trudnowski, Montana Tech University
- Prof. Matt Donnelly, Montana Tech University
- Prof. Josh Wold, Montana Tech University
Inter-Area Oscillations Jeopardize Grid Stability

Western Power System Breakup on August 10, 1996
Inter-Area Oscillation Damping Control

- Based on 1970s BPA experiments on Pacific DC Intertie (PDCI) later shown to have destabilized BC-US oscillatory mode.
- Idea revived in 2007 - 2012 by BPA with Montana Tech leveraging Phasor Measurement Unit (PMU) deployments in Western Interconnection.
- Project launched in June 2013 as a collaboration of SNL, MTU, BPA, and DOE to develop and demonstrate damping control on the North-South oscillatory mode using wide-area PMUs for real-time feedback.
Visualizing Oscillatory Mode Shapes

North South Mode
0.36 Hz, 13.7% damping
Excitation Methods for System Identification

Natural disturbances

Chief Joseph Brake (1.4GW, built in 1974)

Pacific DC Intertie Probing Signal Generator
Inter-Area Oscillations Jeopardize Grid Stability

Western Power System Breakup on August 10, 1996

Power systems are susceptible to low frequency oscillations caused by generators separated by long transmission lines that oscillate against each other.

These oscillations are not as well damped as higher frequency "local" oscillations.

High penetration of renewable generation can impact damping ➔ potential reduction in reliability.
BPA Damping Controller Project

1. PMUs take measurements
2. PMUs send data packets over network
3. Packets arrive at damping controller
4. Controller sends power command to PDCI
5. PDCI injects power command into grid
BPA Damping Controller Hardware

- Watchdog circuit module
- Key switch
- Heartbeat indicators
- E-Stop button
- Server for select supervisory functions
- Real-time Control platform
Analysis, Simulations, and Post-Testing Analysis

Inject disturbances and analyze ringdowns
System identification (e.g. Prony, ERA)
Simulation tools
  ◦ GE, PSLF
  ◦ Siemens, PSSE
  ◦ PowerWorld
  ◦ Powertech Labs, SSAT
  ◦ MATLAB
Model validation with test results.
Repeat tests multiple times per day,
different times of year,
over several years.

Typical System Model (WI)
• 19,000 buses
• 4,000 generators
• 9,000 loads
• 8,000 transformers
• 16,000 transmission lines
Tests conducted at Celilo Converter Station on September 28-29, 2016

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief Joseph Brake test</td>
<td>Damping of North-South B Mode improved 4.5 percentage points (11.5% to 16.0%) in closed-loop vs. open-loop operation.</td>
</tr>
<tr>
<td>Square wave pulse test test</td>
<td>Damping controller significantly reduces amplitude of North-South B mode oscillations in 15 seconds vs. 23 seconds in open-loop tests for the same reduction.</td>
</tr>
<tr>
<td>All tests</td>
<td>Controller consistently improves damping and does no harm to grid.</td>
</tr>
</tbody>
</table>
Frequency Estimation to Enable “Virtual” Inertia

- The increase of converter interfaced generation both at the transmission and distribution levels is creating unprecedented challenges to the grid operation.
- Frequency is a key indicator of network stability and the balance between generation and consumption (plus losses).
- Key research question: For a corrupted/distorted waveform, what is frequency?

**Problem:** inertial response and primary frequency regulation of the system is affected (stability of the system is threatened)

**Solution:** fast power injections controllers (or synthetic inertia) using CIG ➔ need estimate of frequency
Damping Control Using Distributed Energy Resources

Advantages:

• Robust to single points of failure
• Controllability of multiple modes
• Size/location of a single site not critical as more distributed energy resources are deployed on grid
• With 10s of sites engaged, single site power capability ≈ 1 MW can provide improved damping
• Control signal is energy neutral and short in time duration ➔ sites can perform other applications
PDCI damping controller was modified to modulate the torque command of a wind turbine at Sandia wind facility (SWiFT).

Actuator (wind turbine) is remote – not co-located with the controller.

Communication channel used the public internet.
Conclusions

• With wide-area measurement systems and distributed energy assets being deployed at an increasing rate ➔ wide-area controls has become more feasible.

• Project with BPA/MTU was the first successful demonstration of wide-area control using real-time PMU feedback in North America and won a 2017 R&D 100 Award.

• Commercialization of DCON being pursued jointly with BPA.

• Biggest driver for the need of wide-area control systems s the rapid adoption of renewables and converter-connected resources on the grid.