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Wide Area Control Systems

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PRESENTED BY

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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:

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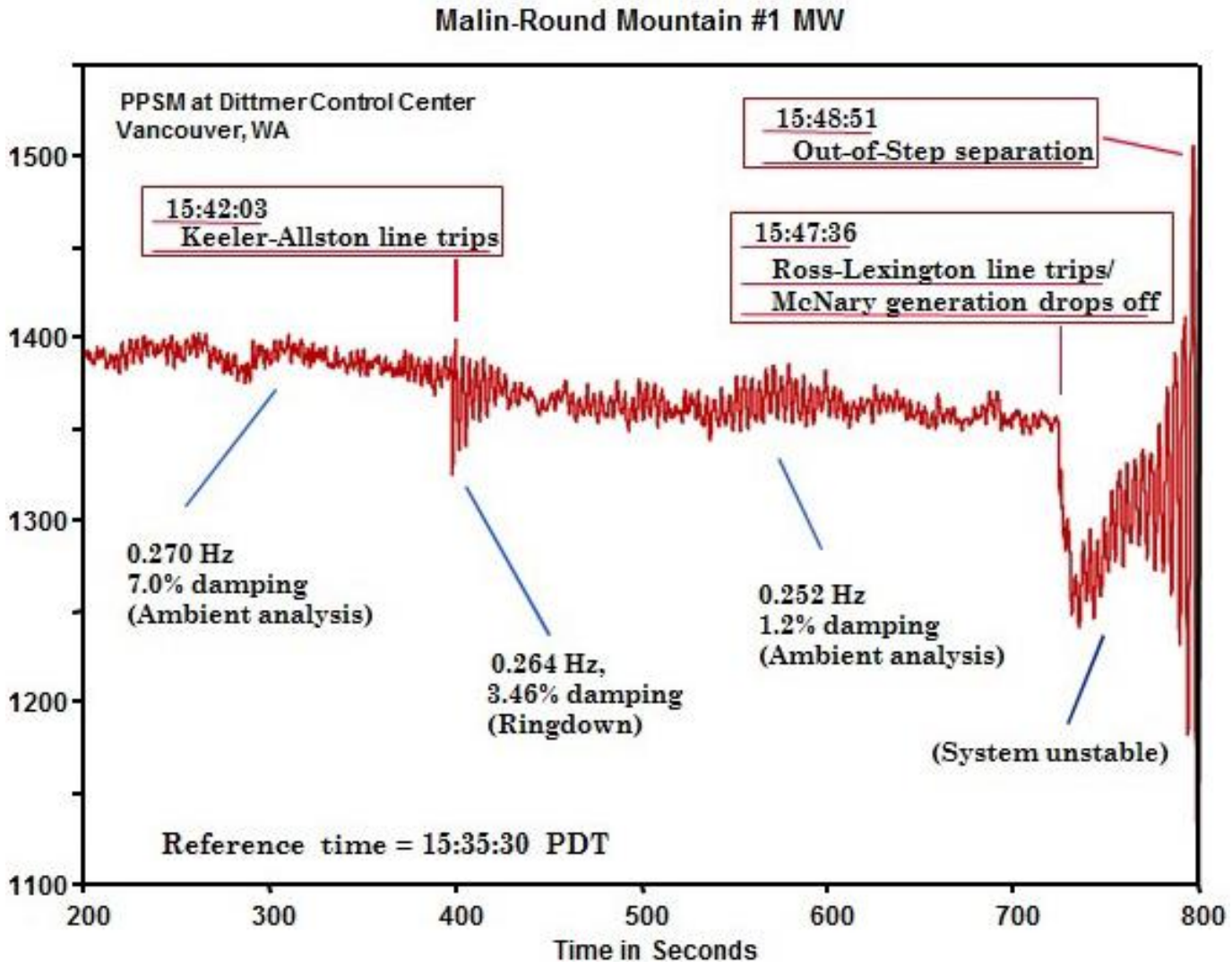
- Jason Neely, SNL
- Brian Pierre, SNL
- Dave Schoenwald, SNL
- Felipe Wilches-Bernal, SNL
- Prof. Dan Trudnowski, Montana Tech University
- Prof. Matt Donnelly, Montana Tech University
- Prof. Josh Wold, Montana Tech University

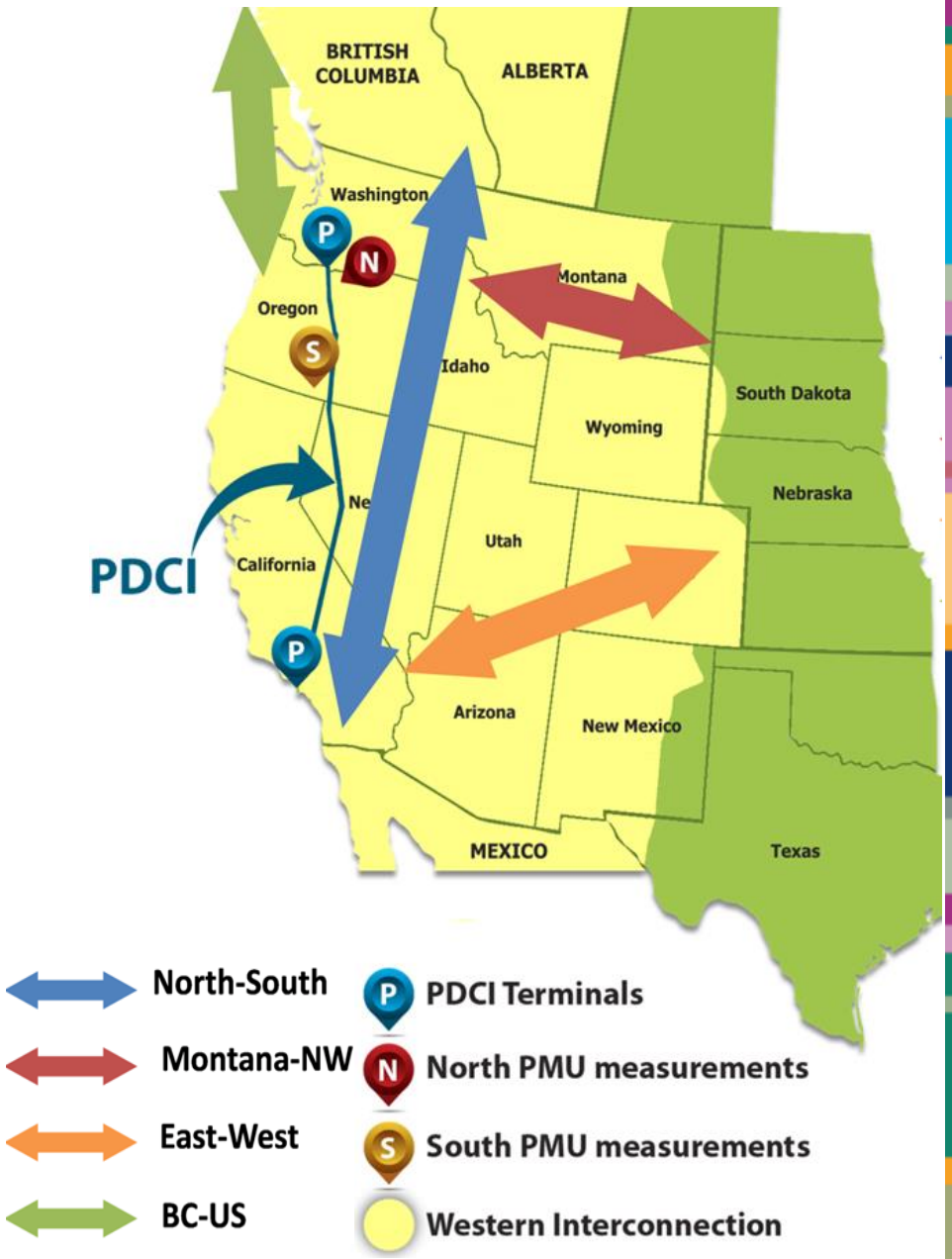
Inter-Area Oscillations Jeopardize Grid Stability

Western Power System Breakup on August 10, 1996



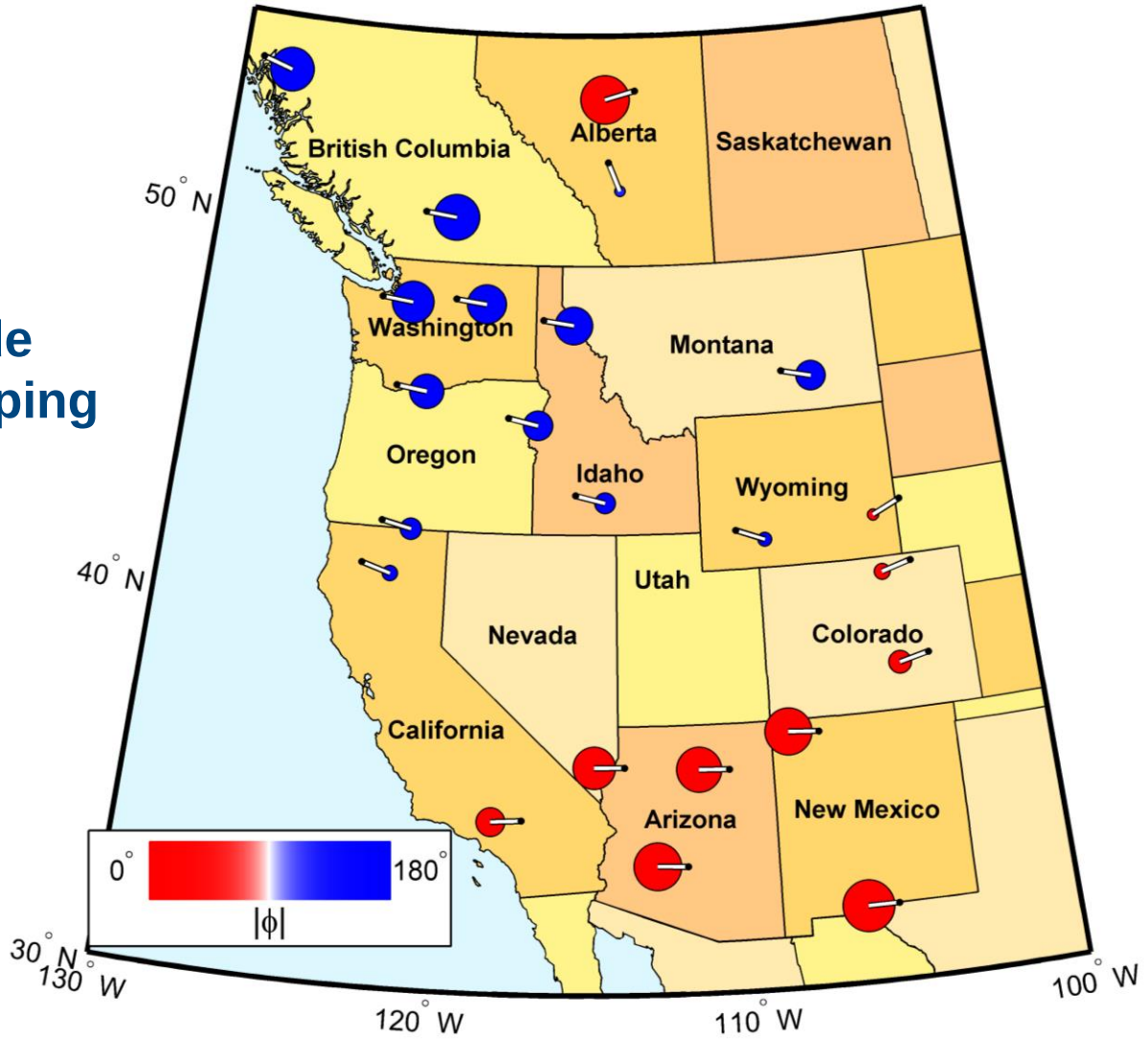
Inter-Area Oscillation Damping Control

- 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

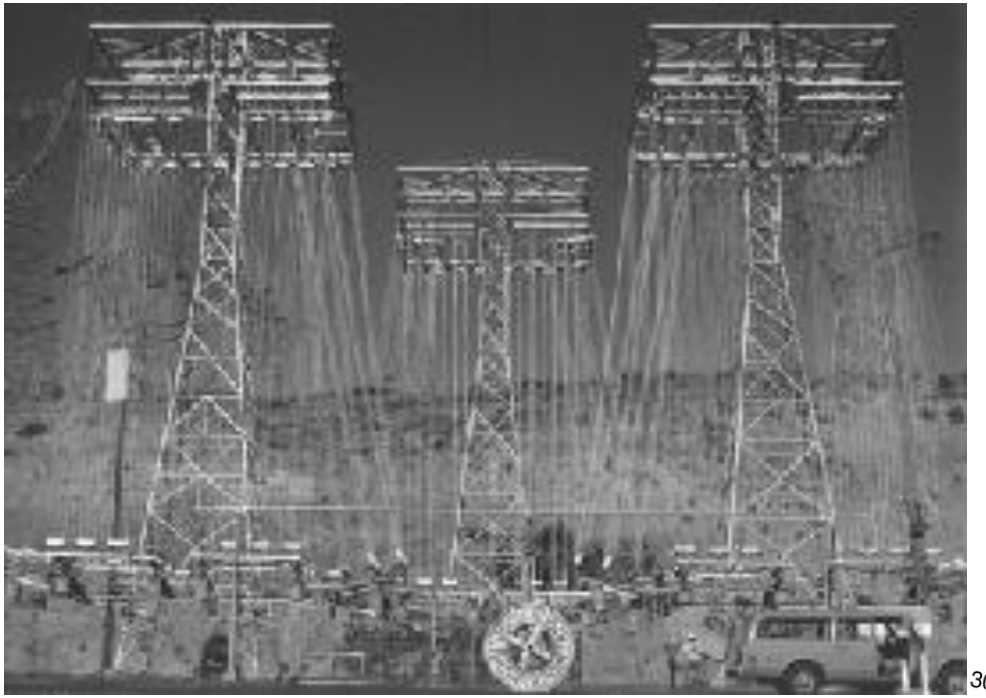


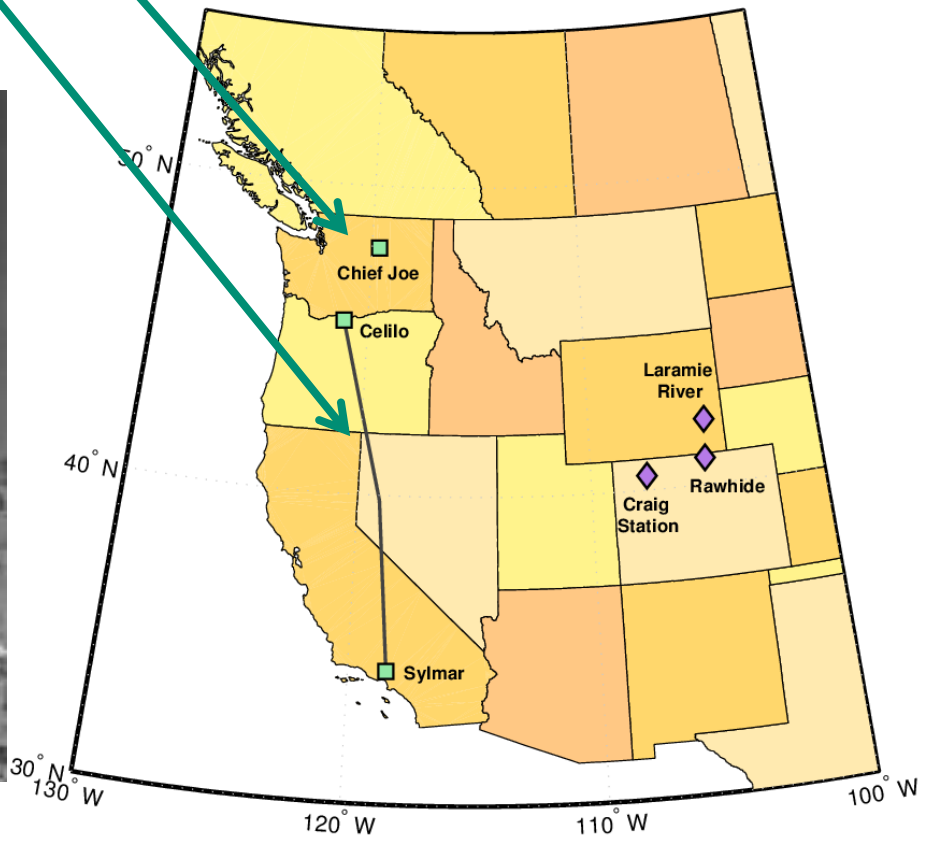
Excitation Methods for System Identification

Natural disturbances

Chief Joseph Brake (1.4GW, built in 1974)

Pacific DC Intertie Probing Signal Generator





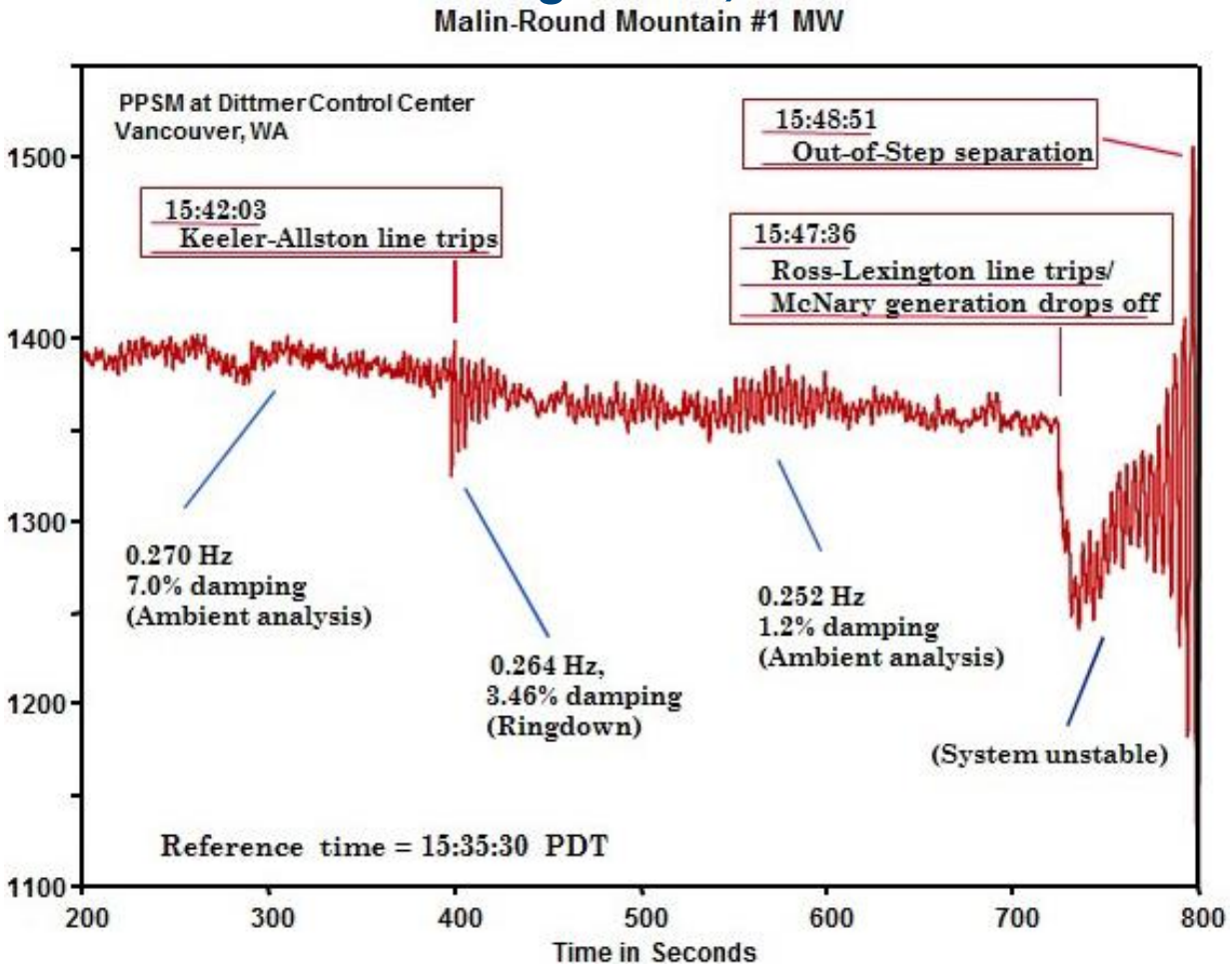
Inter-Area Oscillations Jeopardize Grid Stability

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

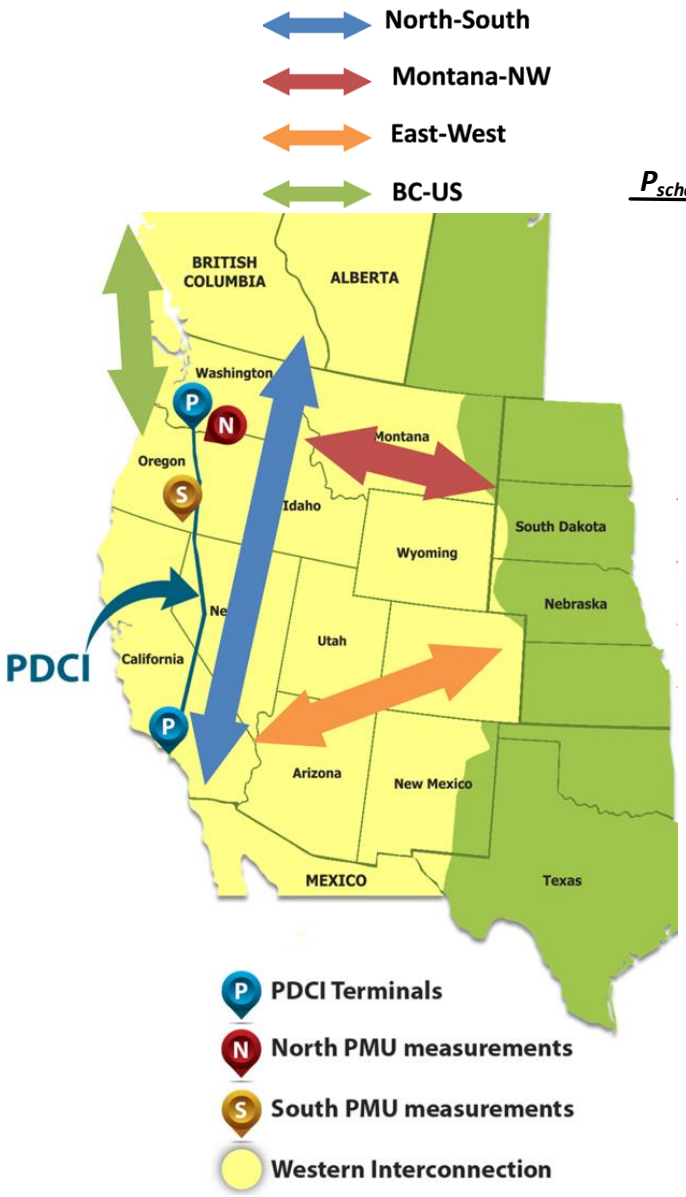
These oscillations are not as well damped as higher frequency "local" oscillations

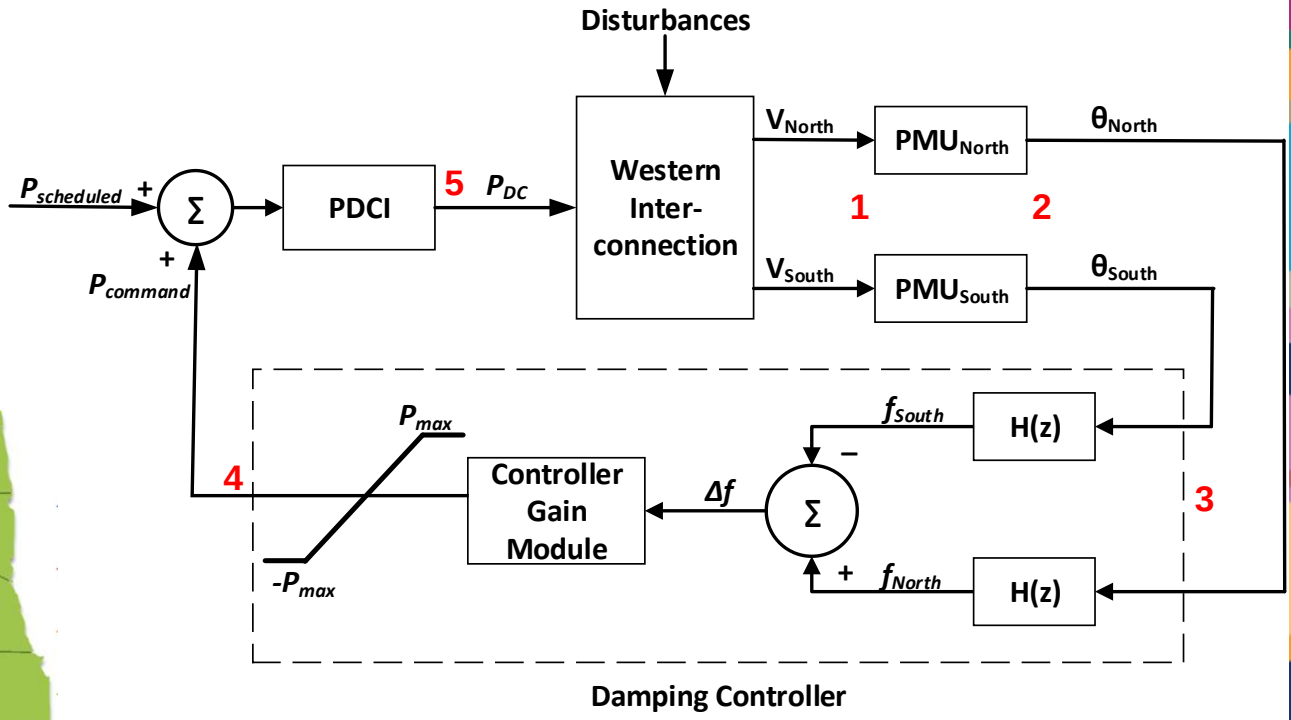
High penetration of renewable generation can impact damping ➔ potential reduction in reliability

Western Power System Breakup on August 10, 1996



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

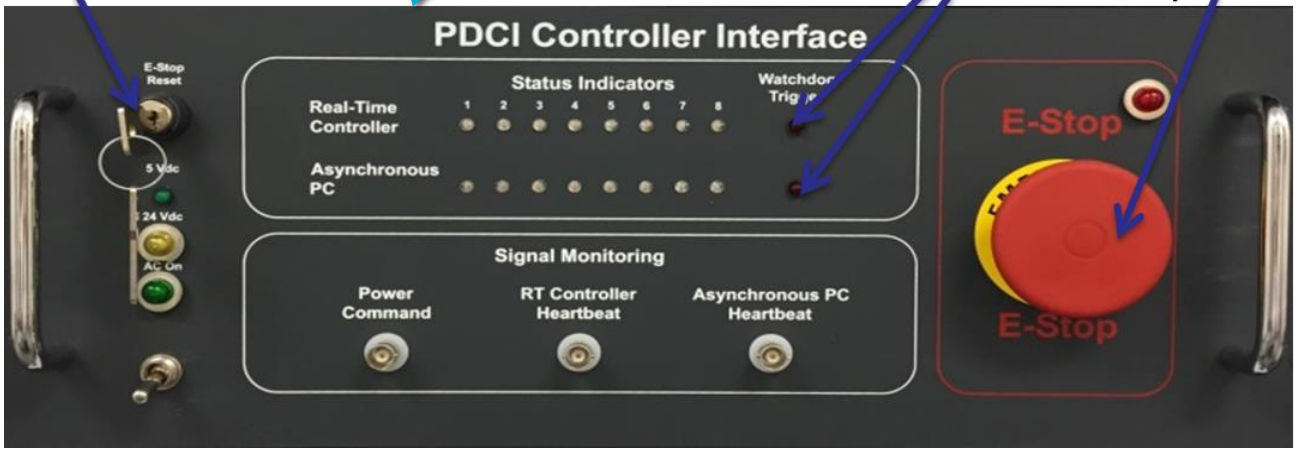
BPA Damping Controller Hardware

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

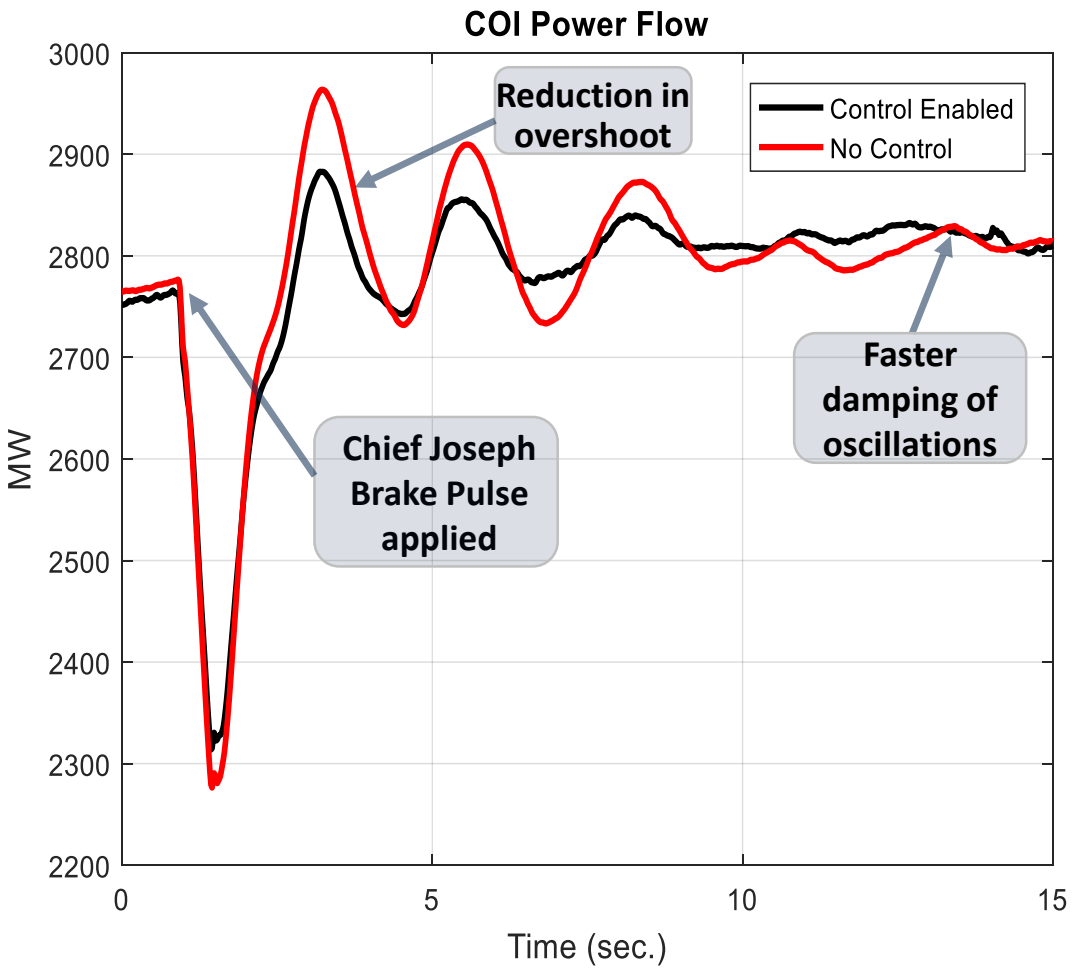
Model validation with test results.

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

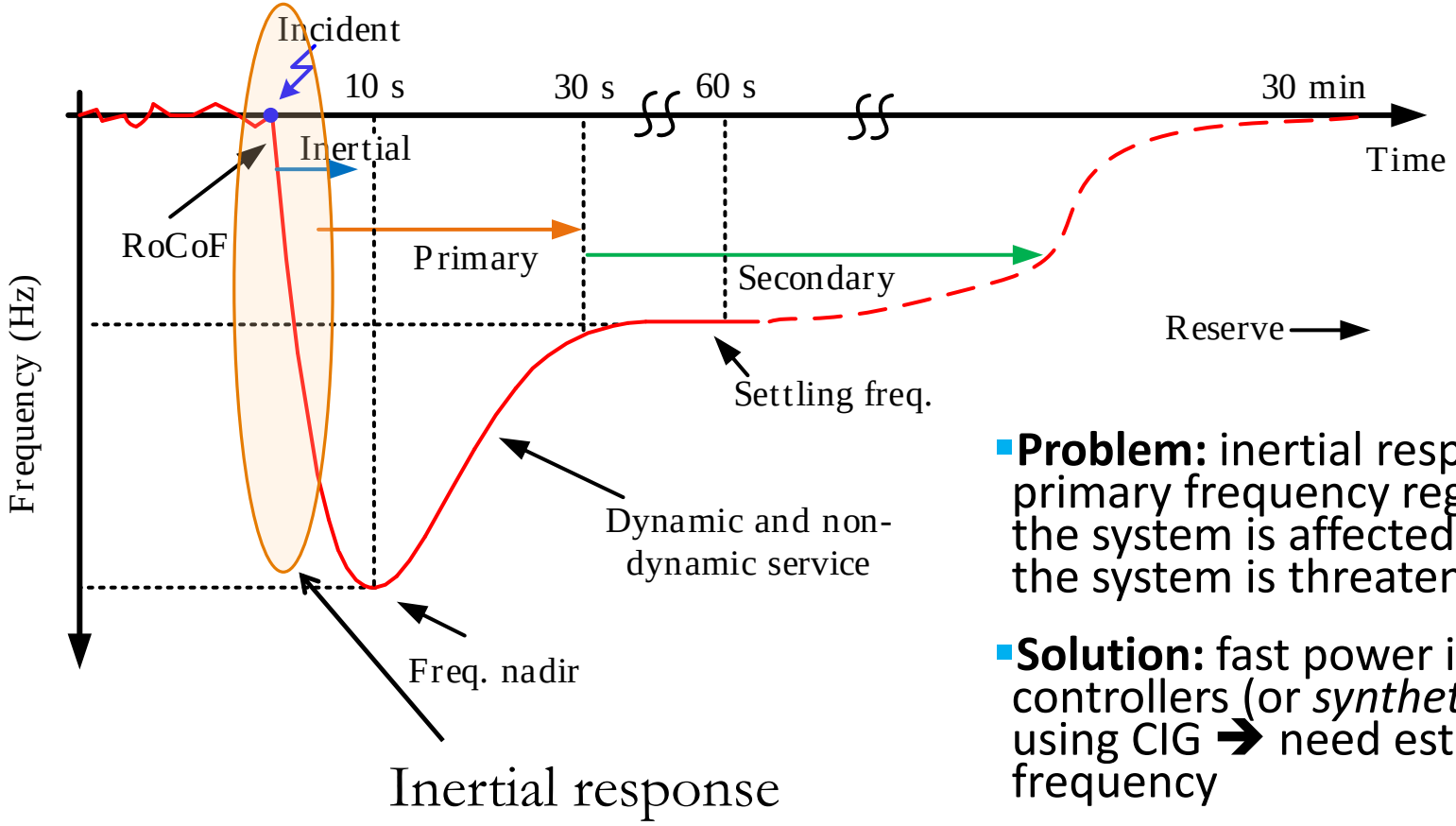
Tests conducted at Celilo Converter Station on September 28-29, 2016



Chief Joseph brake test	Damping of North-South B Mode improved 4.5 percentage points (11.5% to 16.0%) in closed-loop vs. open-loop operation.
Square wave pulse test	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.
All tests	Controller consistently improves damping and does no harm to grid.

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?

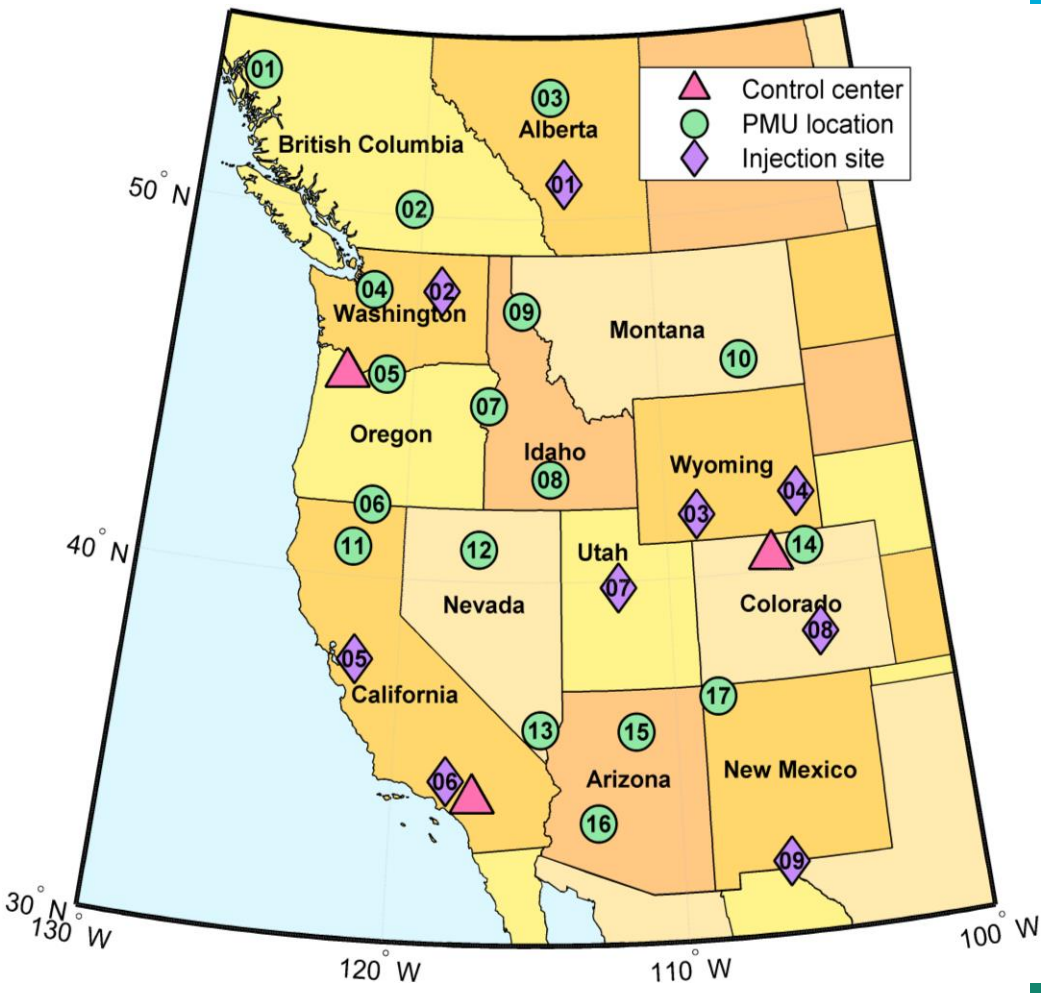


- **Problem:** inertial response and primary frequency regulation of the system is affected (stability of the system is threatened)
- **Solution:** fast power injections controllers (or *synthetic* inertia) using CIG ➔ need estimate of frequency

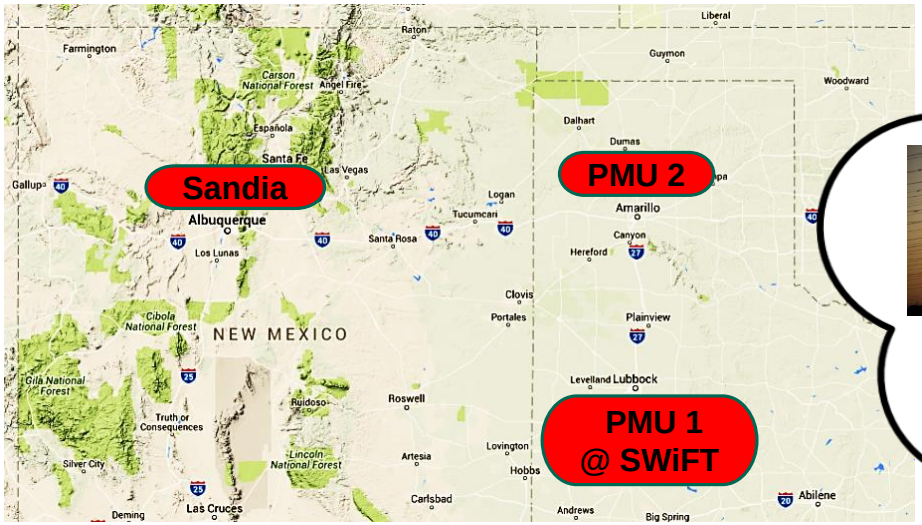
Damping Control Using Distributed Energy Resources

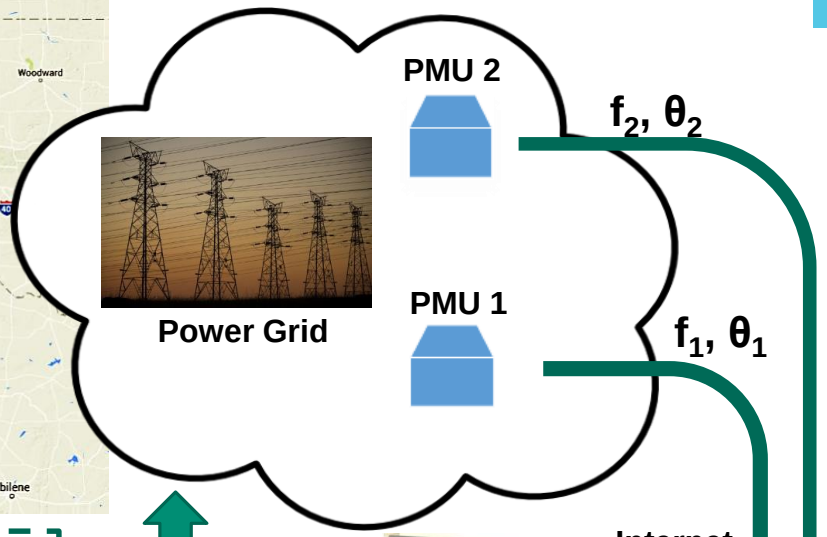
Advantages:

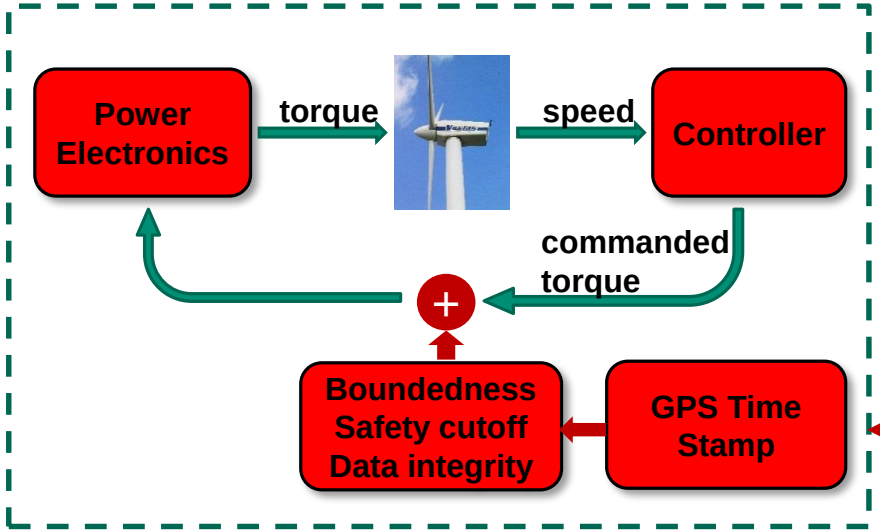
- Robust to single points of failure
- Controllability of multiple modes
- Size/location of a single site not critical as more distributed energy resources are deployed on grid
- With 10s of sites engaged, single site power capability ≈ 1 MW can provide improved damping
- Control signal is energy neutral and short in time duration ➔ sites can perform other applications



Damping Control Using Wind Turbines







Real Power Flow

X-Net

Command Level Controller at SNL

- 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.