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Damping of Power Grid Oscillations Using Energy Storage and PMU Feedback

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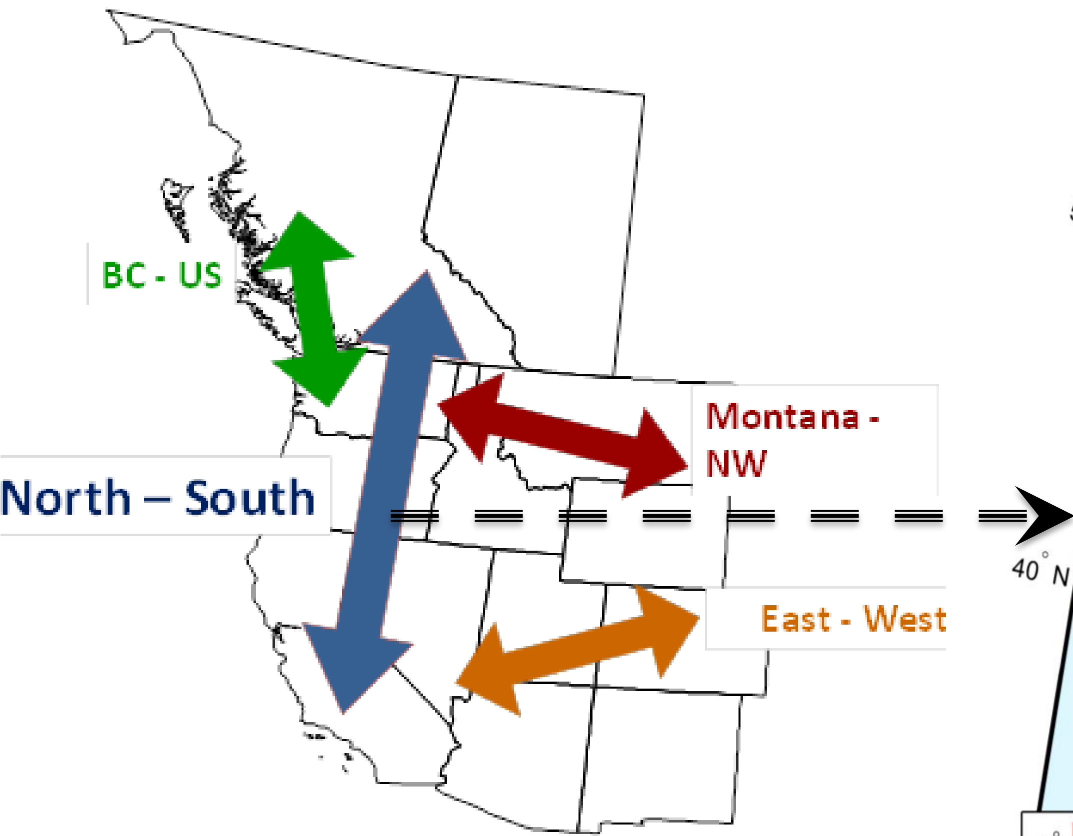
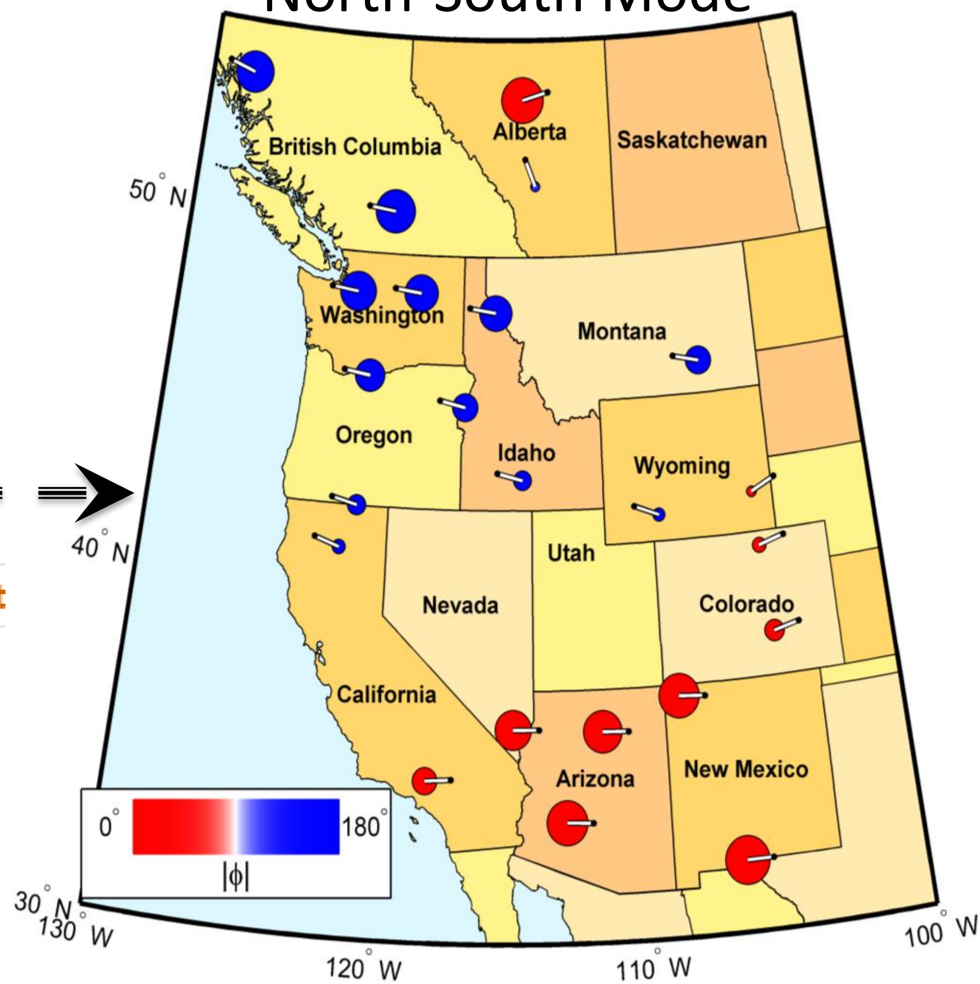
  - BPA Technology Innovation Office – Project # 289

Project Overview

- **Objectives:**
  - Design and construct a prototype control system to damp inter-area oscillations by using HVDC modulation and real-time PMU feedback.
  - Design and simulate a distributed damping control system based on energy storage and wide-area PMU feedback.
- **Status:**
  - A prototype control system has been developed, which modulates active power through the Pacific DC Intertie (PDCI) and uses frequency information from BPA-based PMUs for real-time feedback control.
  - The prototype has been successfully demonstrated in open loop and probe testing mode on the PDCI and will shortly be tested in closed loop operation.

Western Interconnect Oscillation Modes

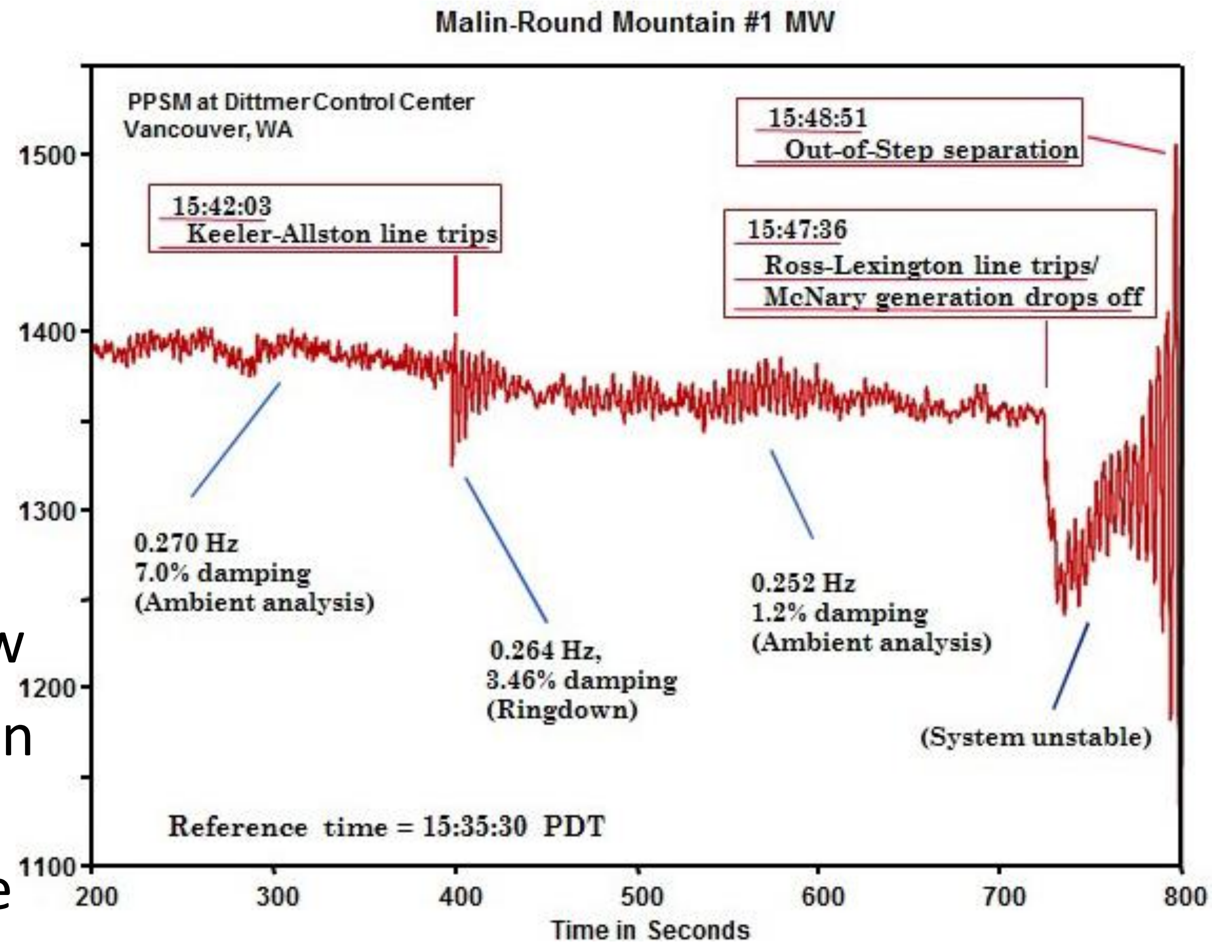




Inter-Area Oscillations Jeopardize Grid Stability

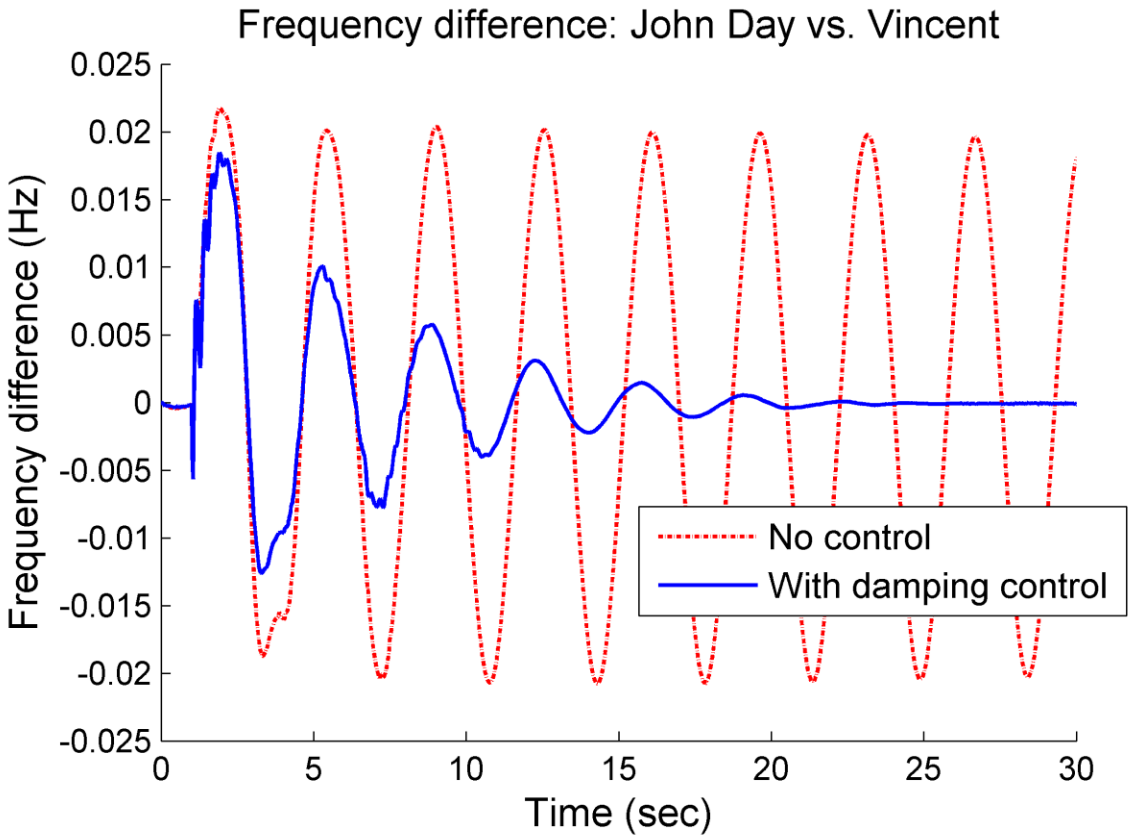
- Large generation and load complexes separated by long transmission lines can develop inter-area oscillations
- Present approach to mitigate this scenario is to maintain large headroom in power flow
- More efficient mitigation strategy is active power injection using real-time PMU feedback

August 10, 1996 Western Power System Breakup



Expected Benefits

- Improved system reliability
- Additional contingency in a stressed system condition
- Economic benefits:
  - Avoidance of costs from an oscillation-induced system breakup (e.g., 1996)
  - Potential future reduced need for new transmission capacity

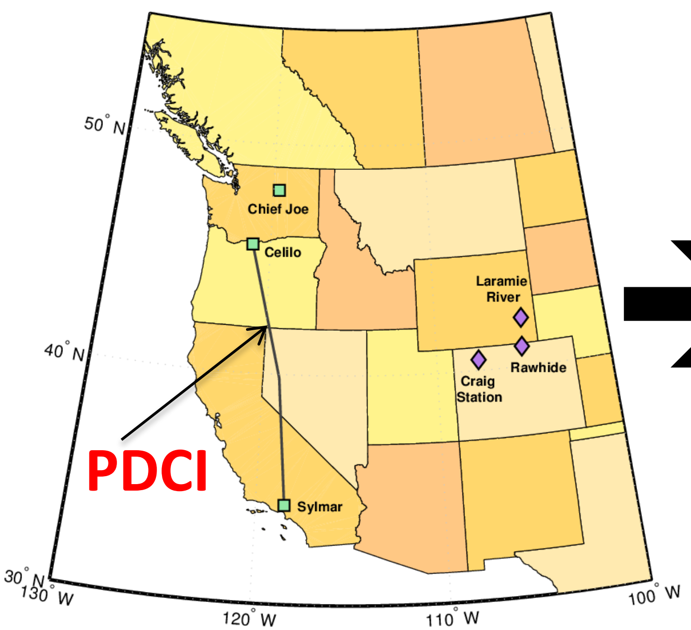


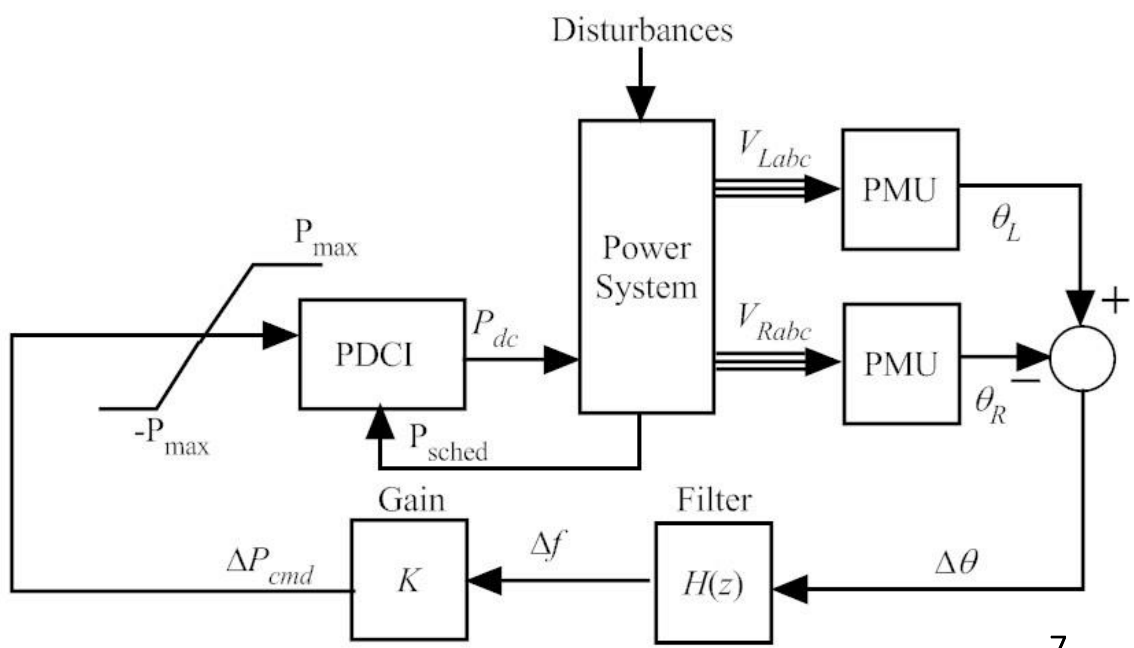
PSLF simulation of control system response to BC-Alberta separation (outage of Cranbrook-Langdon intertie)

Design Objectives for PDCI-based Controller

- Control Objectives:
  - Dampen all modes of interest for all operating conditions w/o destabilizing peripheral modes
  - Do NOT worsen transient stability (first swing) of the system
  - Do NOT interact with frequency regulation

Feedback control should be proportional to frequency difference of the two areas (Local minus Remote)





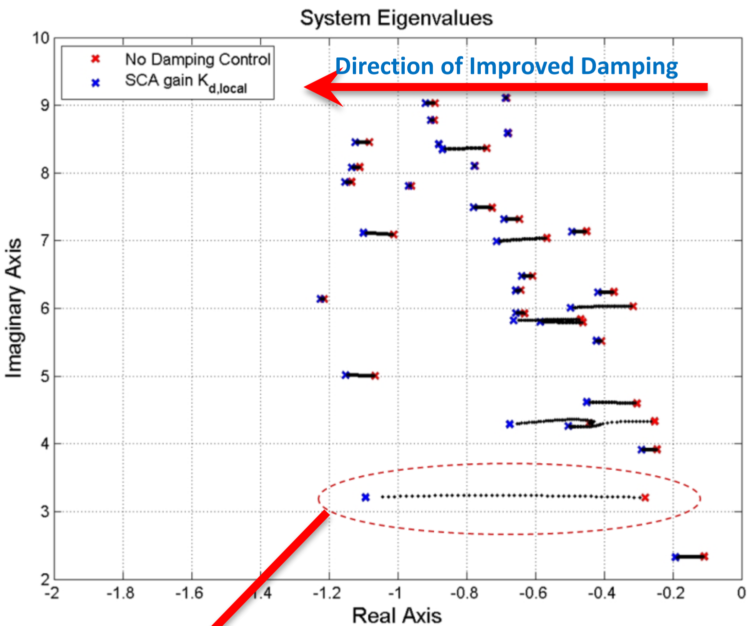
Energy Storage–Based Damping Strategy: Multi-Node Distributed Control

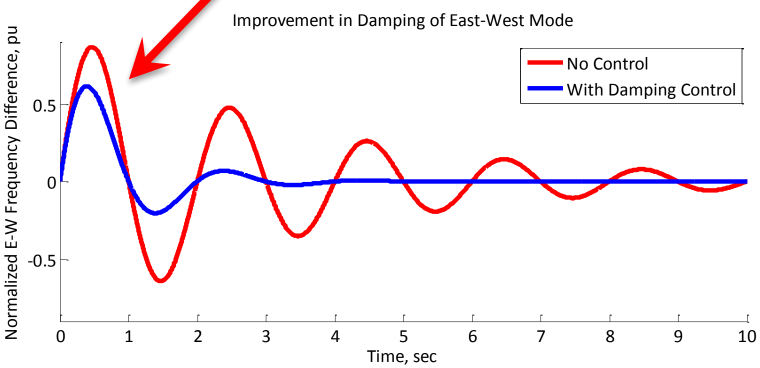
Advantages:

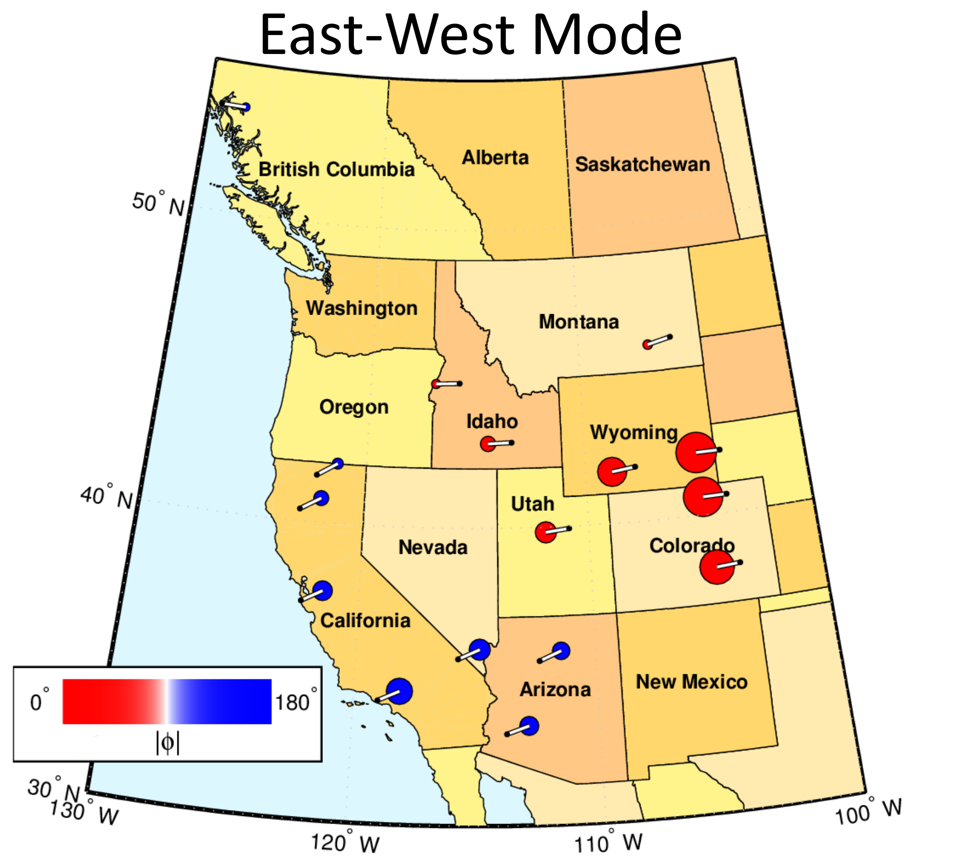
- Robust to single points of failure
- Controllability of multiple modes
- Size/location of a single site not as critical as more storage is deployed

Damping Control using Distributed Storage

- Total storage capacity on order of 20 – 50 MW is sufficient
- With 10s of sites deployed, individual ESS capacity ≤ 1 MW will work
- Control strategy uses existing ESS ➔ minimal additional cost for large benefit







J. Neely, et al, "Structured Optimization for Parameter Selection of Frequency-Watt Grid Support Functions for Wide-Area Damping," *International Journal of Distributed Energy Resources and Smart Grids*, vol. 11, no. 1, pp. 69-94, 2015.

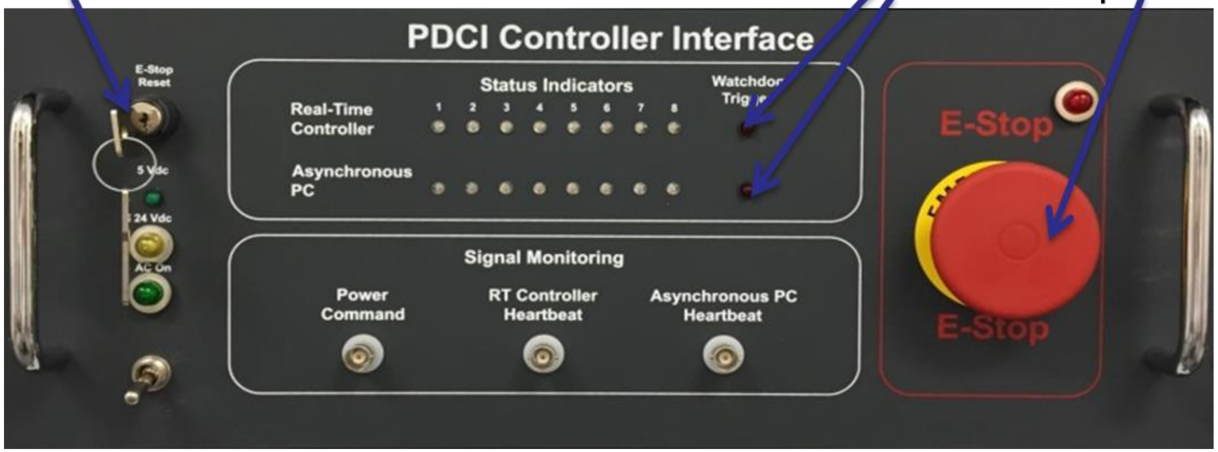
Supervisory System Ensures "Do No Harm"

Watchdog circuit hardware supervisor

Key switch

Heartbeat indicators

E-Stop button



Best in Conference Paper Award Session, 2016 IEEE PES General Meeting, Boston, MA, July 18, 2016, B. Pierre, R. Elliott, D. Schoenwald, J. Neely, R. Byrne, D. Trudnowski, and J. Colwell, "Supervisory System for a Wide Area Damping Controller Using PDCI Modulation and Real-Time PMU Feedback".

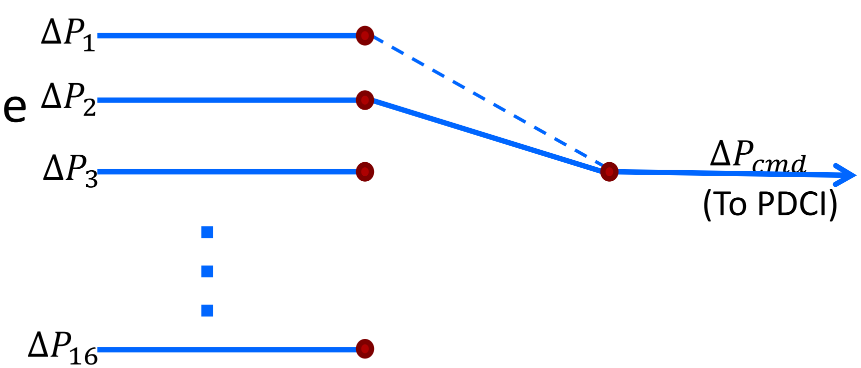
Server for select supervisory functions

Real-time Control platform

Redundancy and Diversity in Feedback

- Diversity ≡ Geographic Spread Redundancy ≡ Multiple PMUs/site
- Controller reads 8 PMUs every update cycle (16.67 ms)
  - 4 local and 4 remote
  - 16 possible PMU feedback pairs
- These 16 real-time feedback pairs, constructed in parallel, are prioritized off-line based on simulation studies.
- Controller continuously re-evaluates rankings of all 16 pairs based on observed data quality and measured latencies.
- Controller seamlessly switches to a different pair based on the most recent rankings of the 16 pairs.
- Typical latencies measured to date are well within tolerances.
  - Network latencies of PMU data are 5-25 ms
  - Actuator bandwidth is above 5 Hz with delay ≈ 20 ms

Index	Local PMU	Remote PMU
1	Local Site 1, PMU 1	Remote Site 1, PMU 1
2	Local Site 1, PMU 1	Remote Site 1, PMU 2
3	Local Site 1, PMU 2	Remote Site 1, PMU 1
⋮	⋮	⋮
16	Local Site 2, PMU 2	Remote Site 3, PMU 1



Summary/Conclusions

- We have built a damping controller based on real-time PMU feedback to modulate power on the PDCI.
- We have conducted extensive simulation studies based on HVDC and energy storage actuation that show significantly improved damping with no harm to the grid.
- Open-loop tests were conducted on the PDCI on Sept. 13, 2016 with very encouraging results.
- Closed-loop tests will be conducted on the PDCI on Sept. 28-29, 2016.
- We have developed and tested a supervisory system to enable robust, reliable, and safe performance.
- We have proposed and simulated multiple candidate damping controllers based on power injection from distributed energy storage sites. Specific work on architecture implementation and the impact of network communication constraints is ongoing.

Thank You to Dr. Imre Gyuk and the DOE/OE for their dedication and support to the ESS community.

Questions?

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