SAND2016-0472C

Technology Innovation

TIP 289: Wide Area Damping Control Proof-of-Concept Demonstration

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Project Summary

- Goal: Design and demonstrate a prototype control system to damp inter-area oscillations.
- Status: Two approaches under investigation.
  1. Modulation of active power through the Pacific DC Intertie (PDCI) ➔ deployment phase
  2. Injections of real power to the grid using distributed energy storage ➔ design phase

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Project Participants

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- Project Consultant:
  - Dr. John Undrill

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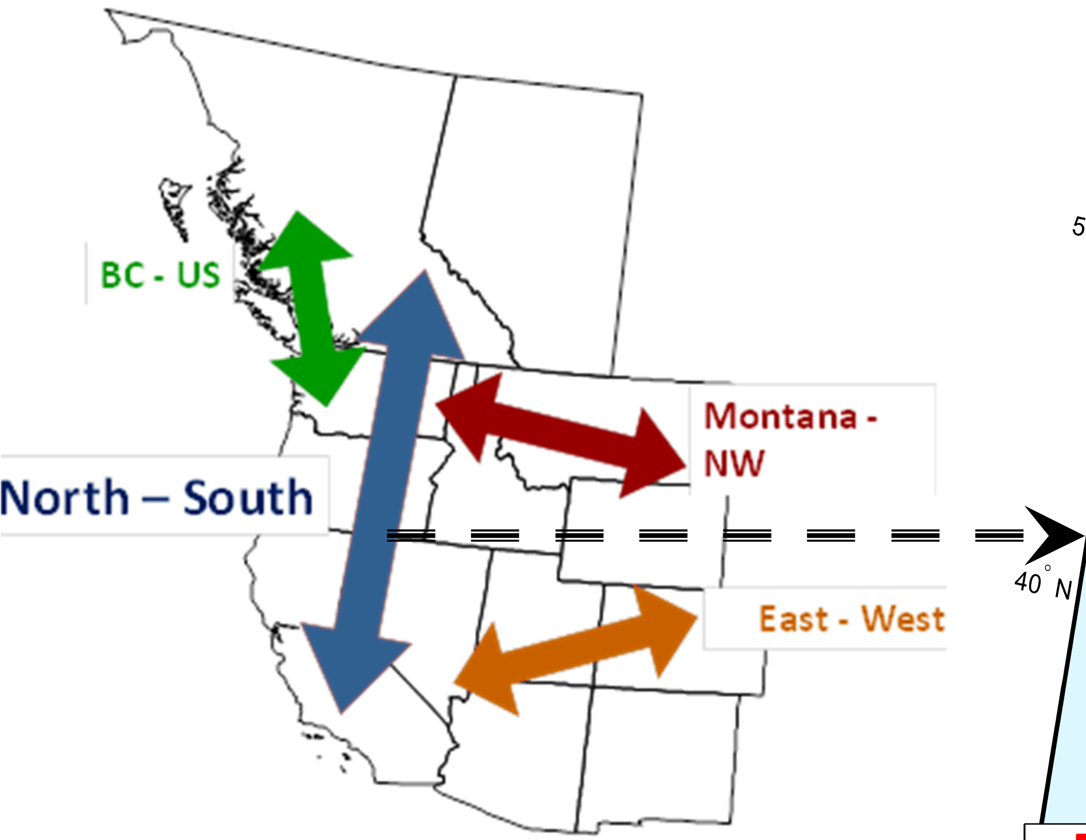
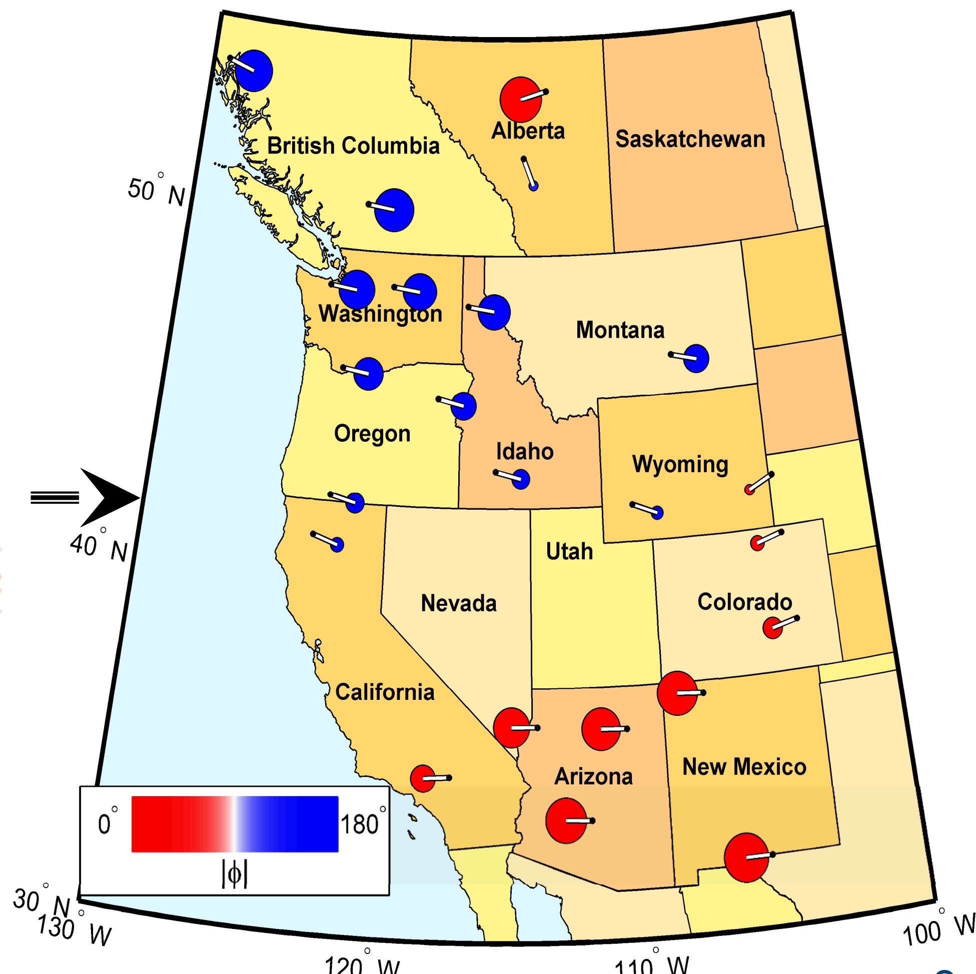
- DOE/OE Transmission Reliability Program – PM: Phil Overholt
- DOE/OE Energy Storage Program – PM: Dr. Imre Gyuk

Project Synopsis

Western Interconnect Oscillation Modes



North-South Mode



Project Synopsis

Project Deliverables:

1. **PDCI-based damping control system**
   - ☑ Open-loop testing in BPA Synchrophasor Laboratory – Phase I
   - Closed-loop testing at Celilo – Phase II
2. **Energy Storage-based damping control**
   - ☑ Development of control algorithms employing distributed storage – Phase I
   - Design of implementation strategies for ESS-based distributed damping – Phase II

Innovative Features of Damping Strategy:

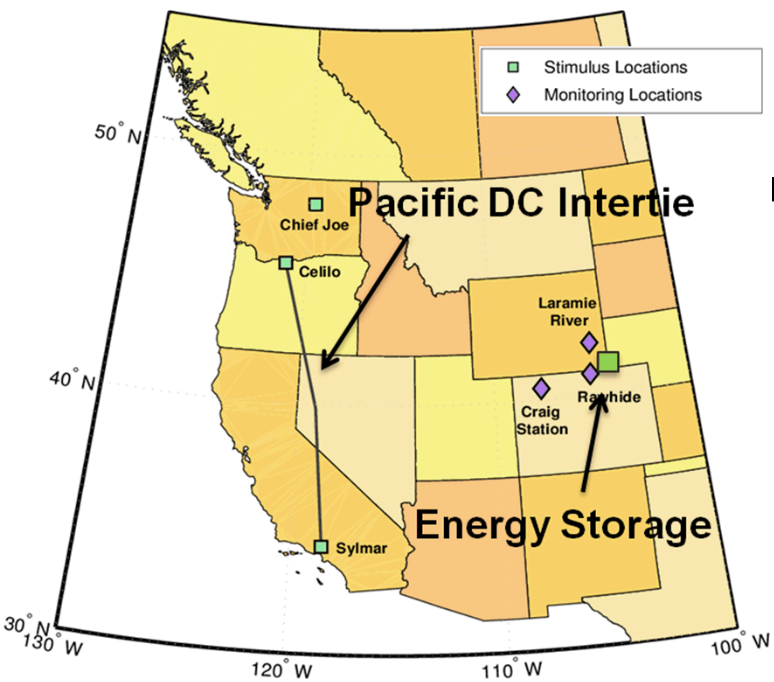
1. **Real-time PMU data** employed in feedback control to damp inter-area modes
2. **Supervisory system** monitors damping effectiveness and ensures **"Do No Harm"**

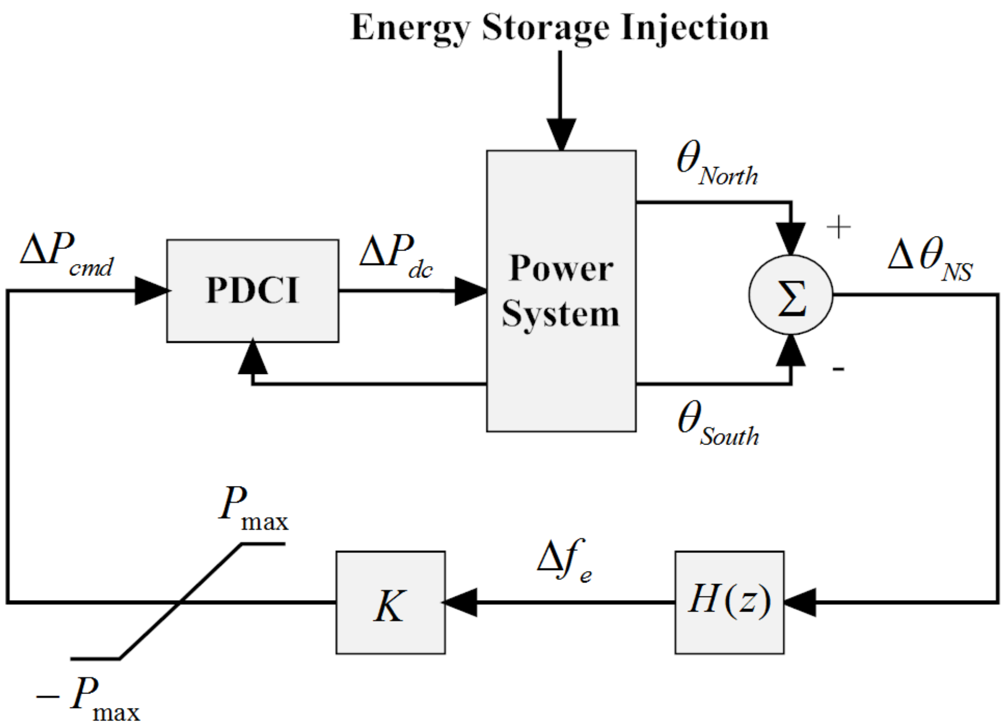
Project Synopsis

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 signal should be proportional to the frequency difference between the two areas



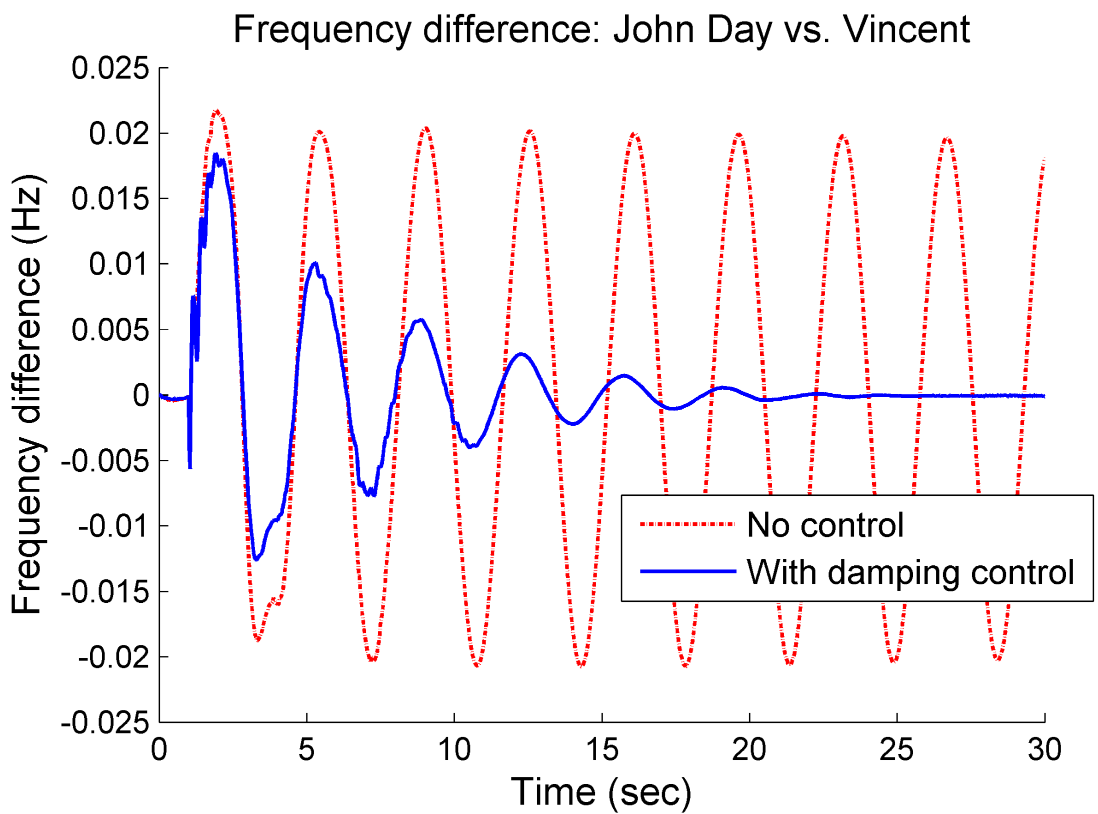


Financial Information FY16

FY	Total Project Budget	BPA Budget	Cost Share	BPA YTD Actual	YTD Cost Share Actual	BPA FTE	BPA FTE Actual
2016	$1060K	$500K	$560K	$360K	$240K		

Expected Benefits

- Improved system reliability
- Additional contingency in a stressed system condition
- Economic benefits:
  - Avoidance of costs from an oscillation-induced system breakup (1996 outage costs>$2B)
  - Reduced need for new transmission capacity (capital cost savings > $1M/mile)
  - Potential for increased power flows through congested transmission corridors

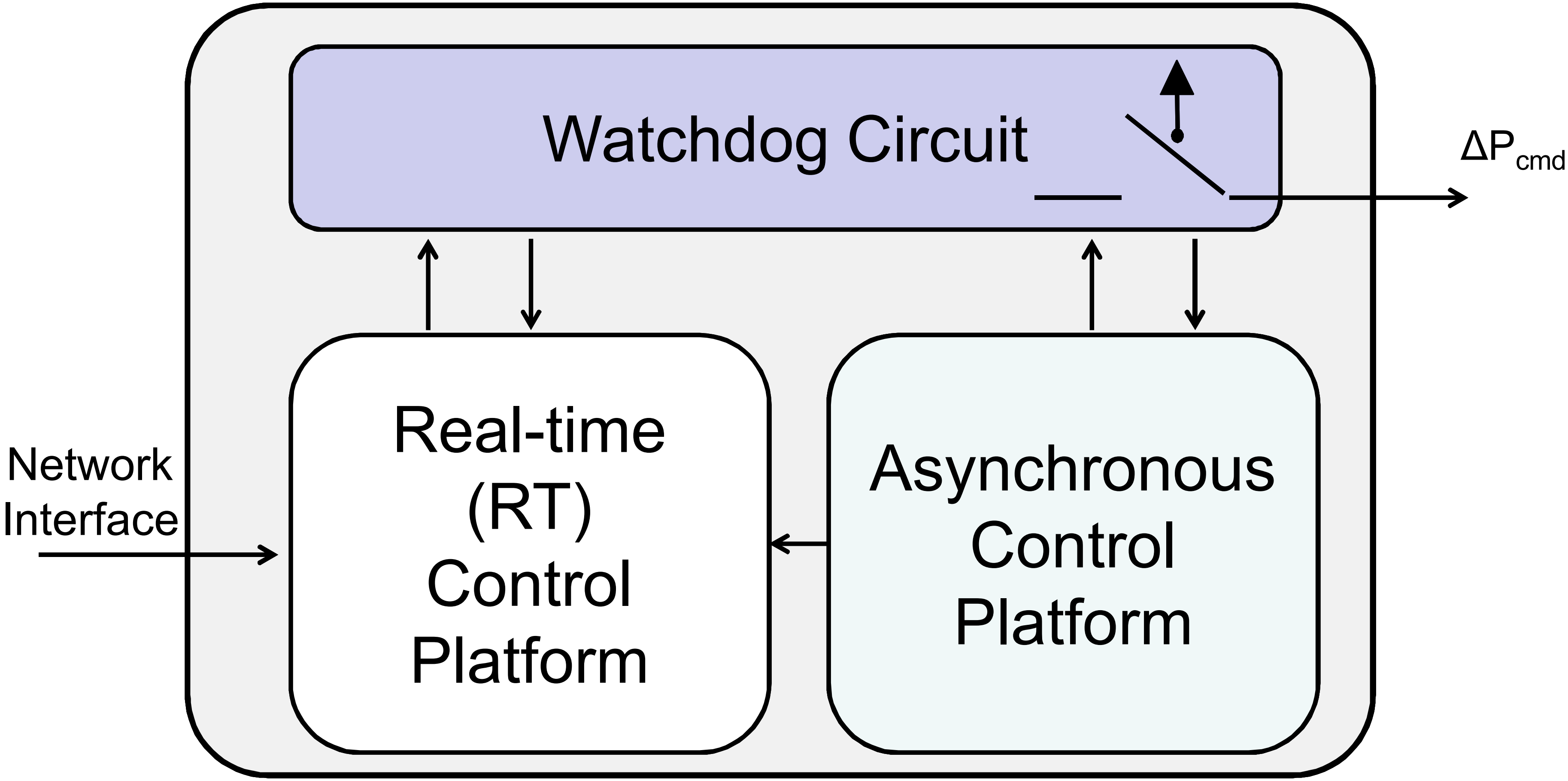


Technology Transfer/Application to BPA

- Phase I – Started at TRL 2, Progressed to TRL 6
- Phase II – Starting at TRL 6, Expectations are TRL 9
- Delivered prototype – operational since Sept 2014
- Developed Energy Storage distributed control algorithms
- Models: two-area, three-area, mini-WECC refinements, PDCI model added to PSLF
- Simulations: reduced-order, mini-WECC, PSLF
- Eigen-analysis tools
- Mode shape visualization
- PDCI Probe Testing Analysis ➔ Sensor Feedback Pairs
- Transition planning to Celilo – telecom, I/O data
- Open-Loop Data Analysis

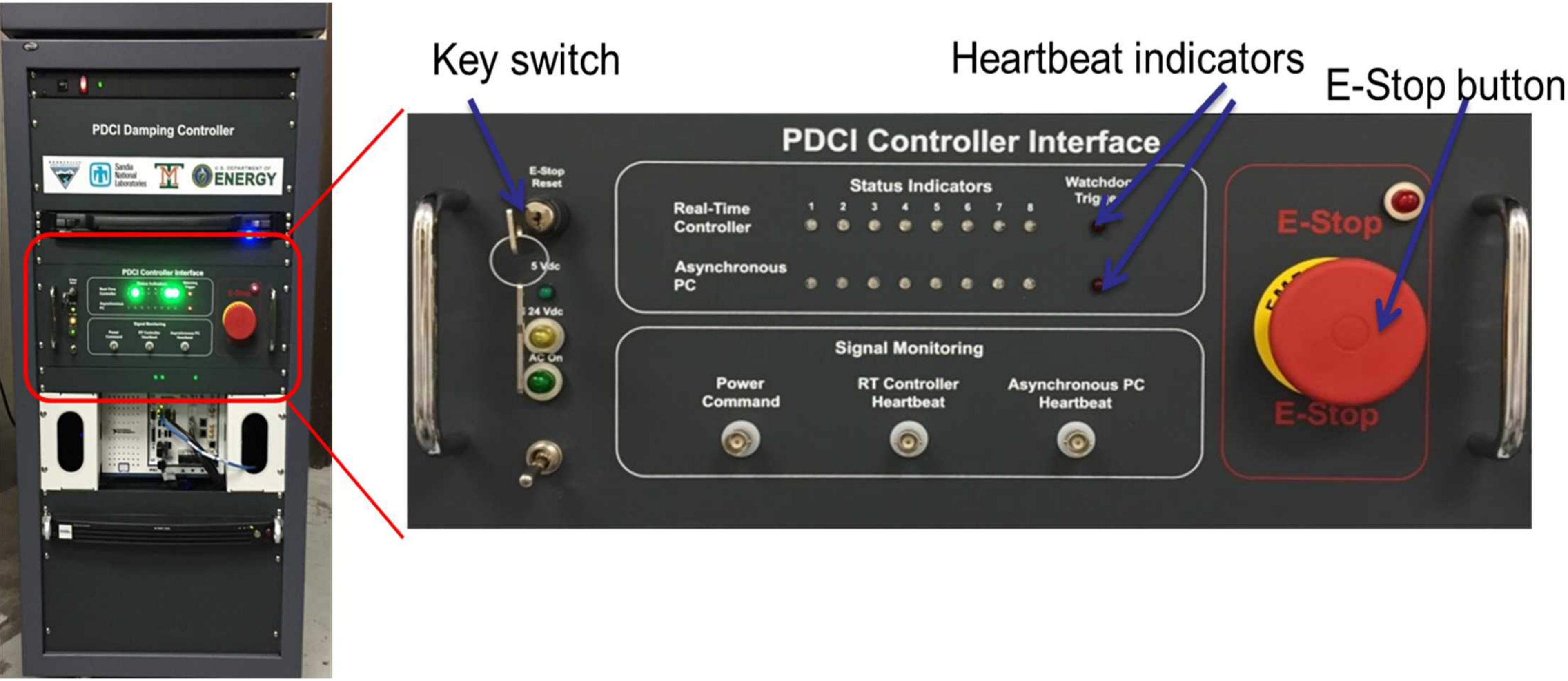
Accomplishments: Distributed Supervisor Design

- Watchdog circuit is implemented in hardware and handles bumpless transfer, heartbeat, and emergency stop functions
- The asynchronous control loop handles estimation and monitoring functions that are slower than real time
- Real-time supervisor must detect and respond to grid conditions



Watchdog Circuit

- Installed at BPA on June 22, 2015 and upgraded on November 9, 2015
- Safety circuit monitors the heartbeat indicators and E-Stop button
- Overriding design philosophy was to make the system “failsafe” – failure of any component would safely disconnect the control system



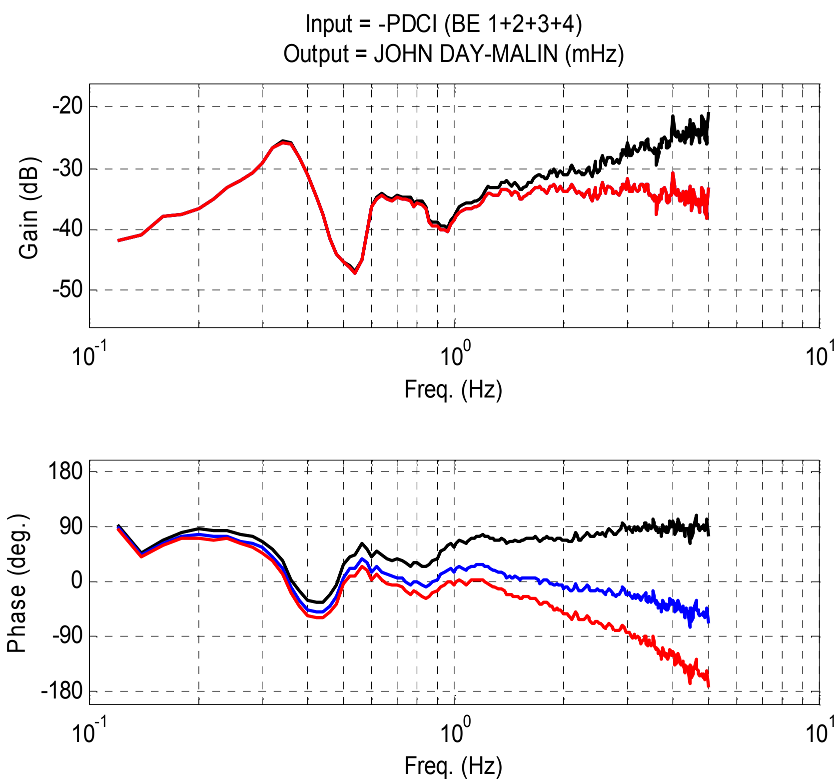
Candidate PMU Pairs for Feedback Control

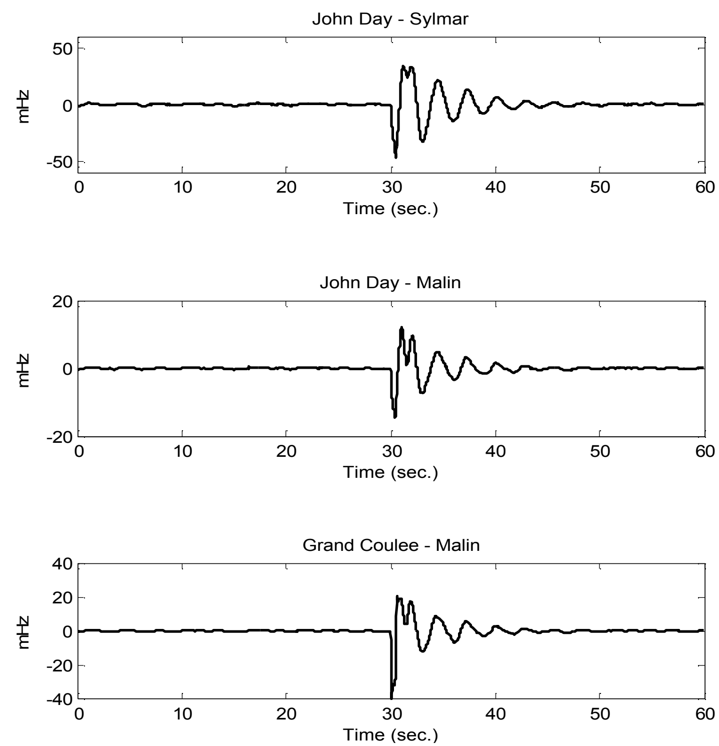
Analysis of PDCI probing tests & PSLF simulation studies have informed:

- **North PMU locations: John Day, Big Eddy**
- **South PMU locations: Malin, Captain Jack**

All pairs are within BPA region. Diversity & redundancy in pairs is employed for robust feedback control.

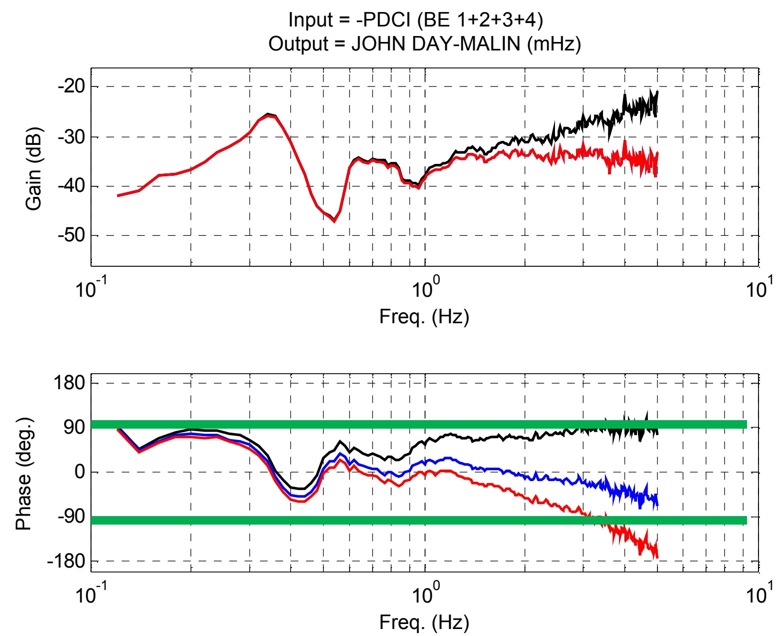
- **PDCI has bandwidth well above 5 Hz and delay ≈ 25 msec**
- **Feedback gain of 5 to 10 MW/mHz will provide significant damping**

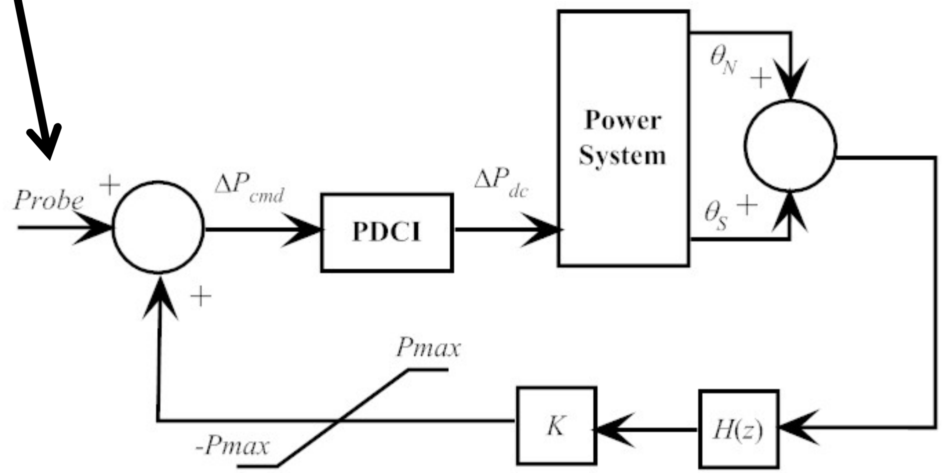




Gain & Phase Margin Monitoring: Do No Harm

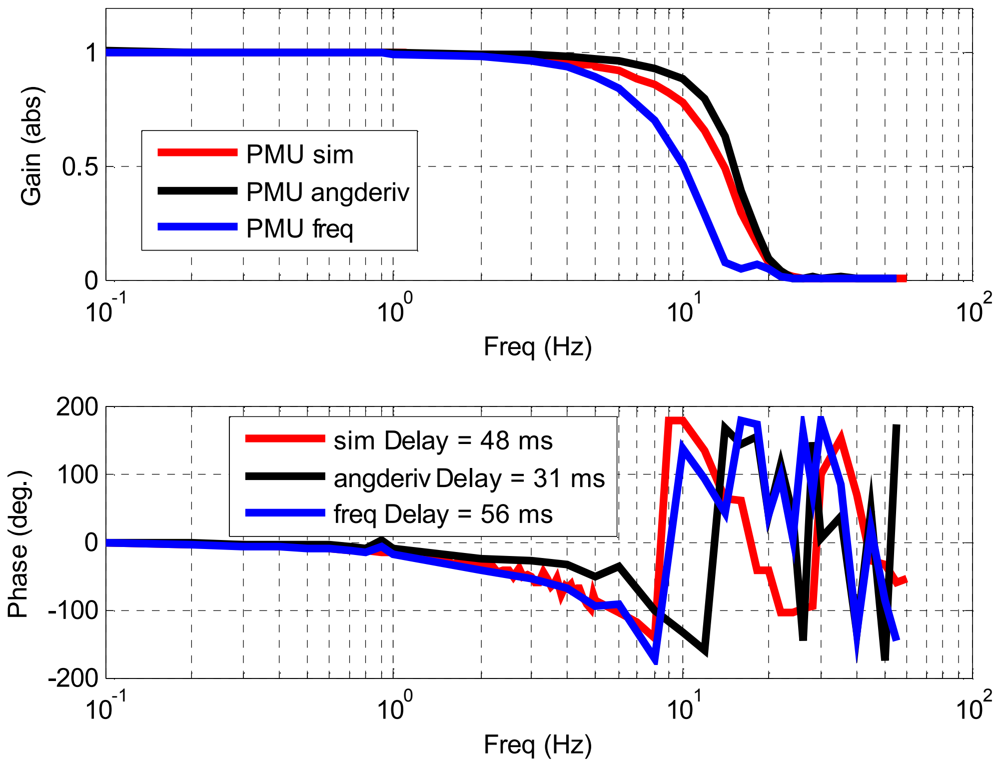
- Gain & Phase Margin tells us if controller will destabilize system.
- Goal – Keep phase of control loop within ±90 degrees
- Approach
  - Periodically inject probe signal into loop for several frequencies across control band (1 to 10 Hz).
  - Estimate loop gain and phase via spectral averaging.
  - Alarm controller if margin exceed acceptable range.





PMU Dynamic Testing

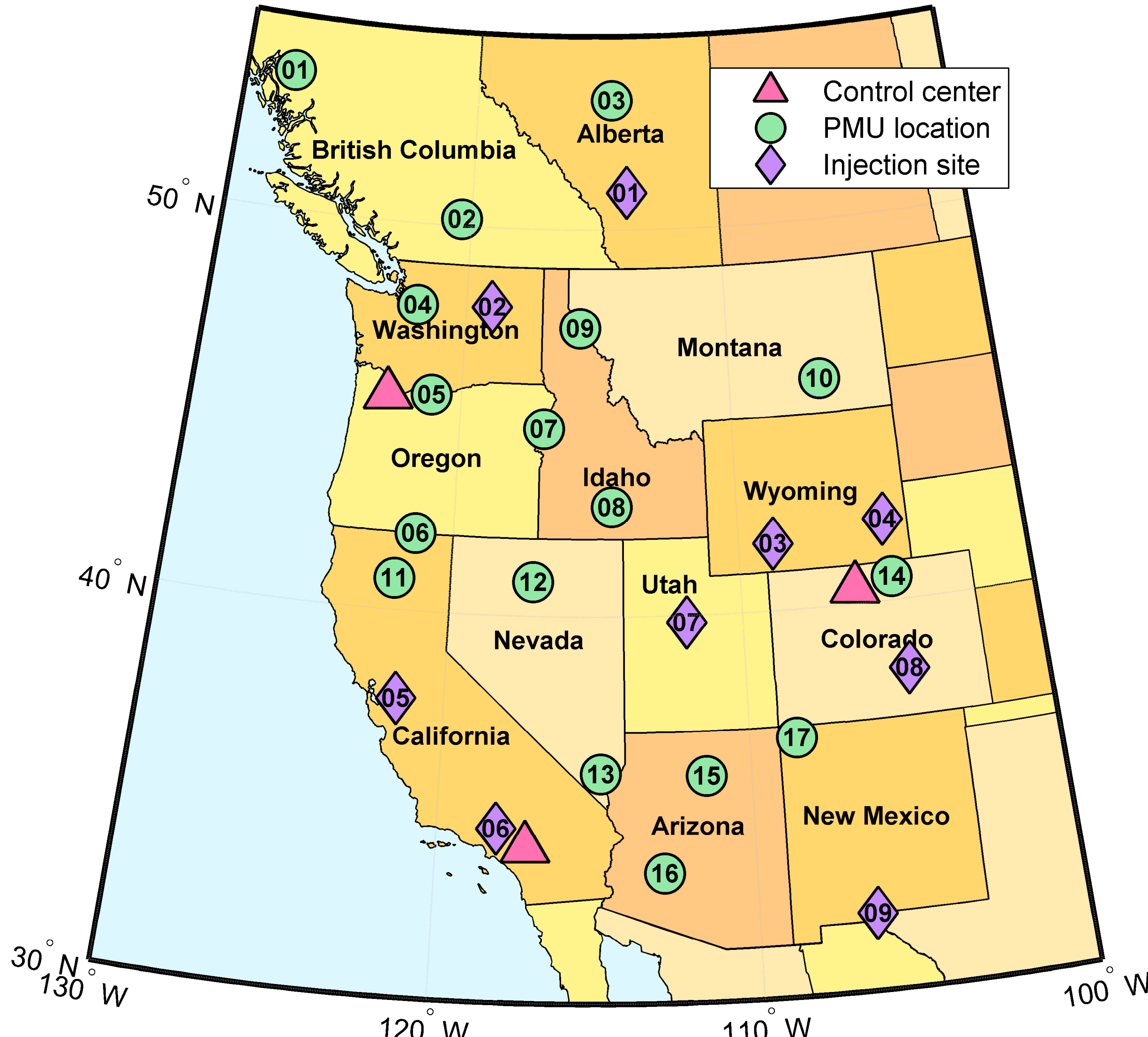
- Initial PMU dynamic testing indicates the PMUs meet requirements.



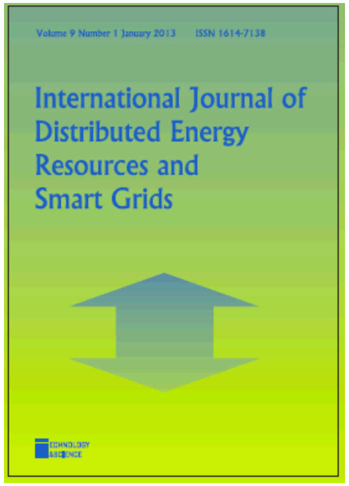
Energy Storage Damping Strategy: Multi-Node Distributed Control

Advantages:

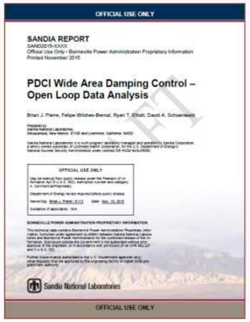
- Robust to single points of failure
- Controllability of multiple modes
- Size/location of a single site not as critical as more storage is deployed



Project Publications



- Journal Paper: *International Journal of Distributed Energy Resources and Smart Grids*, vol. 11, no. 1, pp. 69-94, 2015.
- IEEE PES General Meetings: 2013 – 2016
- Electrical Energy Storage Applied Technologies (EESAT) Conference: 2013, 2015
- Project Reports: Open-Loop Data Analysis, Quick Start Guide, Telecom Requirements, Phase I Final Report, I/O Data Requirements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Project Direction/Next Steps – Phase II

- PDCI modulation component of project will focus on deployment with the goal of **demonstrating closed-loop operation:**

  Phased approach ➔ Gradual increases of both magnitude and duration of closed-loop testing with go/no-go decisions between phases. Communication network and cyber security issues will also be a high priority.

- Energy storage component of project will focus on **distributed damping:**

  Implementation of algorithms ➔ Design strategies will account for communication network issues and likely ESS penetration levels

Planned Phase II Timeline

PDCI:

- Start Phase II
- Open-loop PDCI probe testing using prototype
- Closed-loop PDCI probe testing using prototype under benign conditions
- Closed-loop testing for extended periods under ambient conditions
- Closed-loop testing under Chief Joseph brake test
- Closed-loop testing for increasing power levels under ambient conditions

ESS:

- Start Phase II
- Design distributed damping strategies
- Characterization of PMU Data and Network Performance
- Conduct PSLF simulation studies of distributed control designs on wNAPS
- Analyze performance of control designs via simulations
- Assess performance differences between distributed and centralized damping

Timeline: Q1 FY16, Q2, Q3, Q4, Q1 FY17, Q2, Q3, Q4

Phase II Stage Gates

FY2016 Stage Gates

- Demonstrate transfer fcn estimation algorithm with simulated data – March 2016
- Submit closed-loop testing plan to BPA under PDCI probe test MOU – June 2016
- Delivery of complete control system documentation & user manual – September 2016

FY2017 Stage Gates

- Implementation of prioritized feedback signal selection algorithm – October 2016
- Demonstration of current injection interface for damping control – January 2017
- Conduct first closed-loop test & provide assessment of test results – March 2017

Conclusions

- Theory → working prototype < 2 years
- Results in all facets of Phase I have been very encouraging
- Phase II (deployment phase) is well underway with transition to closed-loop operation being carefully coordinated with Celilo staff & BPA telecom experts

↓

- Project team will continue its comprehensive and prudent approach to ensure success in Phase II

Q&A