DOE/OE Transmission Reliability Program

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Wide-Area Damping Control

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Project Team

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  - DOE-OE Transmission Reliability Program – PM: Phil Overholt
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  - BPA Technology Innovation Office – Project # 289

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Project Overview

- **Objectives:**
  - Design and construct a prototype control system to damp inter-area oscillations by using HVDC modulation and real-time PMU feedback.
  - Demonstrate the performance, reliability, and safety of this prototype control system by conducting closed-loop tests on the PDCI.
- **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.
  - Development of the prototype control system is on schedule and progressing towards closed-loop testing at Celilo in Summer 2016.

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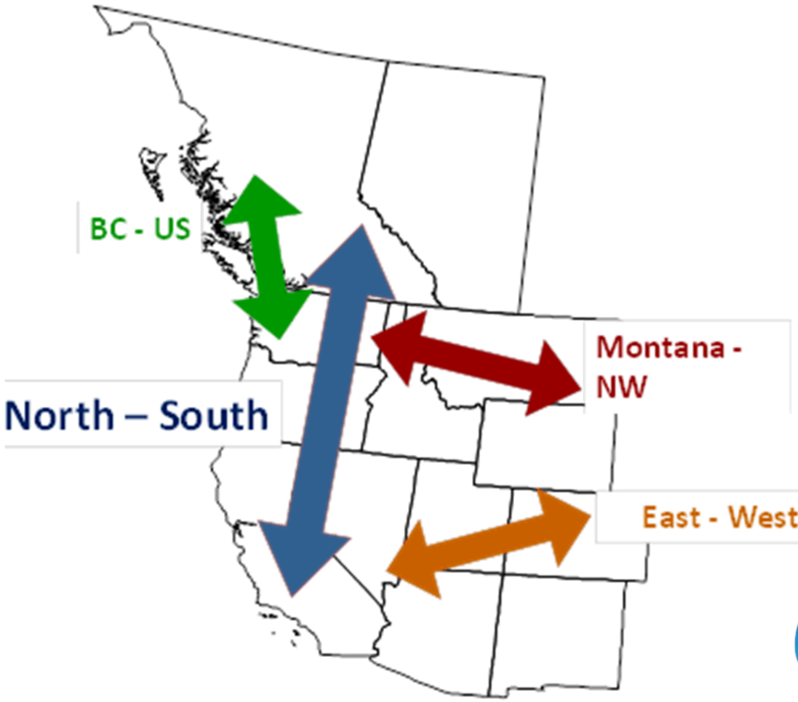
Expected Benefits

- **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



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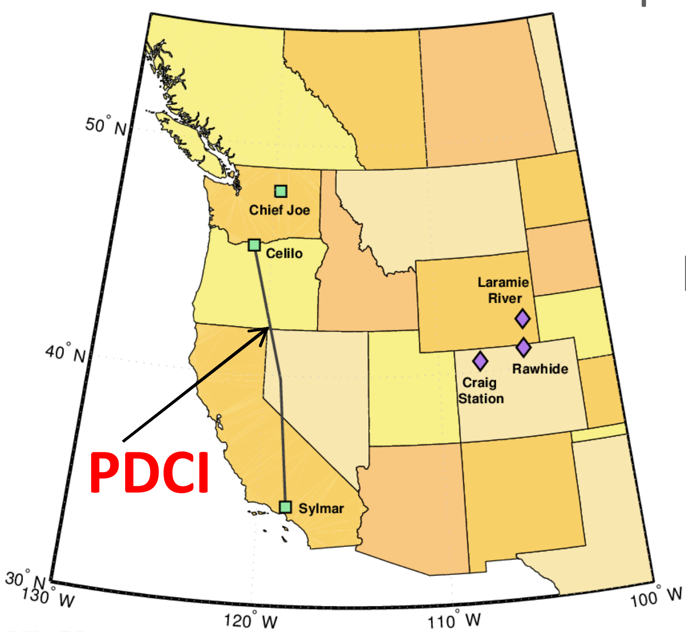
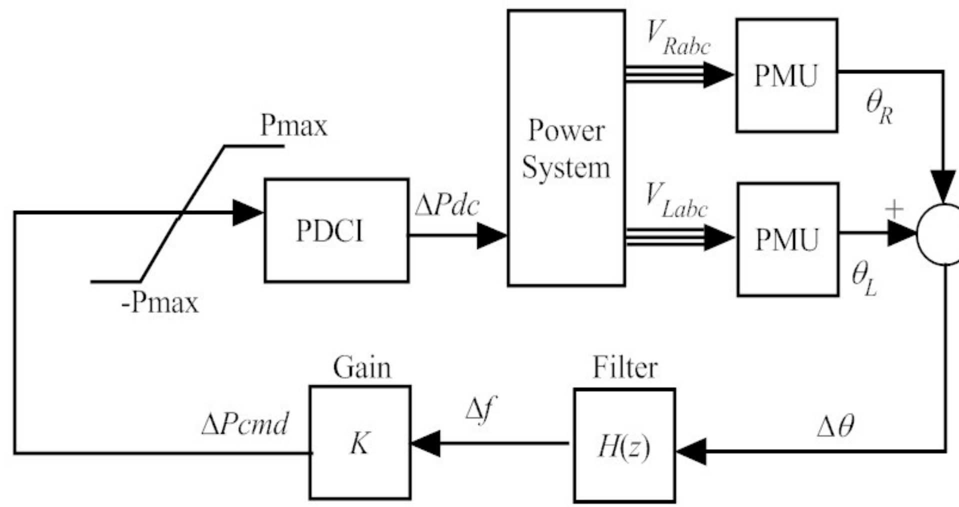
Design Objectives for PDCI-based Controller

- **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

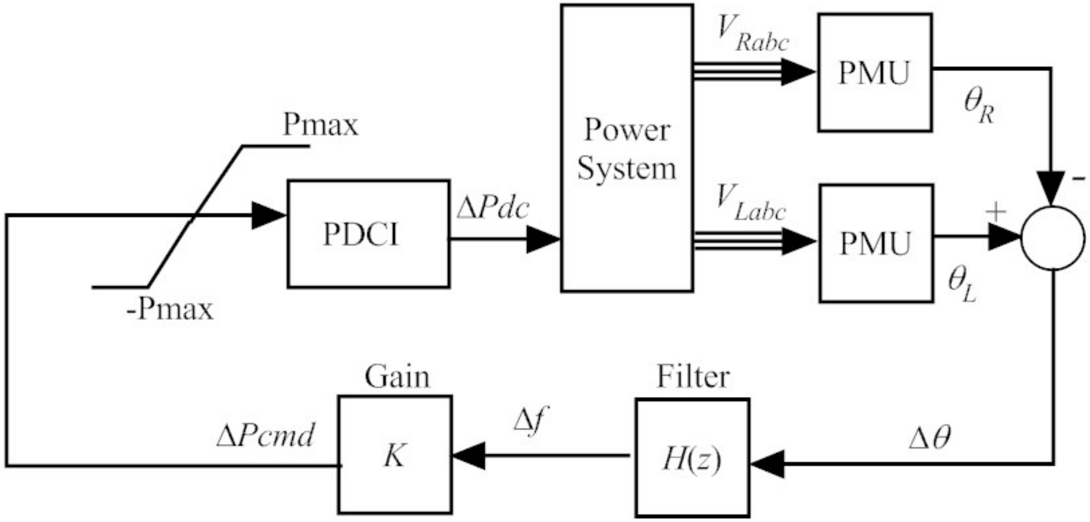
Feedback control should be proportional to frequency difference of the two areas (Local minus Remote)





Final Controller Design

- **Based on:**
  - Extensive control theory analysis
  - Many simulation cases
  - Many years of actual system probing tests
- **Local Location = Lower Columbia basin.**
- **Remote Location = COI.**
- ***H*(*z*) = "Customized" Bessel derivative filter.**
- ***K* = 5 to 15 MW/mHz**
- **Pmax ≈ 125 MW**



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1. D. Trudnowski, D. Kosterev, J. Undrill, "PDCI Damping Control Analysis for the Western North American Power System," Proceedings of the *IEEE PES General Meeting*, July 2013.
2. D. Trudnowski, "2014 Probing Test Analysis," Report for BPA project TIP-289, Jan. 2014.

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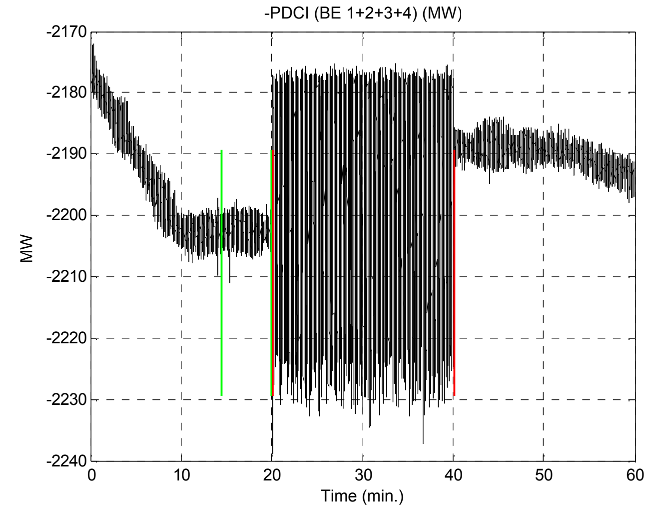
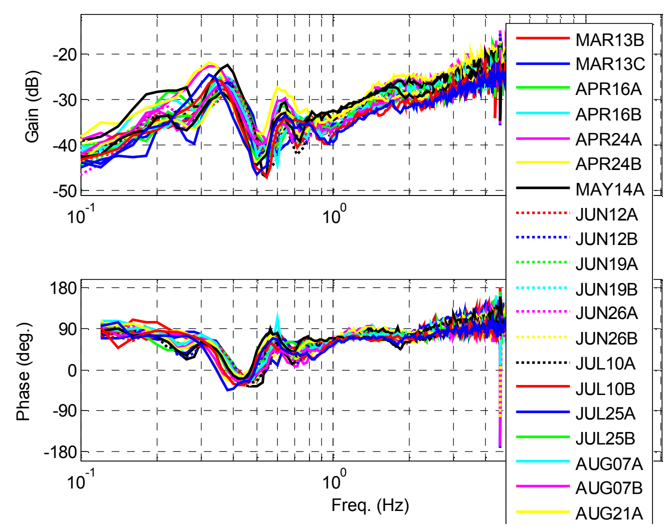
PDCI Probing Tests

- **Low frequency** probing tests (2009-2014) modulate PDCI by +/- 20 MW from 0.02 Hz to 5 Hz
- **High frequency** probing tests (2014) modulate PDCI by +/- 5 MW from 1 Hz to 28 Hz
- Goal of **low frequency** tests is to excite the 0 – 5 Hz range of oscillations in WECC
- Goal of **high frequency** tests is to evaluate the dynamics of the PDCI system
- What we've learned
  - Why this control didn't work in 1970s
  - New theory supported by tests
  - Identified optimal feedback signal locations (local and remote)
  - Feedback gain of 5 to 10 MW/mHz will provide **SIGNIFICANT** damping
  - PDCI has adequate bandwidth
  - Optimal design of feedback filter
  - Extensive testing and fine-tuning of PMUs (on going)





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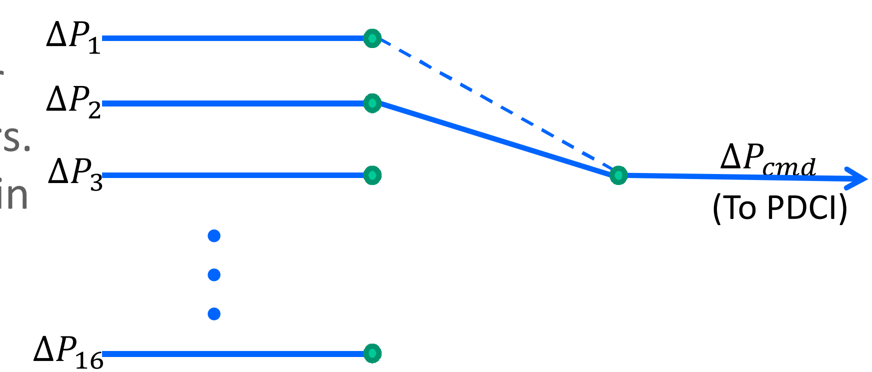
Redundancy and Diversity in Feedback

- Diversity ≡ Geographic Spread Redundancy ≡ Multiple PMUs/site
- Controller reads 8 PMUs each 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
  - PDCI bandwidth >> 5 Hz with delay ≈ 20 – 25 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



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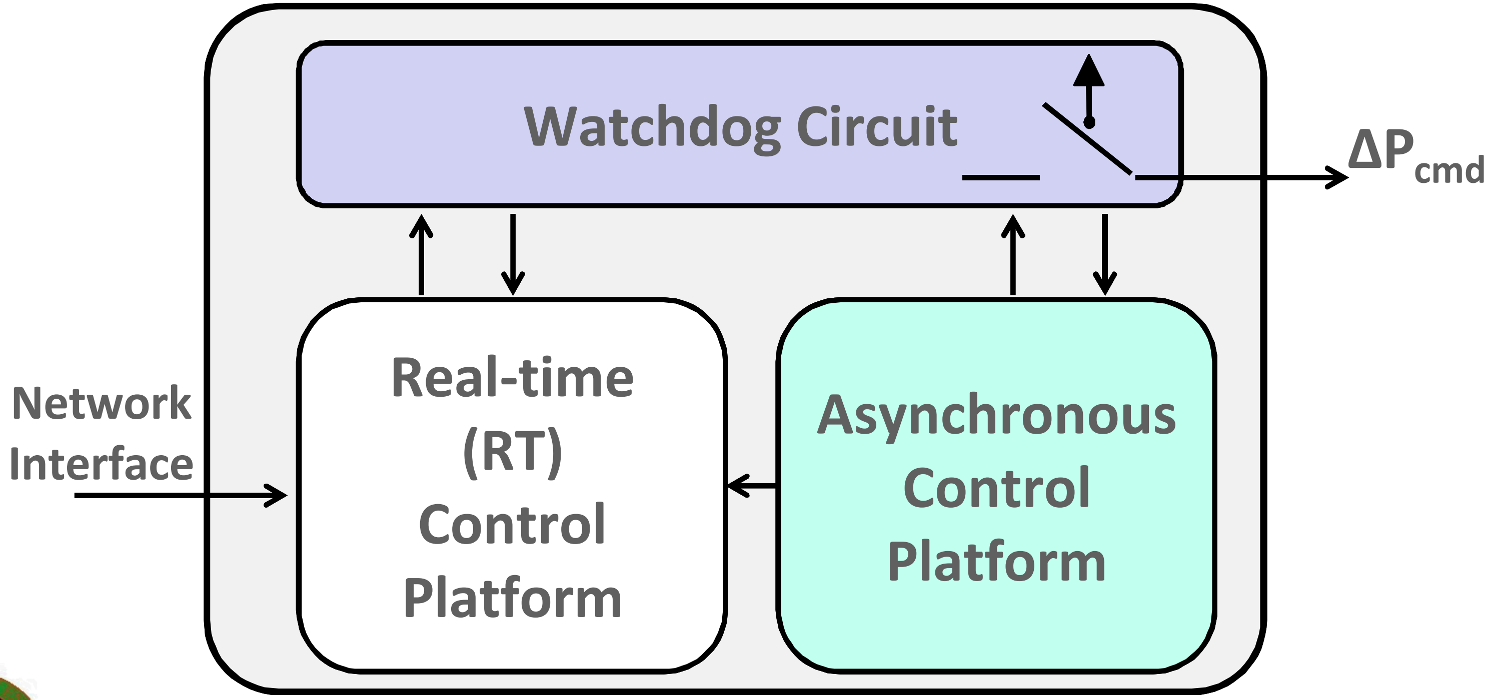
Do No Harm: Supervisory System Design

- 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



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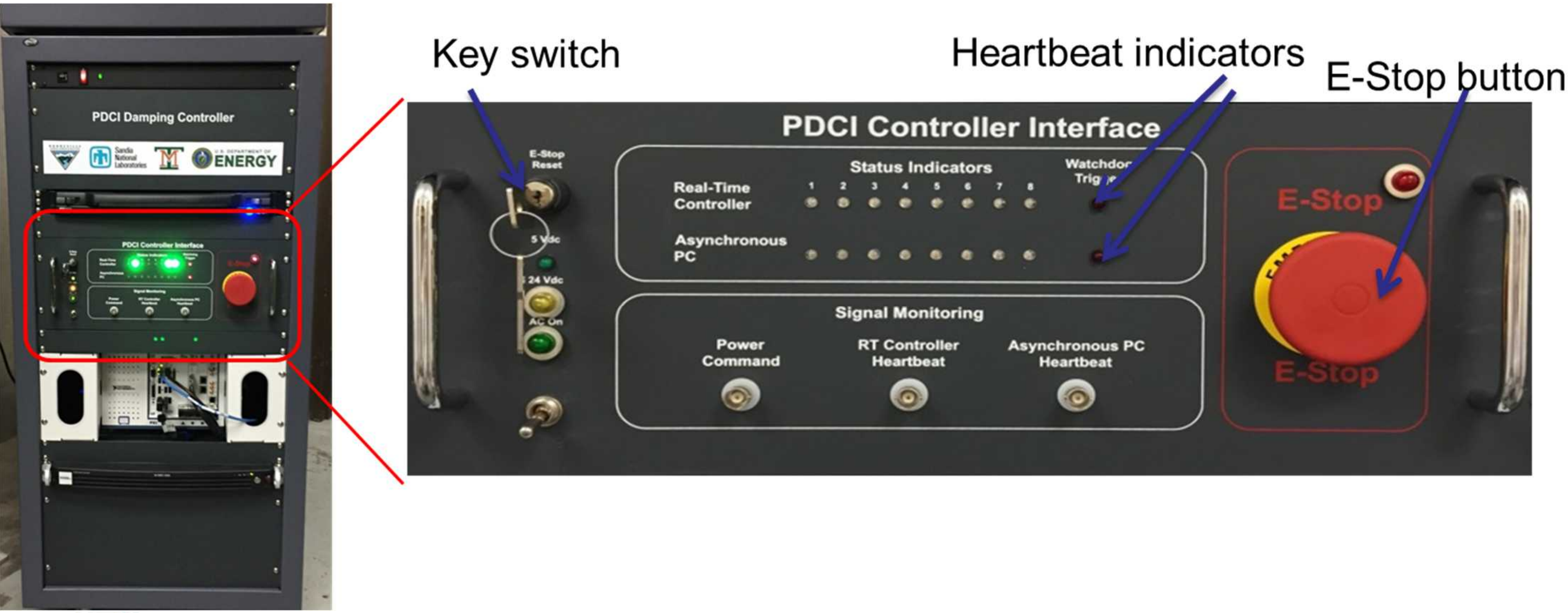
Watchdog Circuit

- Installed on prototype at BPA in June 2015 and upgraded in November 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



Real-Time Supervisor

- **Immediately disarms controller if any abnormal condition is detected**
- **Oscillation detection**
  - Disarm controller if out-of-band oscillations are detected in feedback signal or on PDCI
- **Islanding detection**
  - Disarm controller if islanding between local and remote signal locations is detected
  - Uses local, remote, and relative frequencies; and relative angle tolerances to detect islanding
- **PMU validity and time-latency management**
  - Bumpless switching between feedback pairs
  - Disarm controller if no pairs available
- **Emergency stop**

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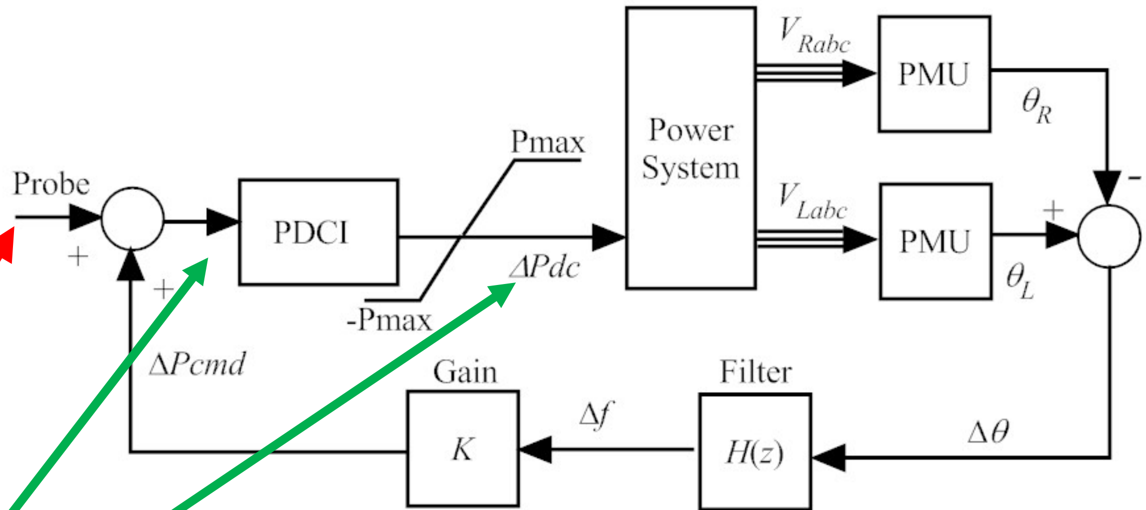
Asynchronous Supervisor

- **Gain/Phase margin monitoring**
  - Assures controller is **NOT** destabilizing any modes
  - Requires periodic low-level probing
- **PDCI monitoring**
  - Makes sure control modulation is entering PDCI system



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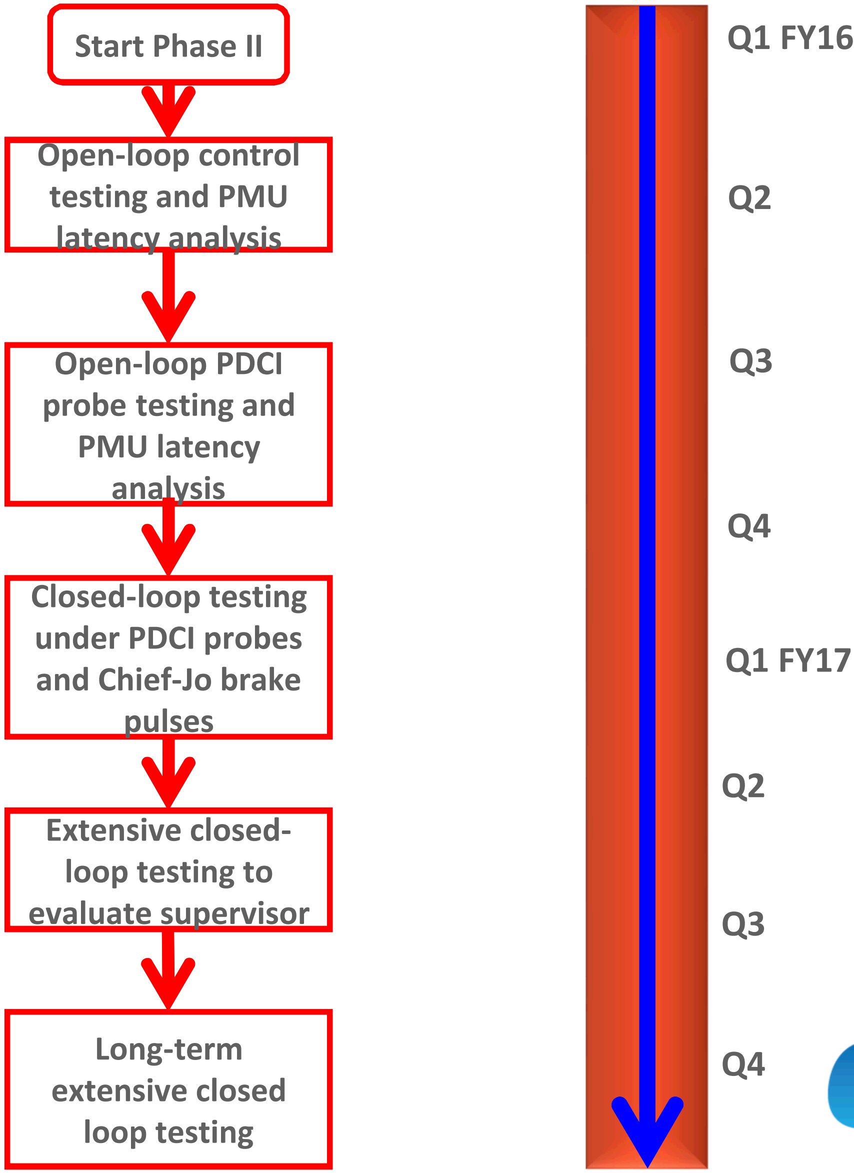
Planned Schedule for Closed-Loop Demonstration



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Project Direction and Next Steps

- Project will focus on control system deployment by demonstrating closed-loop operation.
- Phased approach → Gradual increases of power modulation magnitude and duration of closed-loop tests.
- Go/no-go decisions between phases based on analysis results.
- Communication network and cyber security issues will be a high priority.

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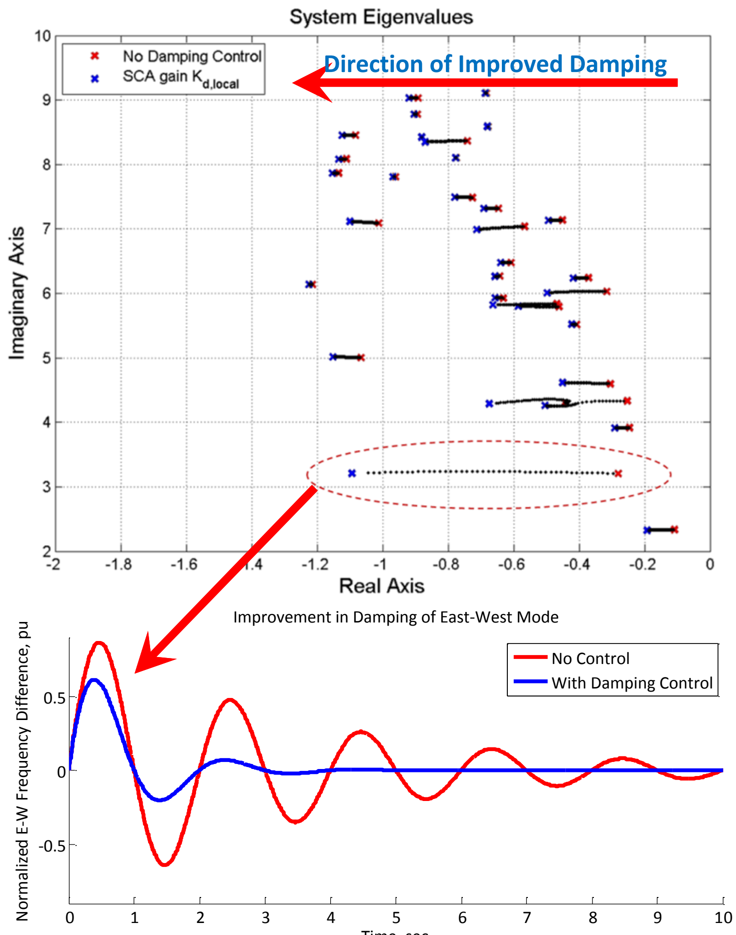
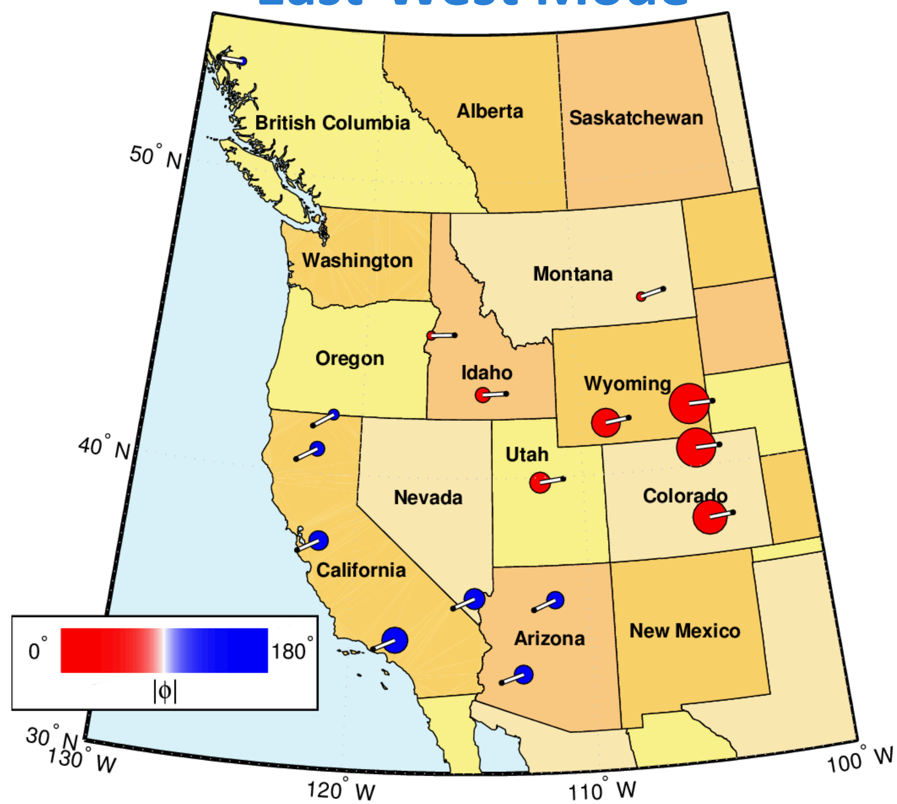
Damping Control using Distributed Storage

- Total storage capacity on order of 50 MW is sufficient
- With 10s of sites deployed, individual ESS capacity ≈ 1 MW is sufficient
- Control strategy uses ESS mostly providing other services ➔ very little additional cost for large benefit



East-West Mode



Jason 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.

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