Wide-Area Damping Control

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Project Team

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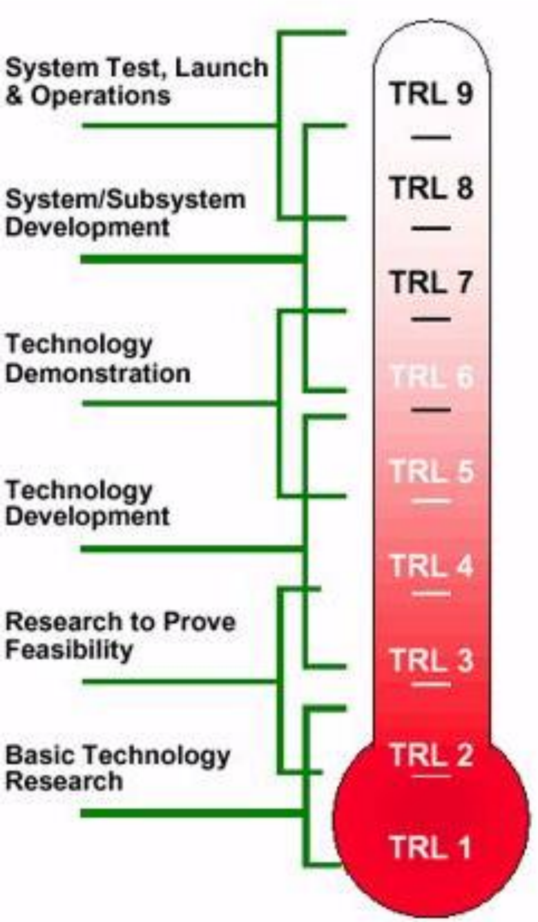
- DOE/OE Energy Storage Program – PM: Dr. Imre Gyuk
- BPA Technology Innovation Program – TIP 289

Wide Area Damping Control Project for BPA

- **Project Goal:**
  - **Significantly increase the TRL** of wide-area damping controllers such that **next phase is deployment-oriented**
  - TRL = 2 at start of project (Summer 2013)
  - TRL = 6 currently (end of Phase I)
  - TRL = 9 planned by end of Phase II
- **Primary Phase I Deliverables:**
  - Constructed and installed a prototype PDCI-based damping controller to BPA for open-loop testing
  - Delivered analysis and modeling tools to assess the capabilities of both High Voltage DC modulation and distributed energy storage for damping control
- **Unique Features of Control Design:**
  - **Real-time PMU** (Phasor Measurement Unit) feedback to dampen inter-area oscillations
  - **Supervisor controller** to monitor damping effectiveness and ensure the **"Do No Harm"** requirement



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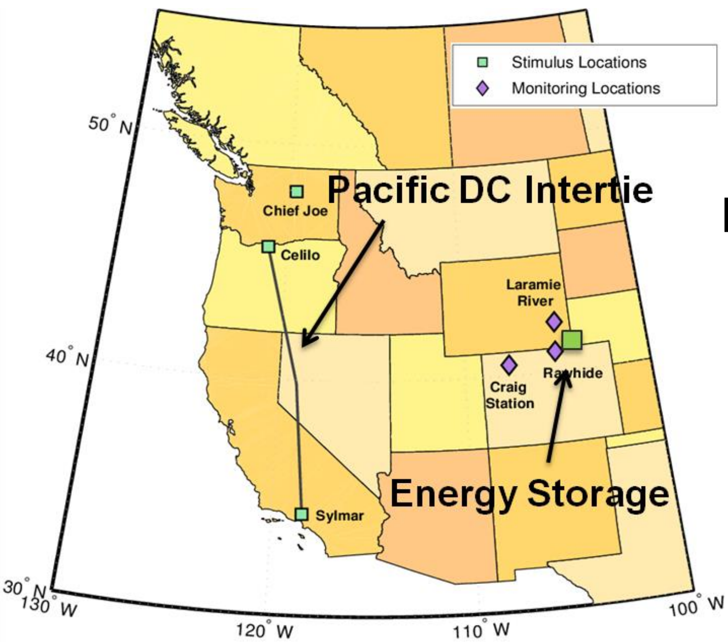
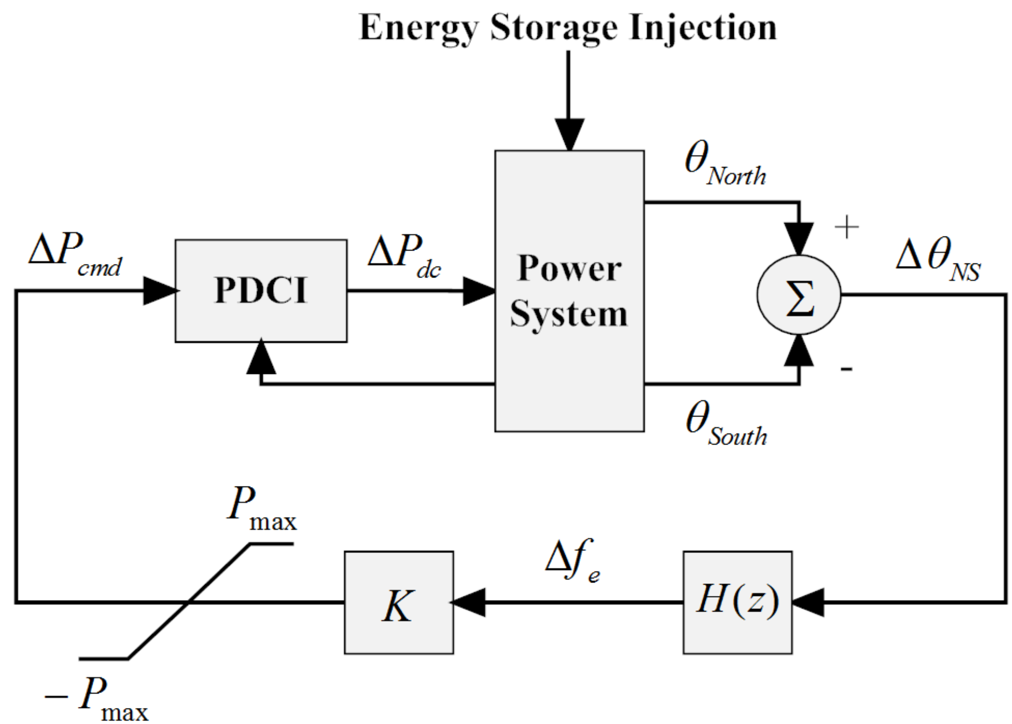
Active Damping uses PDCI Modulation and Energy Storage for Actuation Signals

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





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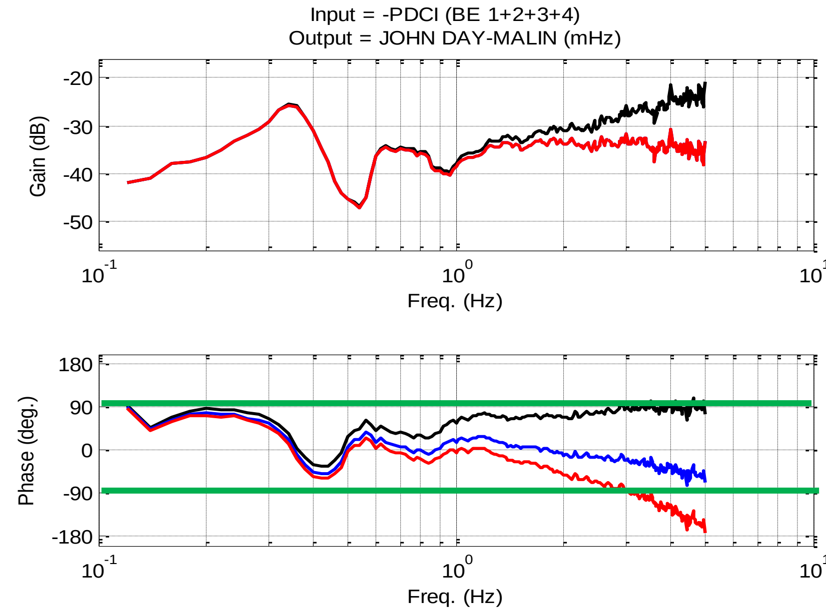
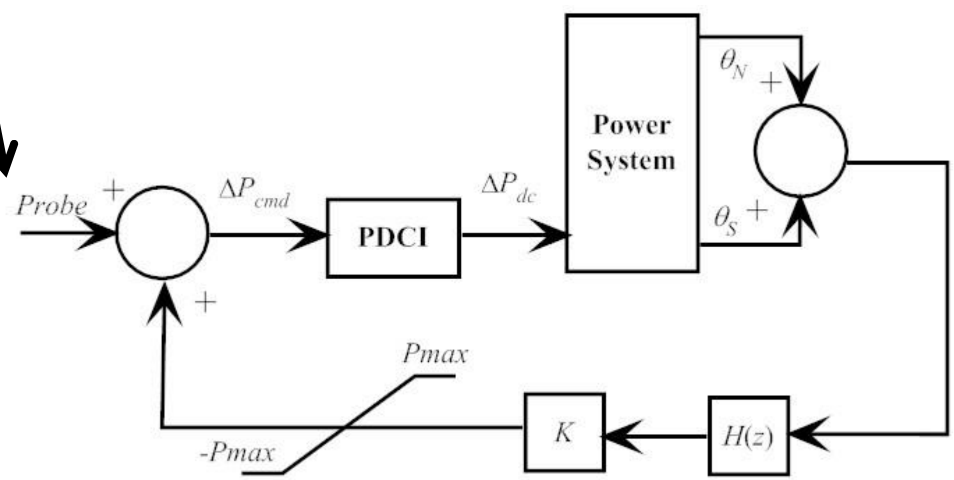
Project Accomplishments

- Installation of **prototype damping controller** at BPA Synchrophasor Lab
- Design of damping controller incorporating **PMU feedback**
- Design of **supervisor control** to:
  - Assure all control settings are correct
  - Monitor system stability
- **Award:** **Dan Trudnowski, Dmitry Kosterev and John Undrill,** "PDCI Damping Control Analysis for the Western North American Power System," **awarded as one of four "Best of the Best"** papers at the 2013 *IEEE Power & Energy Society General Meeting*
- Design of an optimal control strategy using **distributed energy storage** for active damping
- Simulation analysis shows PDCI modulation augmented with energy storage will mitigate E-W mode
- Publications:
  - 2015 International Journal of Distributed Energy Resources and Smart Grids
  - 2014 & 2013 IEEE Power & Energy Society General Mtg
  - 2013 EESAT

Gain & Phase Margin Monitoring

- Gain & Phase Margin tell 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 falls outside acceptable range.





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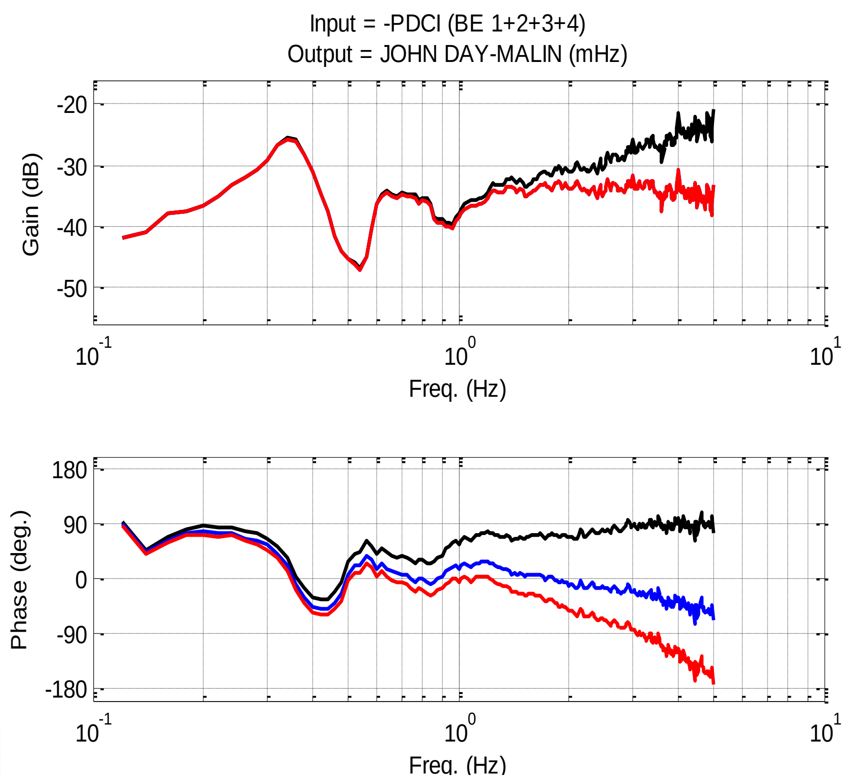
Candidate PMU Pairs for Feedback Control

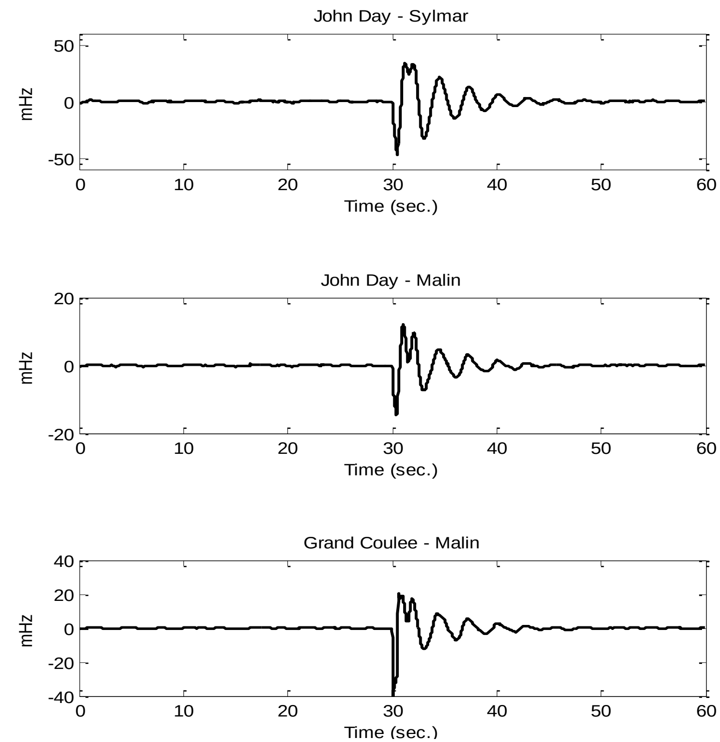
Analysis of PDCI probing tests and PSLF simulation studies have elucidated:

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

All pairs are within BPA region. Diversity & redundancy in pairs is essential 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





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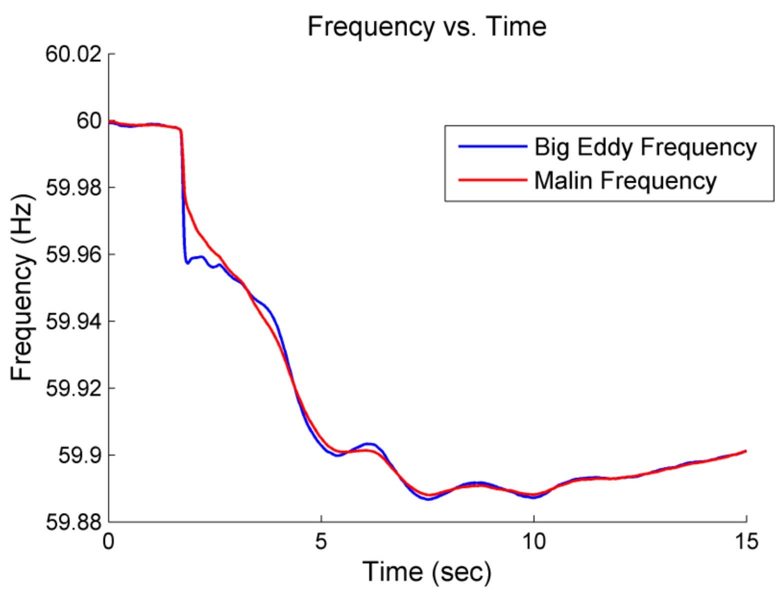
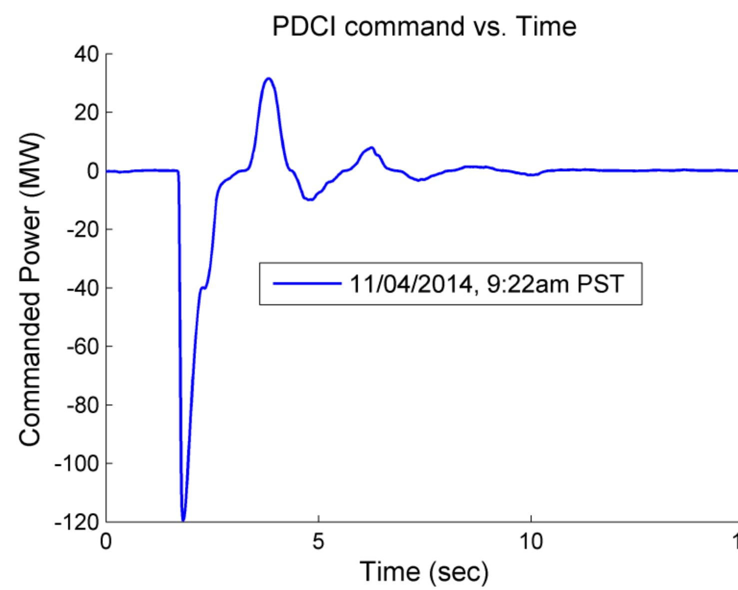
Open Loop Testing Results from Prototype

- Continuously operating (24/7) since mid-October 2014 in BPA Synchrophasor Lab
- Acquires live PMU data from multiple sites (e.g. John Day, Big Eddy, Malin)
- Constructs real-time feedback control signal from acquired data
- Control signal is not sent to PDCI (goes to log file for analysis)
- Example system event: morning of November 4th, 2014
  - An apparent generation outage led to a 120mHz decline in system frequency (moderate inter-area deviation = 18mHz).
  - Control system performance is precisely as expected





Supervisor Control Design Philosophy

Supervisor

Asynchronous Control Loop

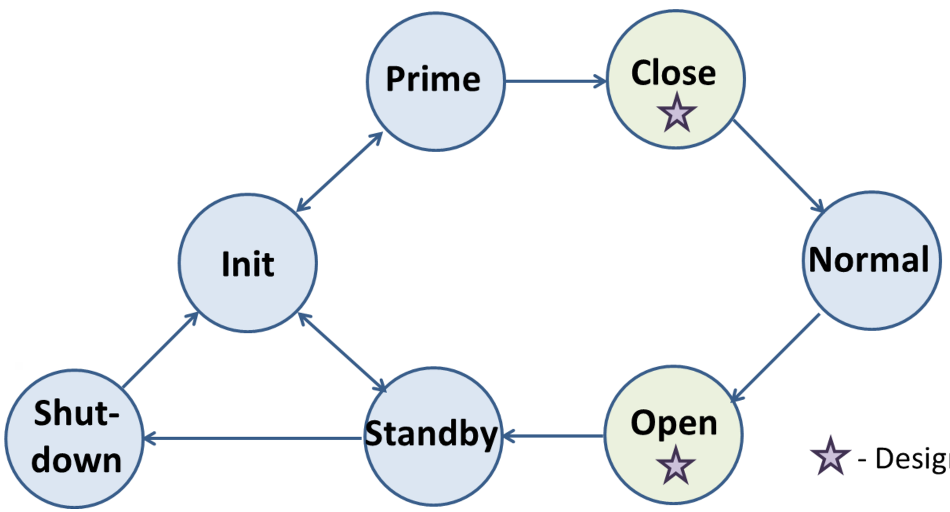
- Automated probing
- Transfer function estimation
- Gain and phase margin estimation
- PDCI monitoring

Real-time Control Loop

- State machine arch.
- Bumpless transfer (SW)
- Oscillation detection
- Separation detection
- Frequency tol. detection

Watchdog Circuit

- Watchdog circuit for async. and RT loops
- Emergency stop button
- Bumpless transfer (HW)
- Reinitialization procedure



State machine architecture ensures the system starts up, shuts down, and reinitializes safely

☆ - Designates transition state

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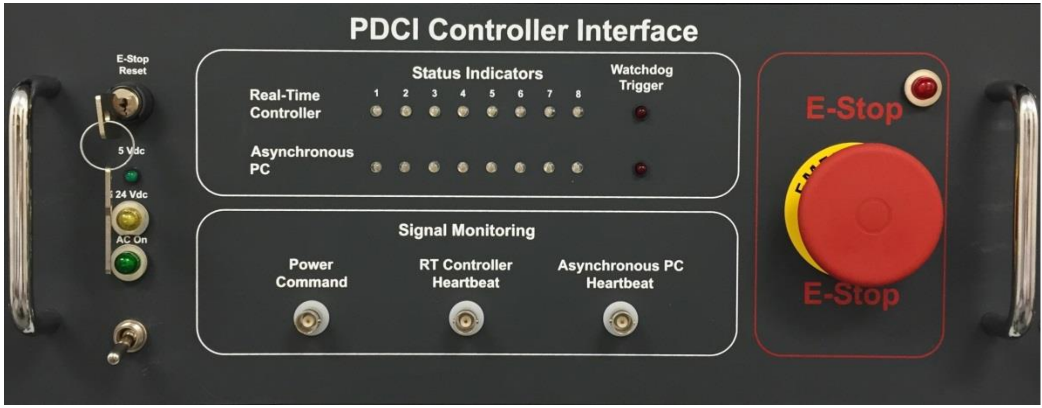
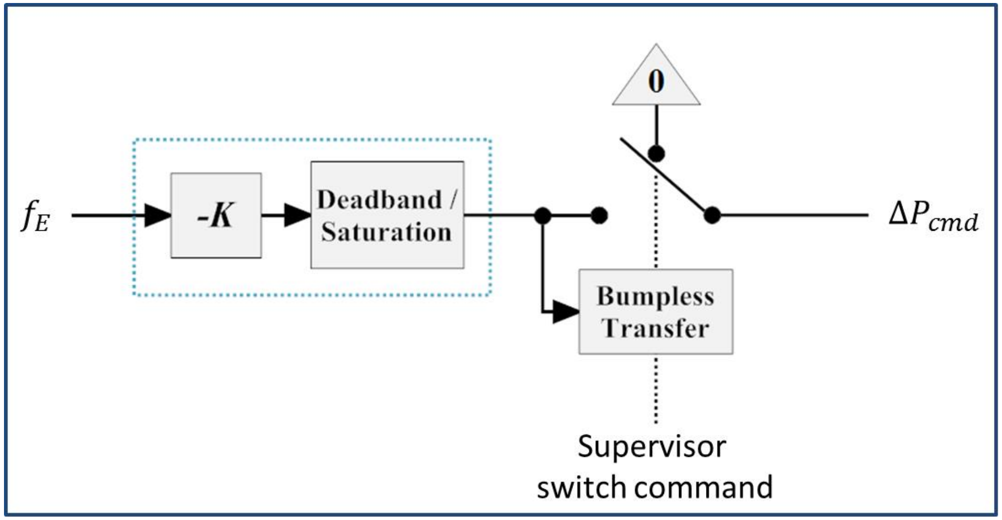
FY15 Deliverable: Safety Circuit

- To be installed on prototype at BPA in Summer 2015
- Safety circuit monitors the following:
  - Emergency Stop button on the chassis
  - Supervisory controller watchdog circuit
  - Real-time controller watchdog circuit
- Overriding design philosophy was to make the system "failsafe" – failure of any component would safely disconnect the control system
- Bumpless transfer refers to seamless transition *between* modes of operation
- Ensures that the controller never injects a step function into the system
- Additionally ensures smooth start-up and re-initialization procedures

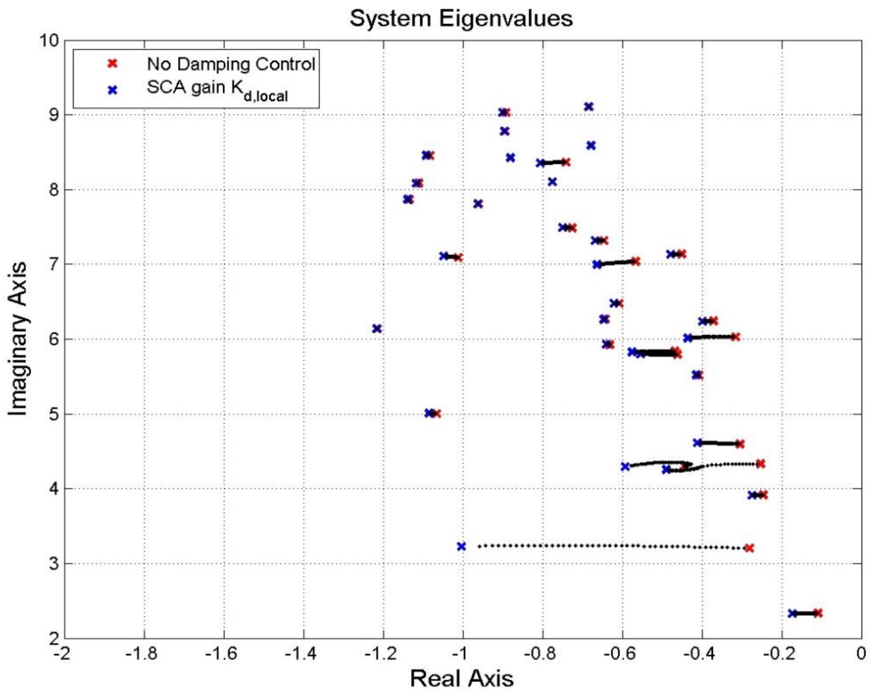


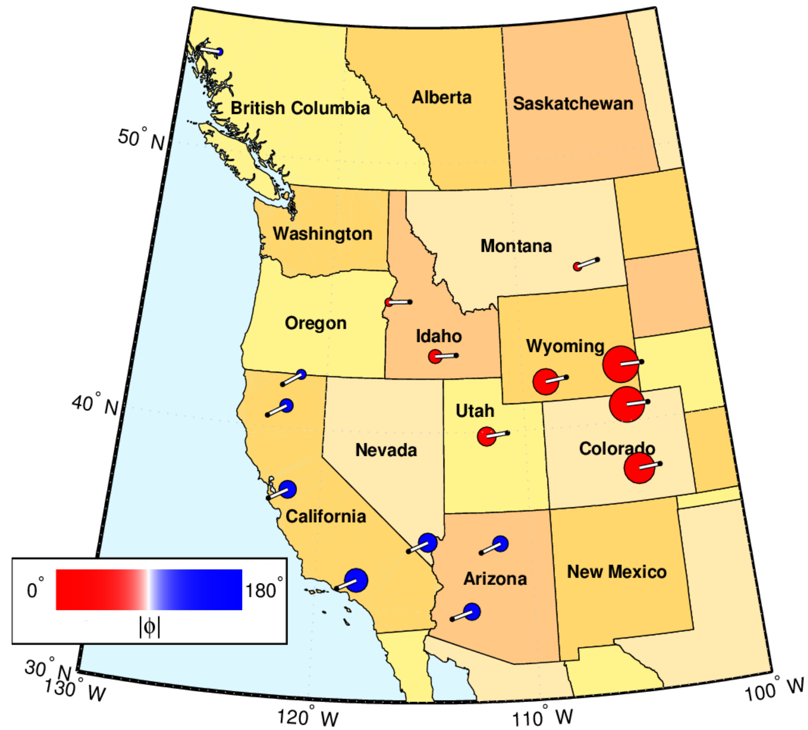


FY15 Deliverable: Damping Control Algorithm using Energy Storage

A Structured Control Algorithm (SCA) will be developed (Sept 2015) to design damping controls employing ***distributed energy storage:***

- Distributed damping provides improved controllability of multiple modes
- Mode shapes may be specified or prioritized through control design
- Example – Algorithm provides selective damping of East-West Mode





Project Direction: FY16 – FY17

1. Phase II of project (FY16 – FY17) will transition to a deployment focus with the goal of **demonstrating closed-loop operation**

   <u>Risk factors</u> to closed-loop implementation:

   a. Unexpected deployment issues ➔ Gradual phasing of both magnitude and duration of closed-loop testing with go/no-go decisions between phases
   b. Legal framework for testing ➔ Existing PDCI probe testing MOU in JSIS to be blueprint
   c. Engagement with broader utility community ➔ Test results to be shared in Peak RC

2. Assessment and mitigation of **PMU data quality and latency issues**

   <u>Risk factors</u> to real-time feedback of PMU signals:

   a. Unexpected latencies (> 100 ms) ➔ Extensive open-loop testing (2+ years)
   b. Handling of data errors ➔ Correction to extent possible; otherwise, disarm
   c. Unacceptable PMU bandwidth ➔ Conducting extensive tests of PMUs – should meet requirements; if not, MT will work with vendor to modify firmware

3. Focus of energy storage component will be **distributed damping**

   <u>Risk factors</u> to distributed energy storage-based damping:

   a. Insufficient ES injection power deployed ➔ Designs to consider "future" scenarios as well as "combining" with PDCI modulation to enhance modes mitigated (e.g. E-W + N-S)
   b. Architecture to deploy distributed damping is lacking ➔ Part of ES deliverable is to detail the necessary communication & control infrastructure

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