DOE/OE Transmission Reliability Program

Wide Area Damping Control Proof-of-Concept

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June 4, 2014
Washington, DC

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Project Team and Sponsors

- **We gratefully acknowledge our sponsors:**
  - BPA Technology Innovation Program – TIP #289 (PM: Dr. Jisun Kim, Technical POC: Dr. Dmitry Kosterev)
  - DOE Transmission Reliability Program (PM: Phil Overholt)
  - DOE Energy Storage Program (PM: Dr. Imre Gyuk)
- **Project Team:**
  - Sandia National Labs – Dave Schoenwald, Ray Byrne, Ryan Elliott, Jason Neely
  - Montana Tech University – Profs. Dan Trudnowski and Matt Donnelly
  - Project Consultant – Dr. John Undrill

Phase I Project Objectives: FY13-FY15

- **Overall Project Goal:**
  - **Significantly increase the TRL** (Technology Readiness Level) of wide area damping control systems such that the **next phase is deployment oriented**
- **Primary Phase I Deliverables:**
  - **Prototype PDCI-based damping control system** to be installed, tested, and validated at BPA Synchrophasor Laboratory
  - **Assessment of energy storage** for control
- **Control Design Components:**
  - Real-time **PMU feedback**
  - Active damping by **PDCI modulation**
  - **Supervisor** to ensure control can **DO NO HARM**

Project Accomplishments: FY13 - FY14

- **Development of hardware and real-time software**
  - Damping control design based on PDCI modulation and PMU feedback
  - Supervisor control design to ensure: **Do No Harm**
  - Controls interface module to link control system with operations
  - Hardware-based safety features (watchdog timer, emergency stop, bumpless state transition)
- **Creation of analytical tools**
  - Oscillatory mode analysis of large-scale power systems using BPA data
  - Map-based visualization of oscillatory mode shapes
  - PSLF-based simulation studies illustrating benefits/limitations of candidate control strategies
- **Damping control strategies incorporating energy storage**
  - PDCI modulation augmented with energy storage to mitigate E-W mode
  - Optimal allocation of distributed energy storage for active damping

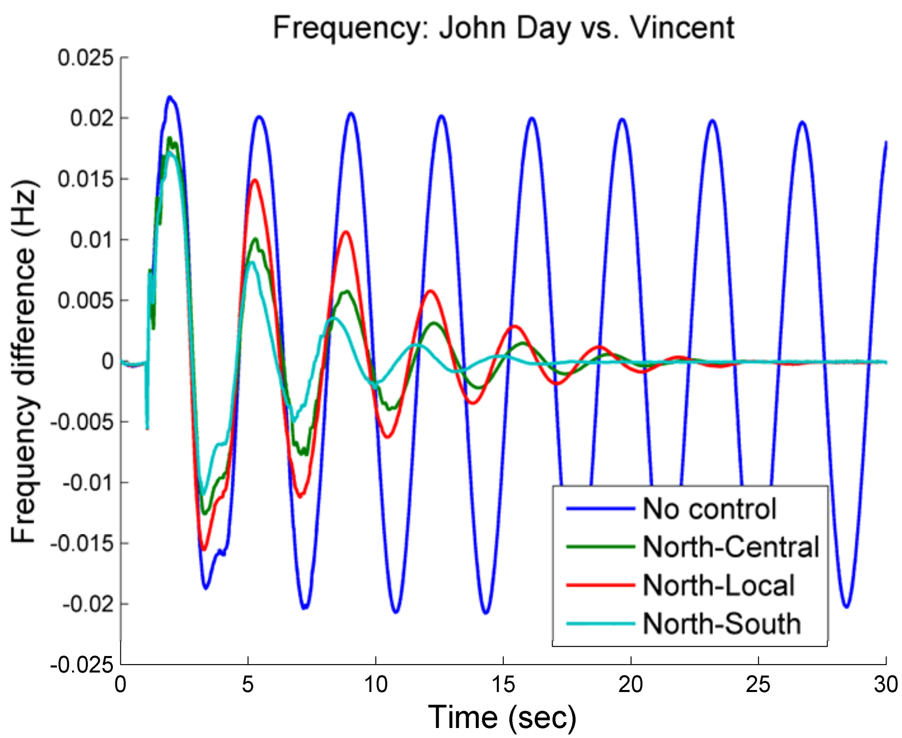
Potential Benefits from Active Damping Control for Inter-area Oscillations

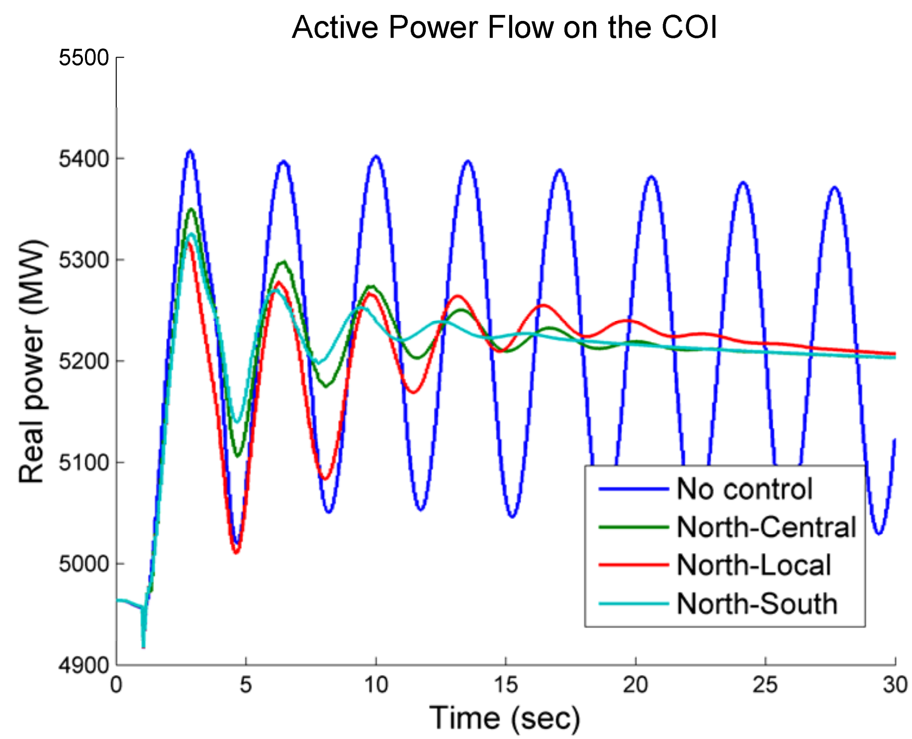
- **Improved system reliability**
- **Additional contingency in a stressed system condition**
- **Economic benefits**
  - Avoidance of costs from an oscillation-induced system breakup (1996 outage costs: > $1B overall impact)
  - Reduced need for new transmission capacity (capital cost savings in excess of $1M per mile)
  - Potential for increased flows in COI (meeting demand on hot summer days in SW)

Active control has the potential to significantly improve damping of inter-area oscillations

Example: BC-ALB Separation

- Without damping control, the system response is nearly undamped.
- With PDCI damping control, the oscillation decays very quickly.





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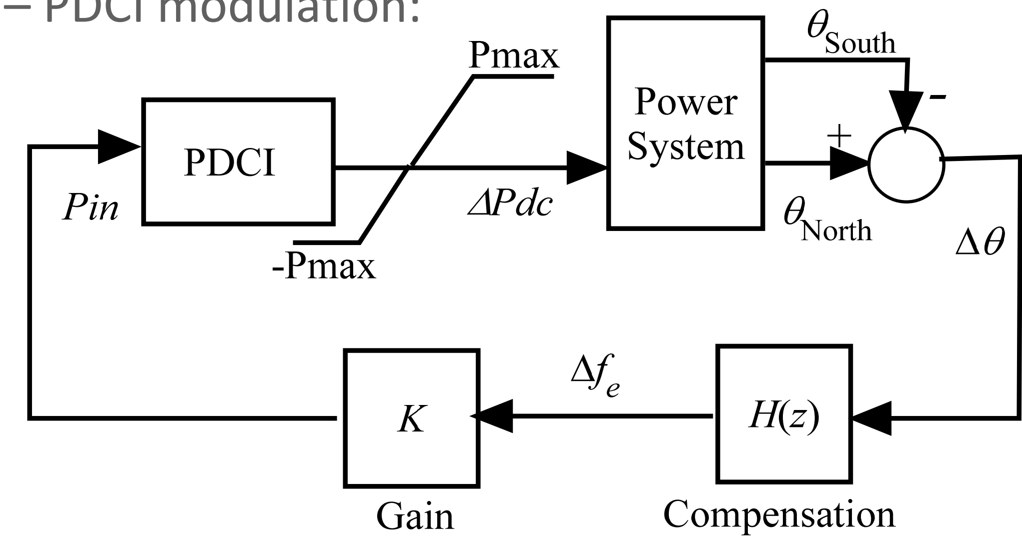
Proposed Damping Schemes use Frequency Difference Feedback

Control Objectives:

- Dampen all modes of interest for all operating conditions without destabilizing peripheral modes
- Do NOT worsen transient stability (first swing) of the system
- Do NOT interact with frequency regulation (e.g. speed governors)
- Example – PDCI modulation:

⇒ Feedback control signal should be proportional to the frequency difference between two areas



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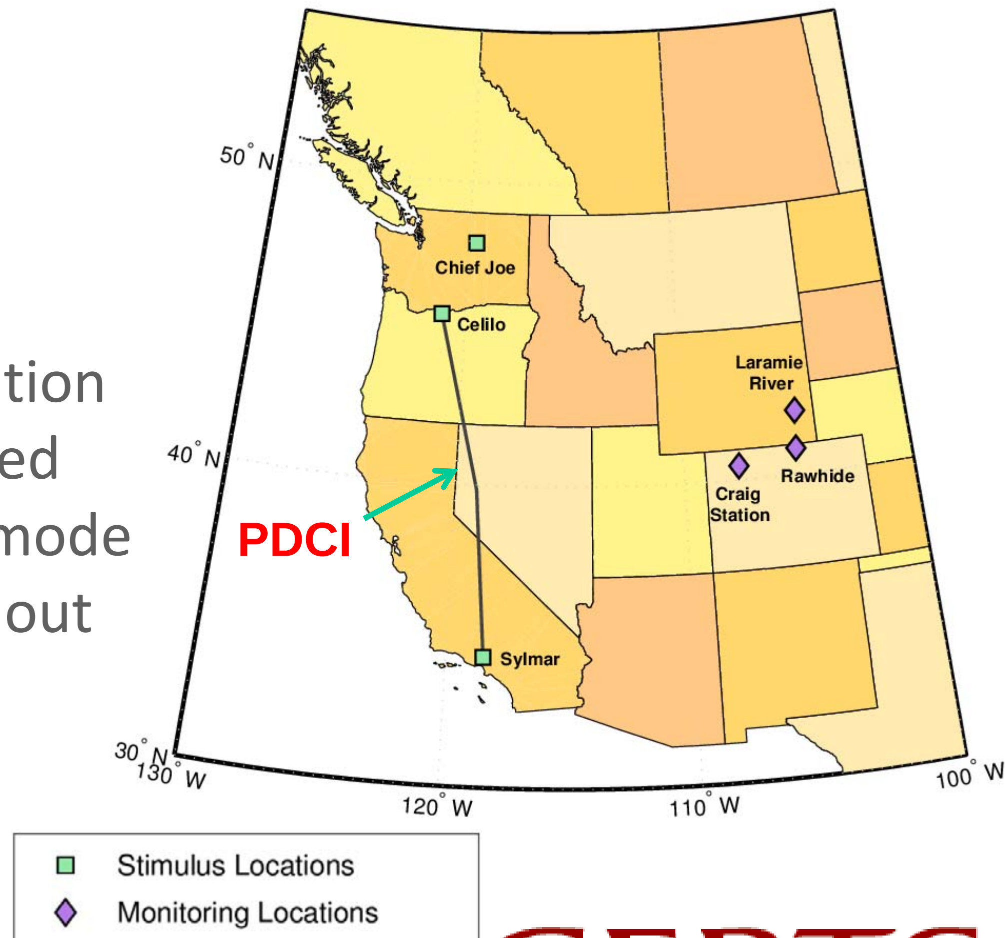
PDCI Modulation is Primary Candidate for Damping Control Actuation

- Oscillation damping using the PDCI has advantages
  - High power capacity
  - Existing infrastructure

- Both theoretical and simulation studies have shown improved damping of North-South B mode using PDCI modulation without destabilizing other modes



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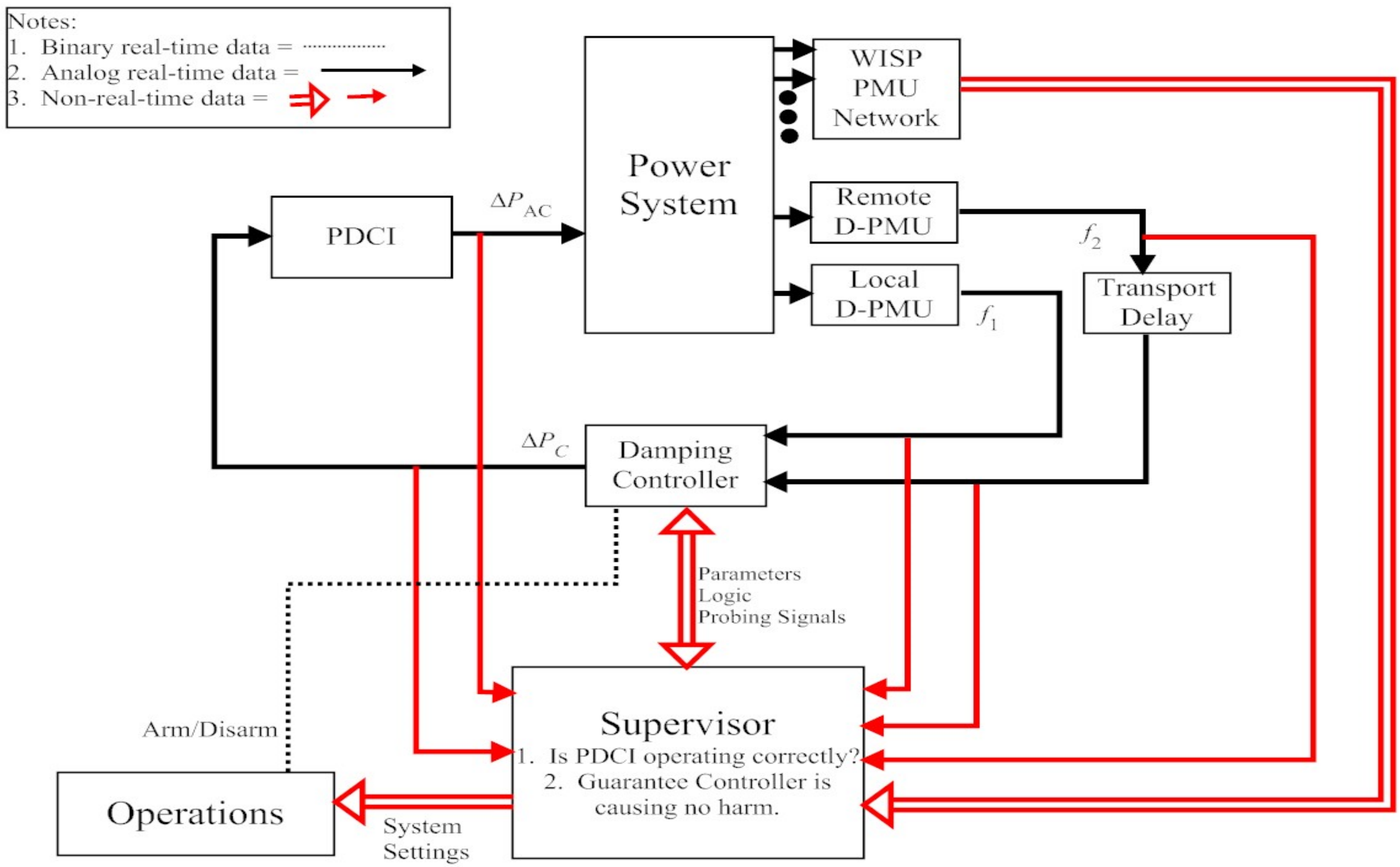
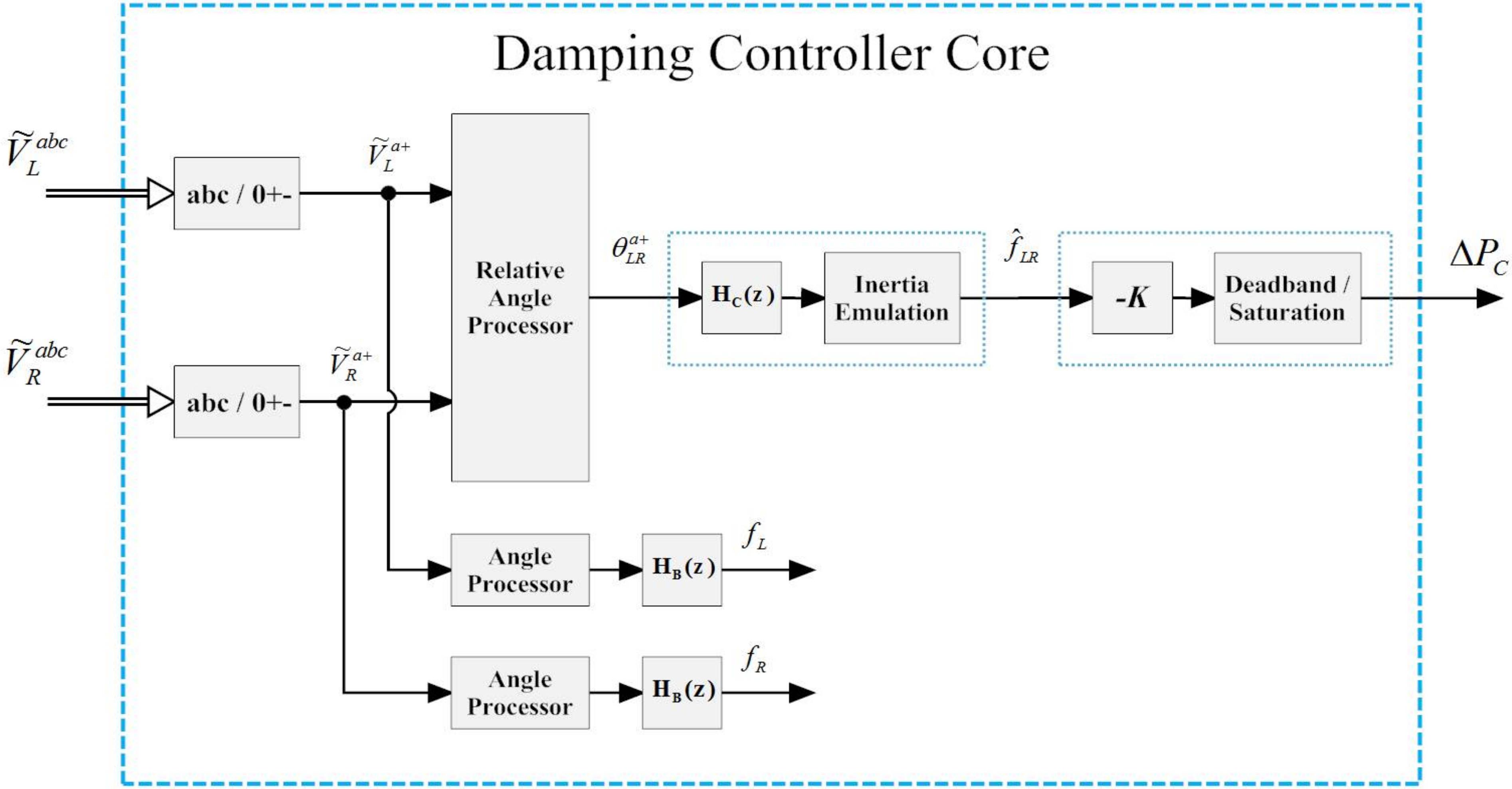
Control System Architecture



Damping Controller Core Components



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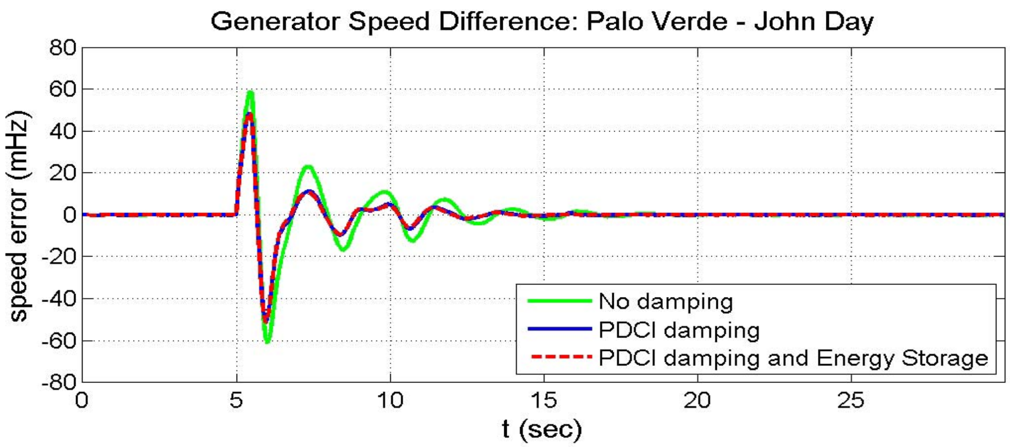
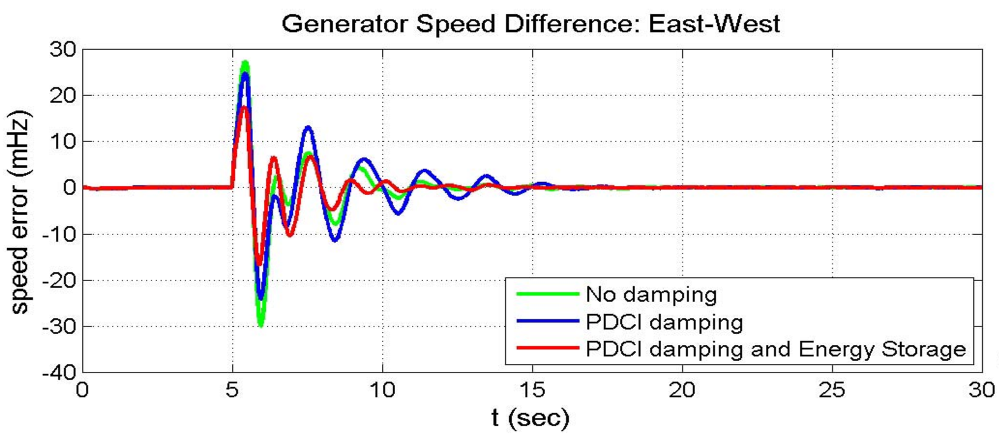
Supervisor Control Properties

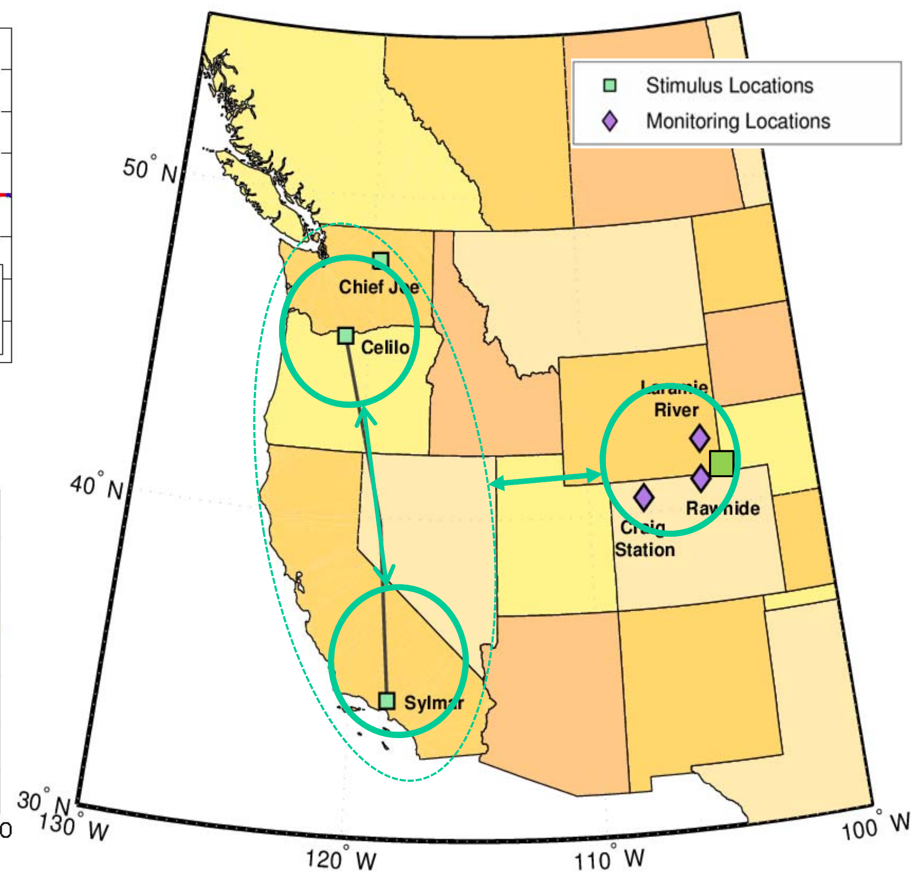
- **Primary Duties:**
  - Monitor Health of PDCI terminal
    - Voltage, real power, reactive power
    - Verify: $-\Delta P_{AC} = \Delta P_C$
  - Ensure Damping Controller is causing **NO HARM**
    - Estimate open loop frequency domain transfer function
      - Calculate gain & phase margins to assess stability
    - Detect and Monitor all oscillations
      - Disarm controller if necessary
- **Supervisor carries out its tasks at three different layers:**
  - Hardware (e.g. watchdog timer, E-stop, hardware bumpless transfer)
  - Real-time (e.g. oscillation detection, angle separation detection)
  - Asynchronous (slower than real time, e.g. transfer function estimation, gain/phase margin checks)

Three Node Damping Control Scheme: PDCI augmented with Energy Storage

Addition of energy storage improves damping of East-West A mode







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Risk Factors

- **Prototype → Deployment**
  - Extensive testing and validation of prototype may raise new issues
  - Controller will need to be refined and revised during this transition
- **Deployment Challenges**
  - Real-time PMU feedback across utility area boundaries
  - Cyber security measures
- **Do No Harm**
  - Must satisfy stakeholders that supervisor is doing its job
  - Continuous real-time testing

Upcoming Tasks for late FY14 and FY15

- Install prototype control system at BPA Synchrophasor Lab
  - Test and validate prototype controller with real-time BPA PMU signals
  - Address control system interface with transmission operations
- Refine mitigation schemes for PMU data quality issues
  - With BPA staff, analyze latencies, noise, and failure modes of PMU data
- Incorporate redundancy & diversity in feedback control signals
- Investigate Distributed Energy Storage as a damping option
  - Technology & Power Requirements
  - Location issues in distributed storage implementation
- Revise visualization software for mode shape display
  - Work with BPA staff to determine most effective visual displays

Project Follow-on

- Successful demonstration of prototype PDCI damping control system will pave the way for
  - Phase II project that is more operations oriented
  - Further analysis of augmenting distributed energy storage with PDCI modulation
- Transition plan from prototype to deployment (phase 1 → phase 2)
  - Rigorous testing & refinement of the prototype controller
  - Comprehensive risk assessment of the proposed control strategy
  - Interface with transmission operations
  - Address cyber security concerns related to deployment
- Collaborations with BPA have been initiated on above issues and will be accelerated in summer 2014 and FY15.

Project Publications

- **Conference Papers**
  - 2012 Modeling, Simulation and Optimization for the 21st Century Electric Power Grid (Engineering Conferences International)
  - 2013 & 2014 IEEE Power and Energy Society General Meeting (PESGM)
  - 2013 Electrical Energy Storage Application and Technology (EESAT)
- **Journal Paper in submission process**
  - IEEE Transactions on Smart Grid (optimal location of distributed energy storage)