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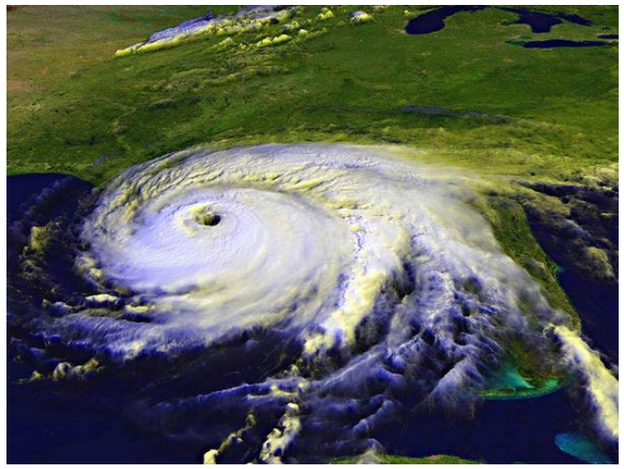

Active Damping of Power System Oscillations Using Distributed Energy Storage

September 23, 2015

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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We gratefully acknowledge our sponsors:

- **DOE/OE Energy Storage Program – PM: Dr. Imre Gyuk**
- **DOE/OE Transmission Reliability Program – PM: Mr. Phil Overholt**
- **BPA Technology Innovation Program – TIP 289**

Project Overview

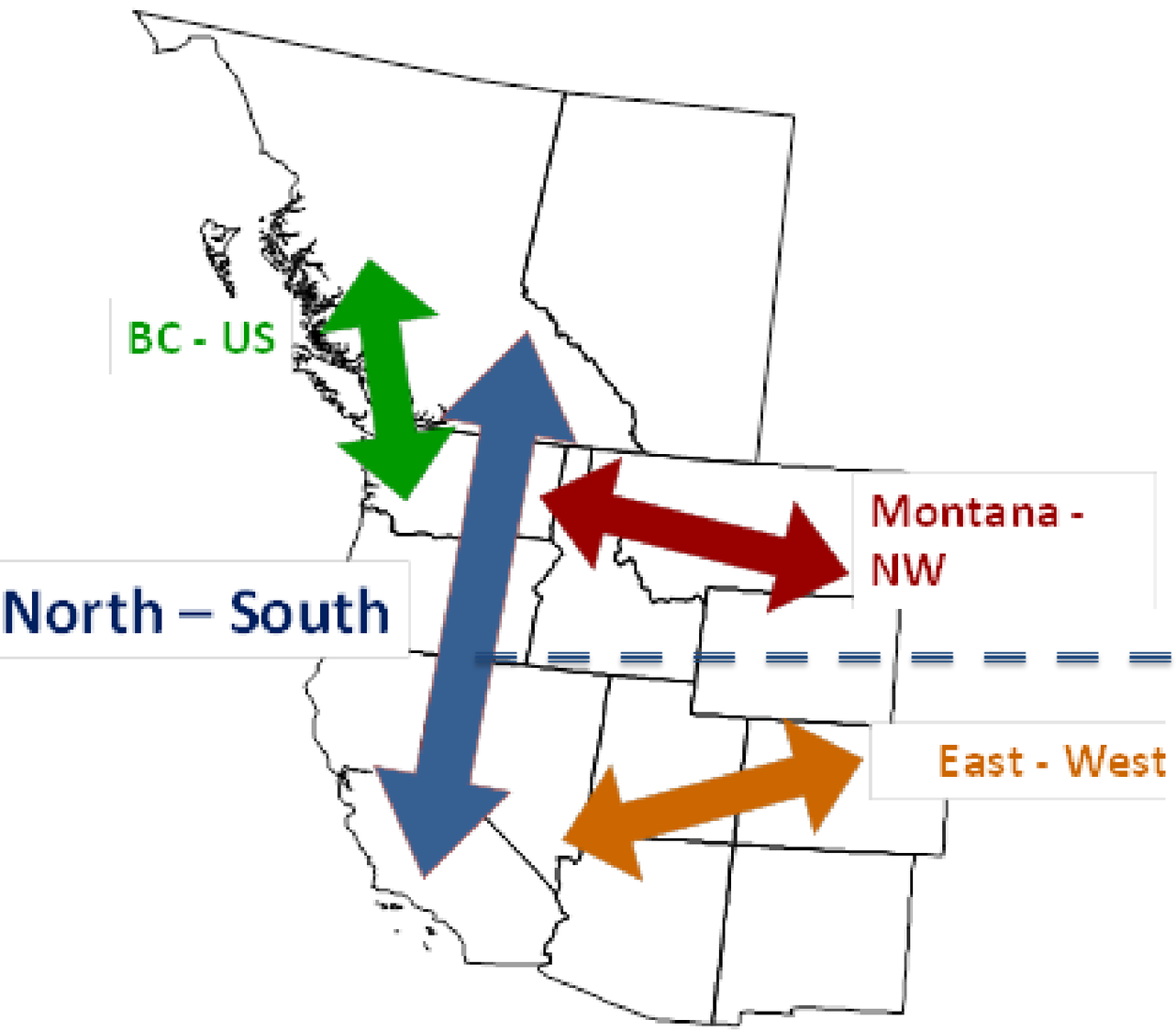
Project Deliverables:

1. **Prototype PDCI-based damping control system**
   - Open-loop testing in BPA's PMU Lab
   - Transition to Celilo for closed-loop testing
2. **Implementation strategy for ESS-based damping**
   - Control algorithms employing distributed storage
   - Implementation strategies for deployment

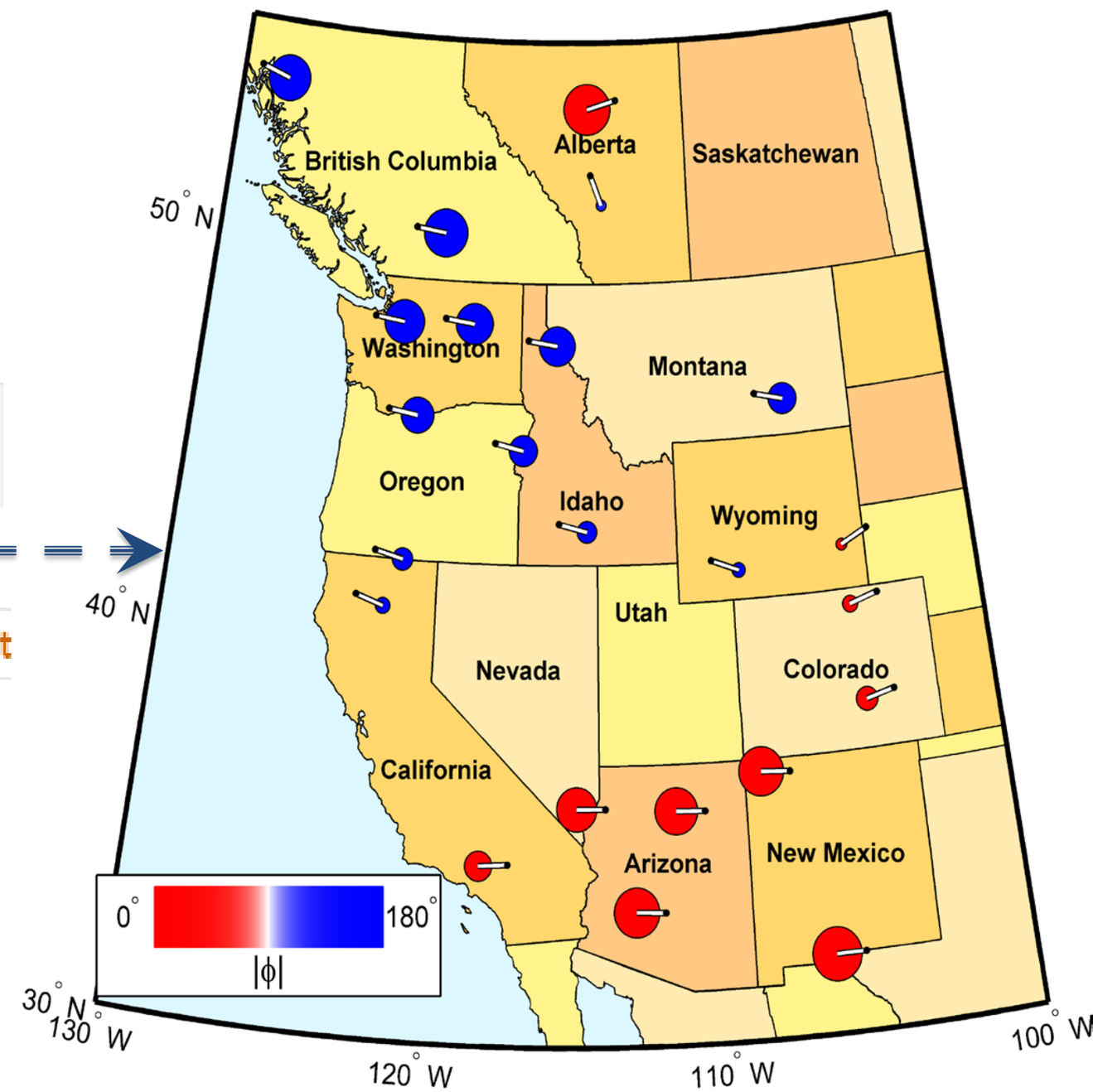
Innovative Features of Project:

1. **Real-time PMU measurements** for frequency feedback to dampen inter-area modes
2. **Supervisor controller** to monitor damping effectiveness and ensure **"Do No Harm"**

Western Interconnect Oscillation Modes

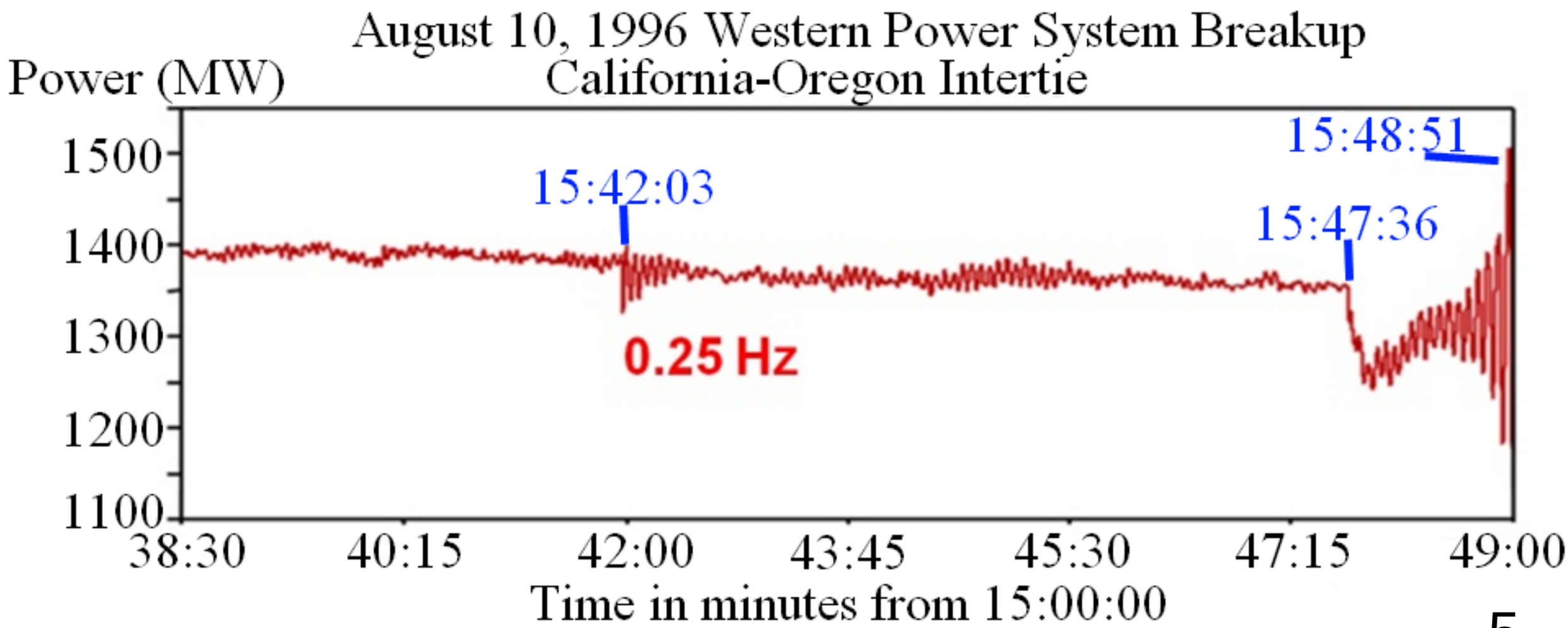


North-South Mode



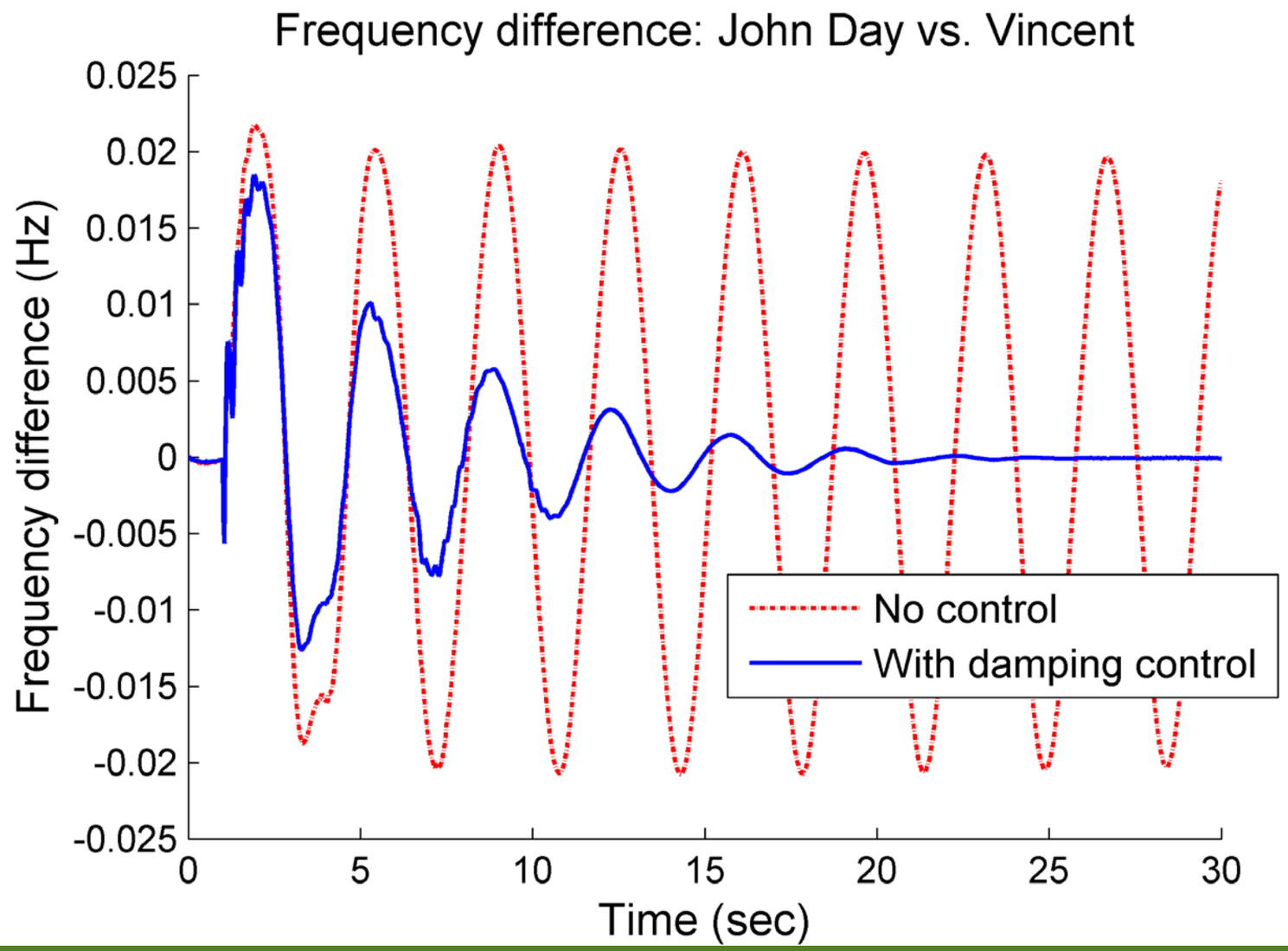
Inter-Area Oscillations Jeopardize Grid Stability

- Large generation and load complexes separated by long transmission lines can develop inter-area oscillations
- Present approach to mitigate this scenario is maintaining large headroom in power flow
- More efficient mitigation strategy is active power injection using energy storage or PDCI modulation



Expected Benefits of Damping Control

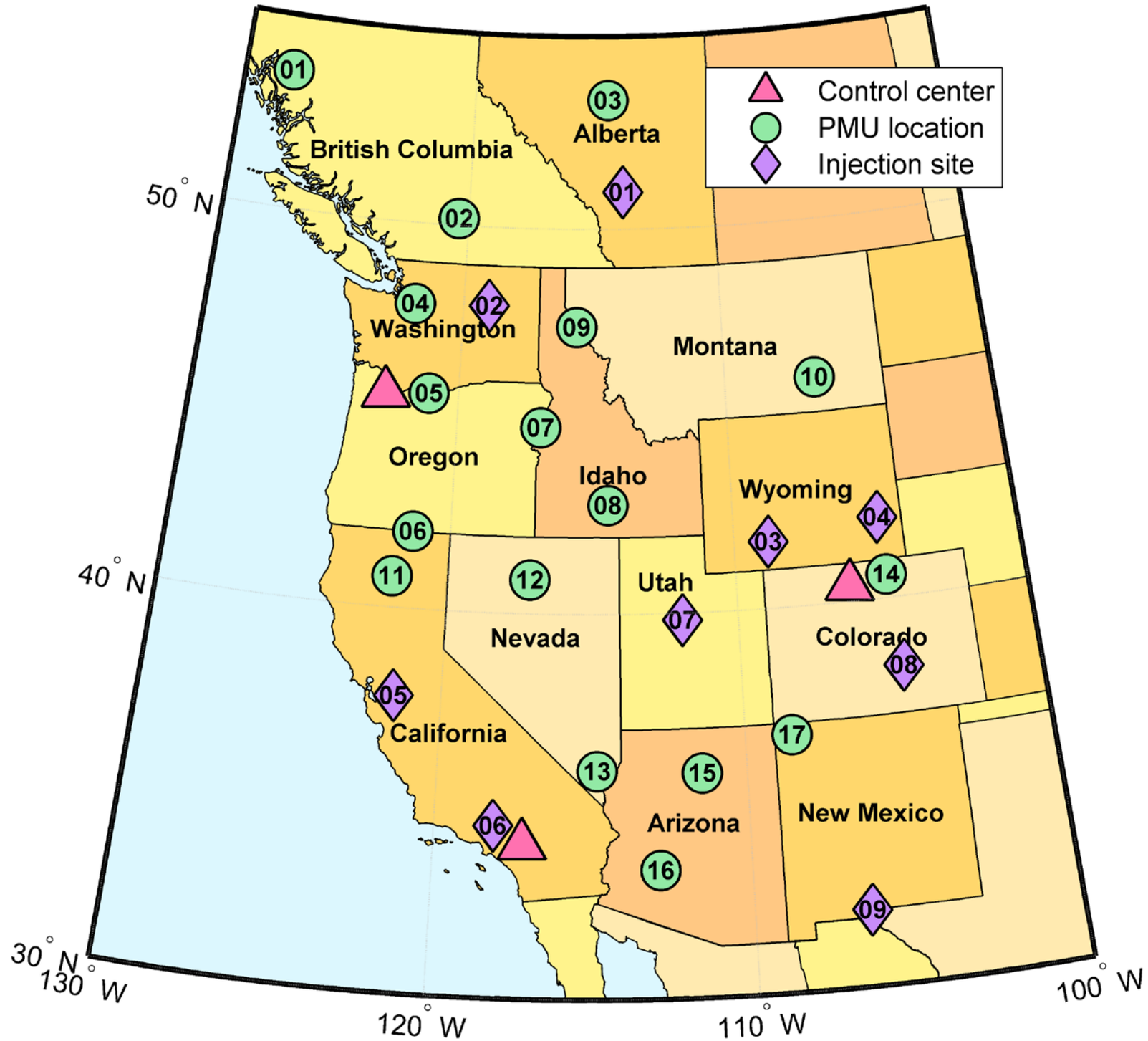
- Improved system reliability
- Additional contingency in a stressed system condition
- Economic benefits:
  - Avoidance of costs from an oscillation-induced system breakup (1996 outage costs: > $3B)
  - Reduced need for new transmission capacity (capital cost savings > $1M/mile)
  - Potential for increased power flows through congested transmission corridors



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

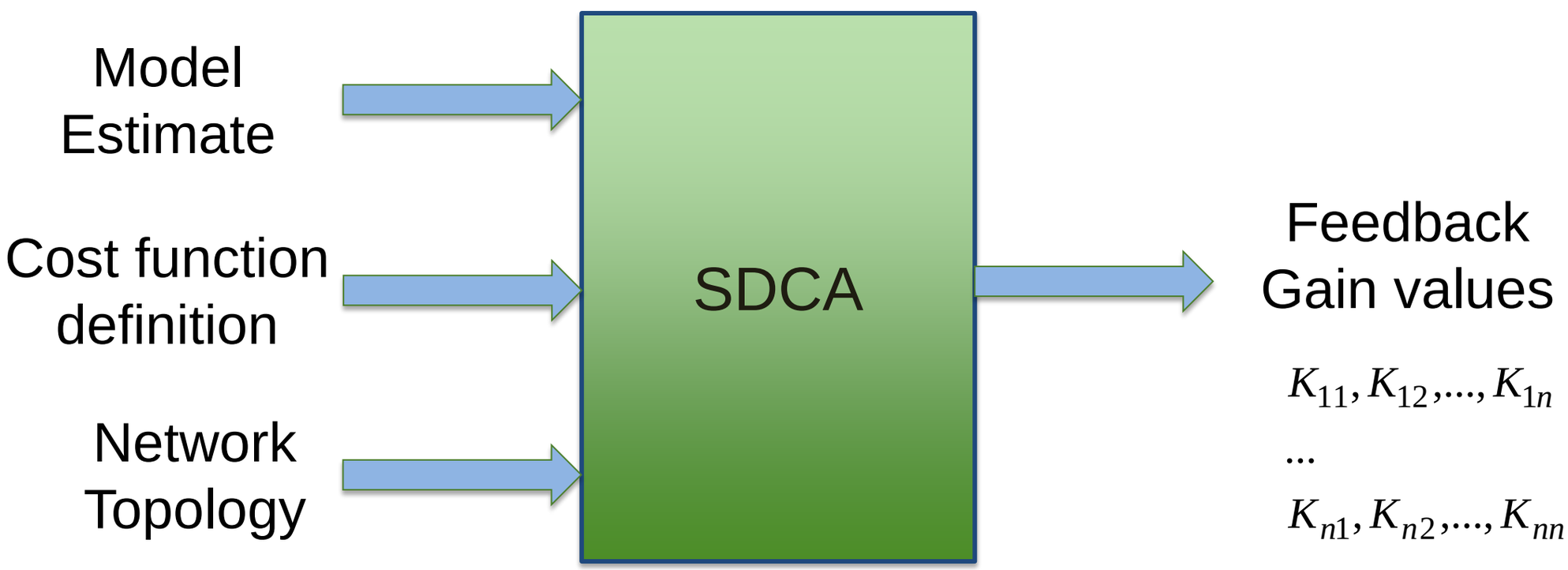


Algorithmic Approach to Multi-Node Distributed Damping

- A scalable *N*-node damping control scheme using distributed energy storage
- Each node modulates power based on local PMUs and multiple remote PMUs

$$\Delta P_i = -\sum_{j=1}^{n} K_{d,ij} f_i$$

- Gains are computed using a Structured Damping Control Algorithm (SDCA)



An Optimization Problem is Formulated

- To attain the control law $u_d = -K_d y$

$$\underset{K_d}{\text{minimize}} \quad J = \int_0^{T_f} \left(x^T Q x + u_d^T R u_d \right) d\tau$$

$$\text{subject to:}$$

$$(1)\ \dot{x}(t) = Ax(t) + B_q q(t) + B_d u_d(t)$$

$$(2)\ y(t) = \begin{bmatrix} \Delta\omega_1 & \Delta\omega_2 & \cdots & \Delta\omega_m \end{bmatrix}^T$$

$$(3)\ u_d(t) = -K_d y(t)$$

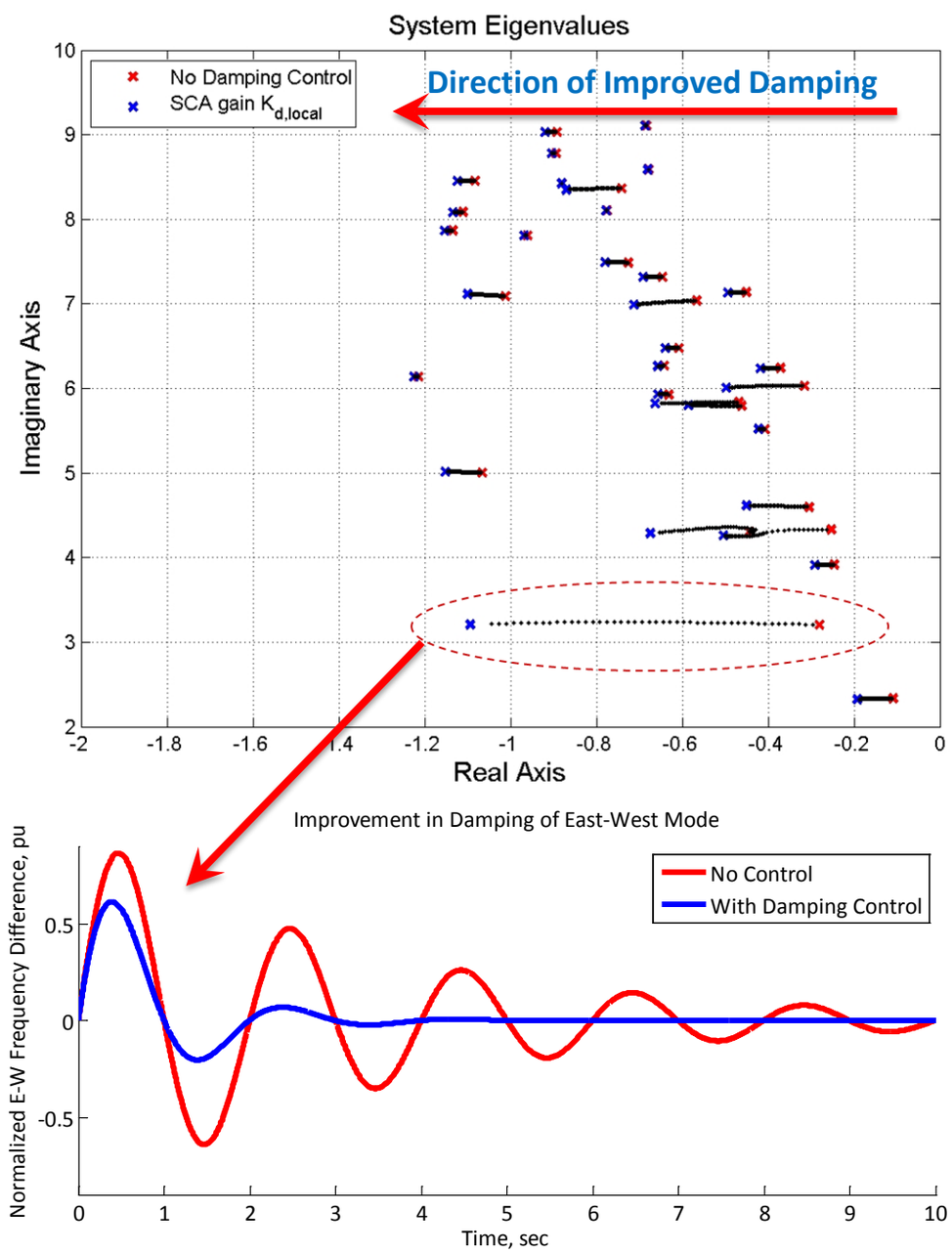
$$(4)\ \ Q \geq 0, R > 0$$

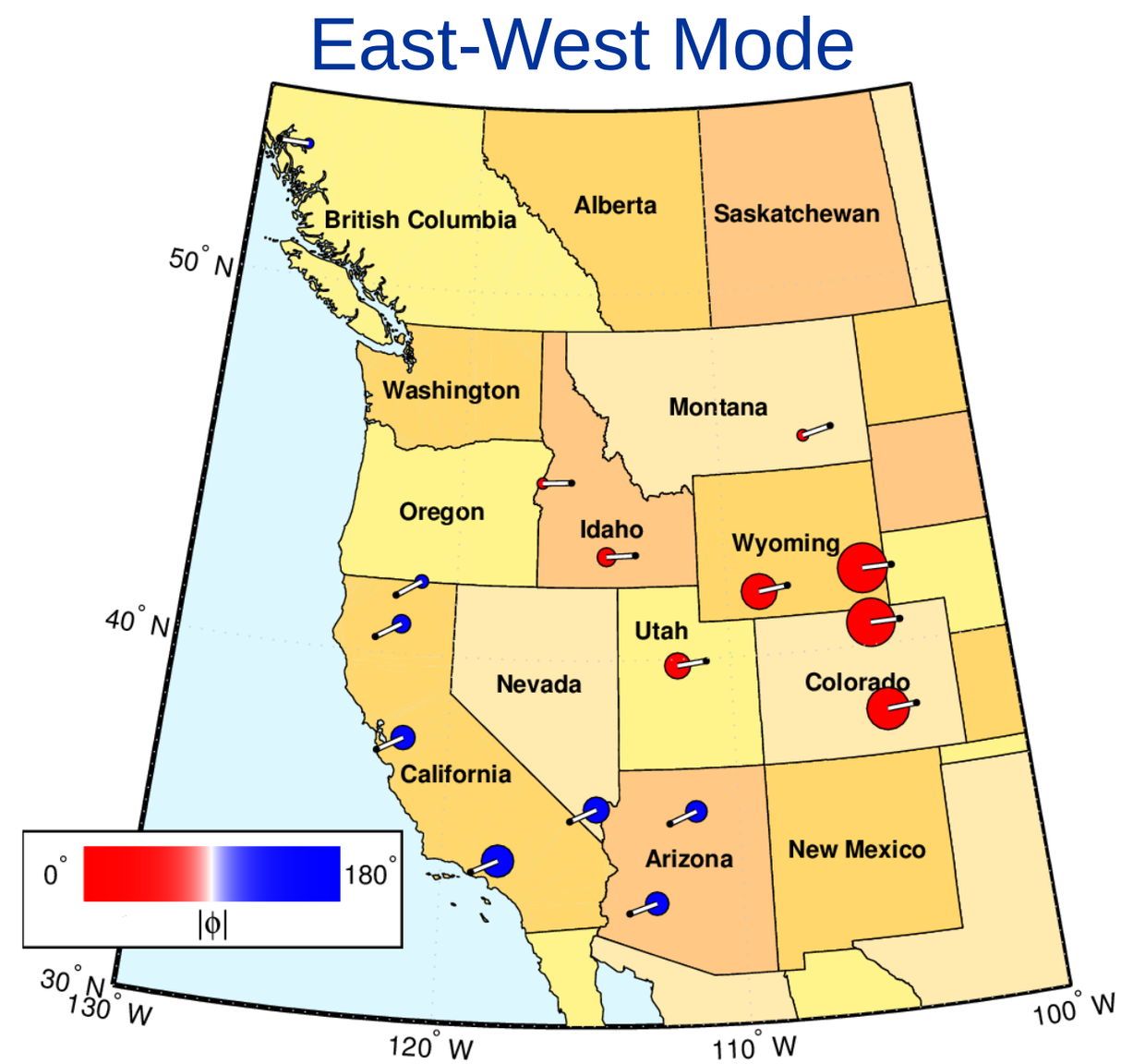
- The above optimization problem must be solved iteratively
- For solution details, see the recent journal paper:

J. Neely, J. Johnson, R. Byrne, and R. Elliott, "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.

Example of 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 primarily serving other applications ➔ very little additional cost for very large benefit





Project Direction: FY16 – FY17

- 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

- 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

Planned Phase II Timeline

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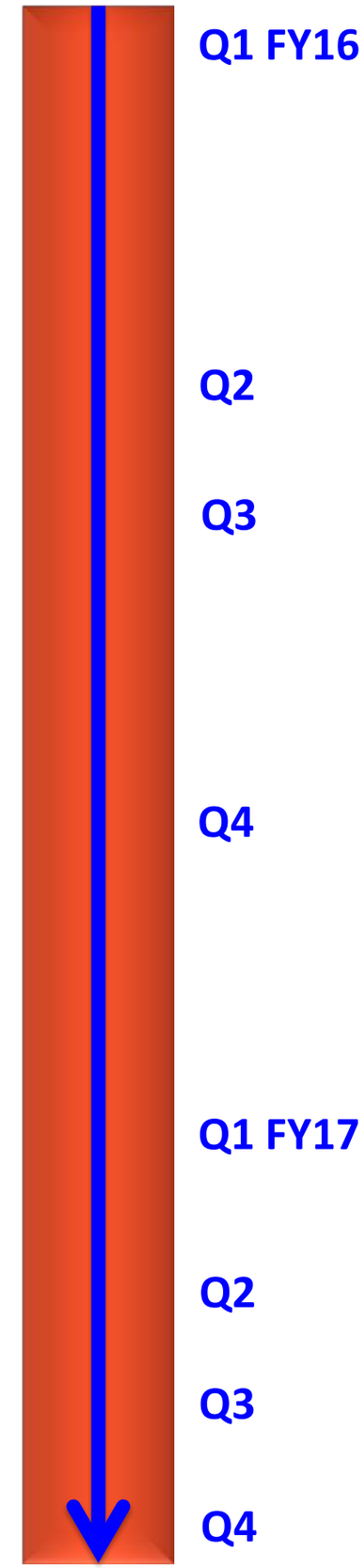
PDCI:

- 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



Thank You to the DOE/OE and BPA for their dedication and support to the ES industry and Sandia's ES Program.

Questions?

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