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The Benefits of Energy Storage Combined with HVDC Transmission Power Modulation for Mitigating Inter-Area Oscillations

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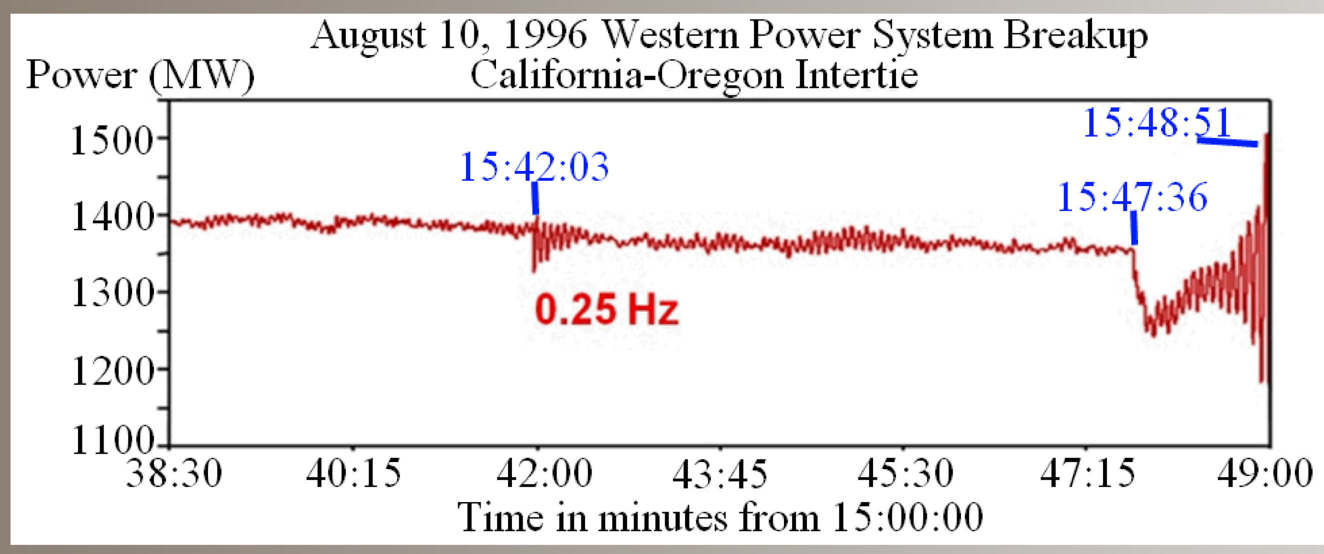
OVERVIEW

Low frequency inter-area oscillations have been identified as a significant problem in utility systems due to the potential for system damage and the resulting restrictions on power transmission over select lines. Previous research has identified real power modulation between two areas using energy storage based damping control nodes or High Voltage DC transmission as promising approaches to mitigate inter-area oscillations. Thus far, the focus has been on two-area implementations. It is noted in this work that energy storage allows for a multi-area damping approach, which can improve damping of more oscillatory modes. An example combining modulation of the Pacific DC Intertie (PDCI) with an additional energy storage damping control is presented.

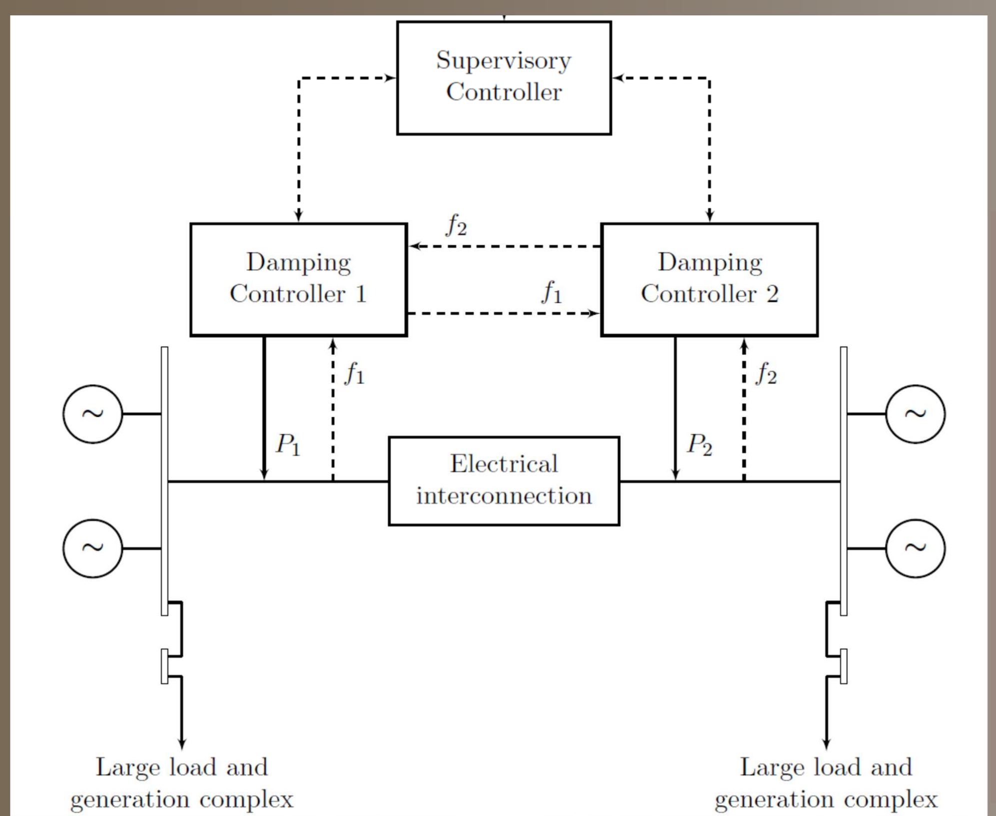
Growing Oscillations Can Result in Equipment Damage or System Break-up

Cases have been documented of system breakups attributed to poorly damped low frequency oscillations



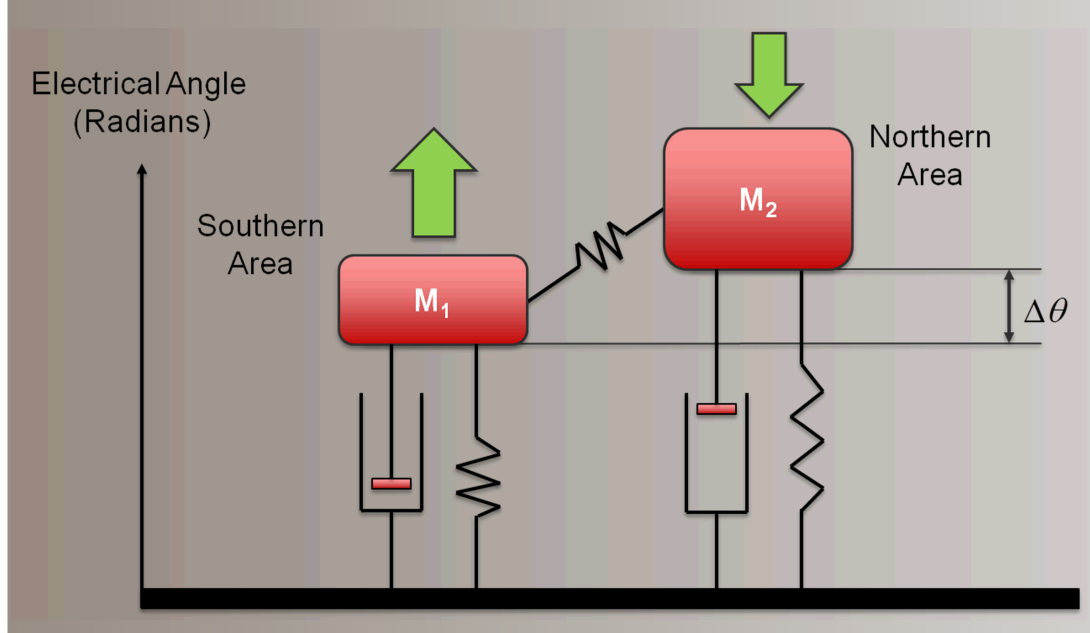
Two-Area Oscillation Damping Using Real Power Modulation

Two *damping controllers* located in different areas, a communication link, and a *supervisory controller* that oversees the control. The damping controllers operate by sourcing or syncing power in each area proportional to the frequency difference between areas.



$$P_1 = -K_d(f_1 - f_2)$$
$$P_2 = K_d(f_1 - f_2)$$

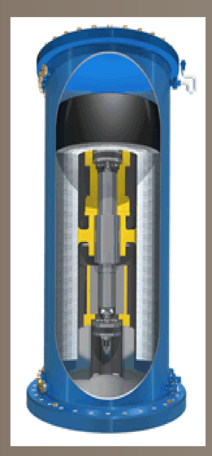
The system is analogous to a pair of mass-spring-damper systems with the objective being to reduce the velocity error between the masses.



Several Damping Controller Implementations Have Been Investigated

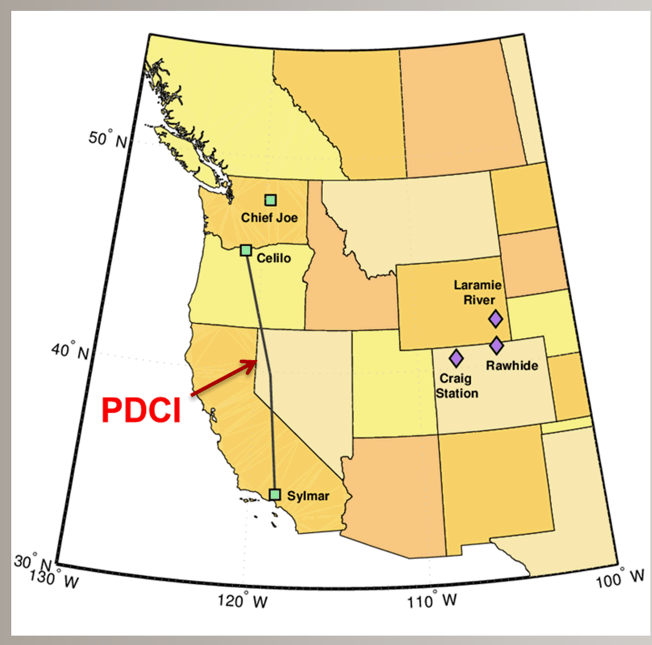
UltraCapacitors

Flywheels



Batteries

High Voltage DC Transmission



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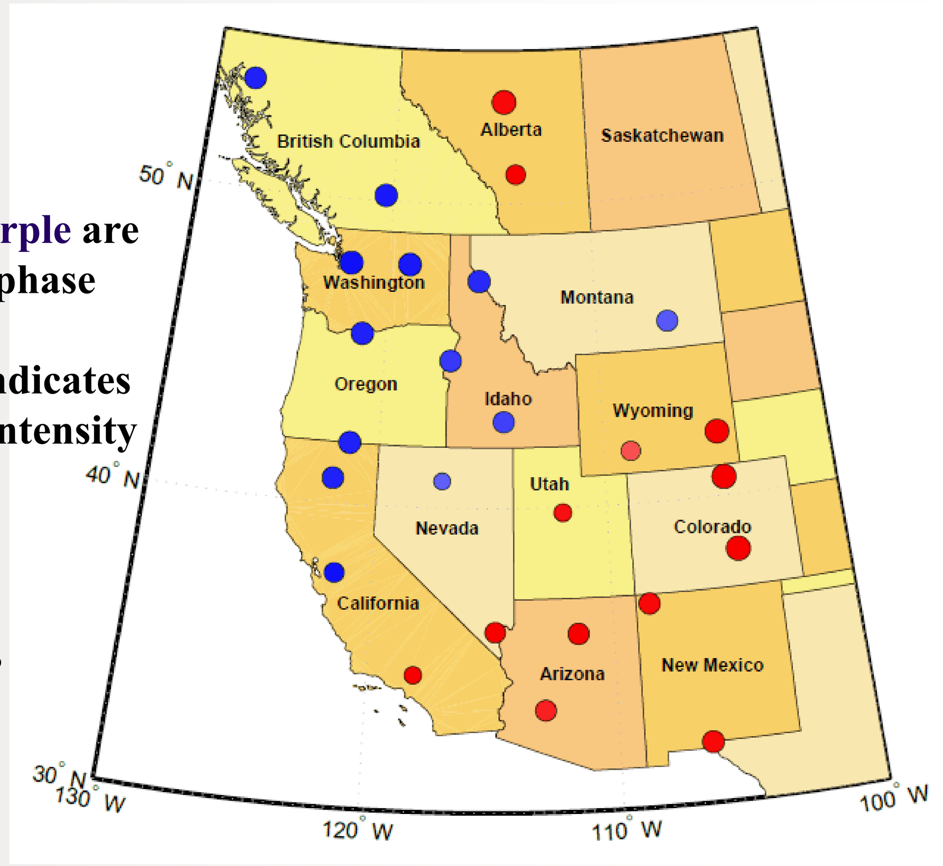
Oscillatory Modes Have Frequency and Shape

Several low frequency oscillation modes in the Western North American Power System (wNAPS) have been identified

- "North-South A" mode, near 0.25 Hz
- "North-South B" mode, 0.4 Hz
- "East-West" mode, near0.5 Hz;
- "BC" mode, near 0.6 Hz;
- "Montana" mode, near 0.8 Hz

0.37 Hz North-South mode B shape



Red and purple are 180º out of phase

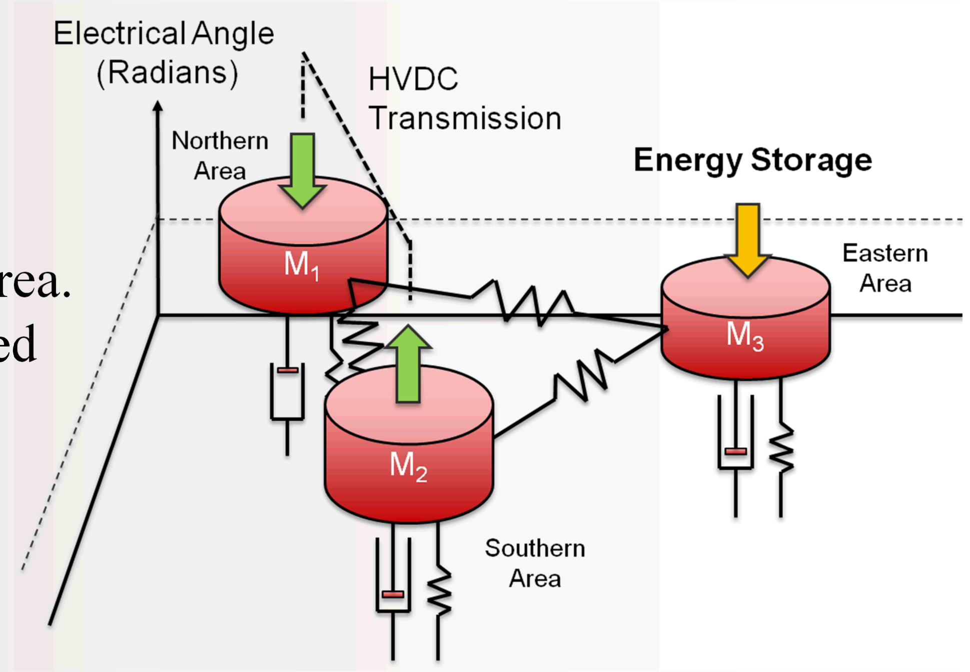
Spot area indicates oscillation intensity

A two-area damping control scheme may not be able to effectively dampen oscillations for all mode shapes.

Multi-Area Damping

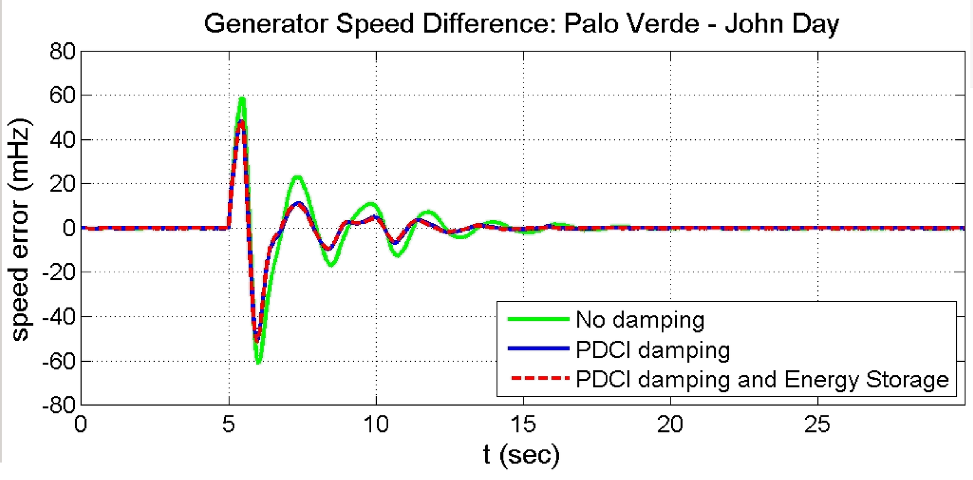
To permit a modest extension of the two-area model, let us consider a three area model. It is noted that a damping scheme that considers just two of the three areas may not be effective in reducing all inter-area oscillations.

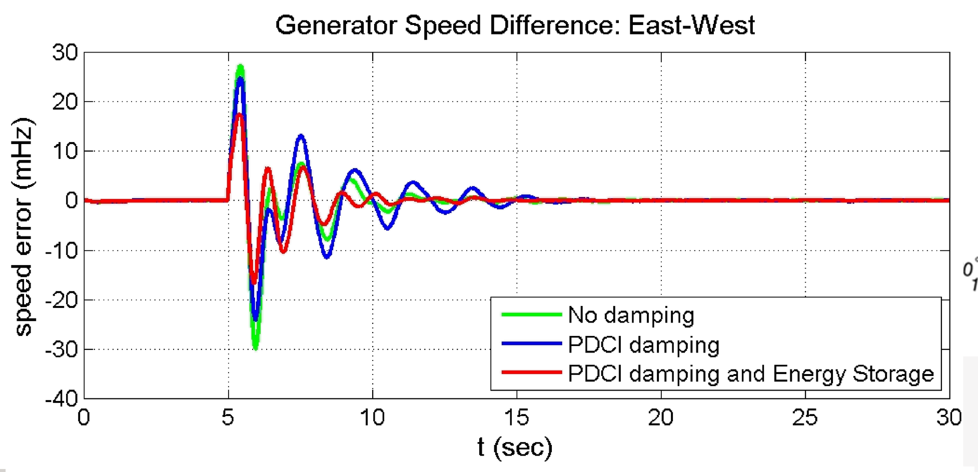
Thus, a third damping node should be added in the third area. An example of this is presented for the wNAPS.

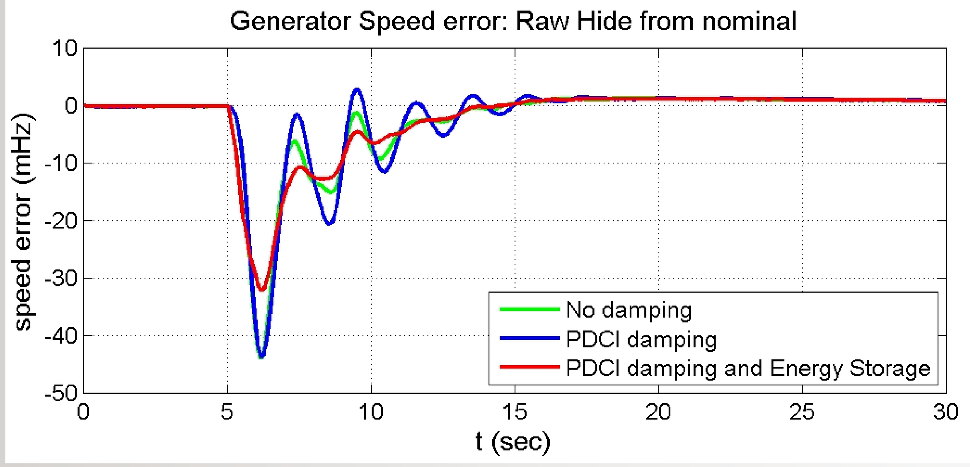


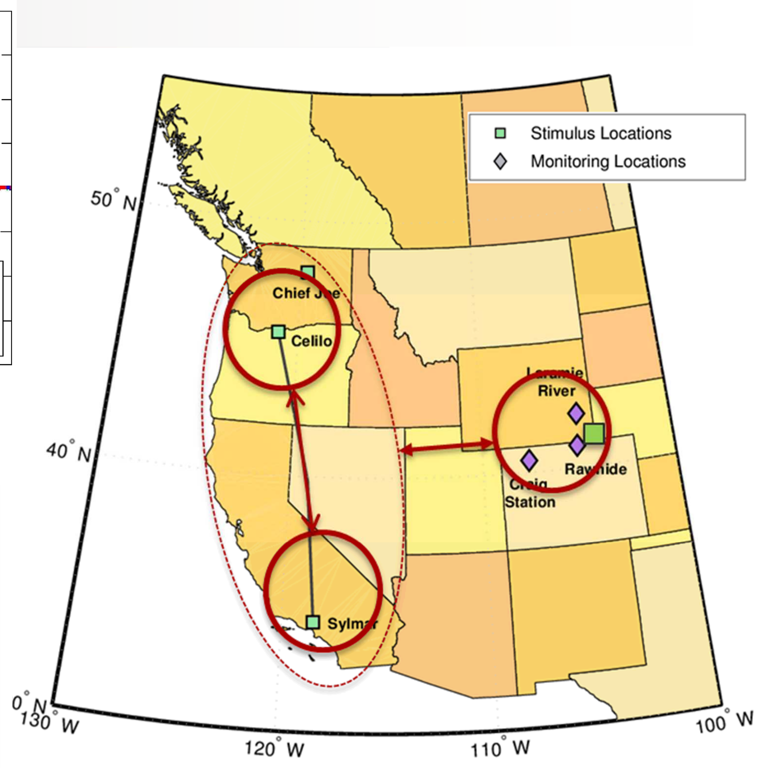
Simulation Results

A dynamic model was developed by the Western Electric Coordinating Council (WECC) to represent a lightly loaded wNAPS in 2022. This model was augmented to include PDCI damping as well as an energy storage damping node in Ault (near Denver). At t=5 sec, an oscillatory response was stimulated using the *Chief Joseph Brake* in Washington. Ring-down responses indicate considerable improvement in damping the East-West mode using a third energy storage damping node.









$$\Delta P_1 = -K_{d1}(f_1 - f_2)$$
$$\Delta P_2 = K_{d1}(f_1 - f_2)\cdot\eta_{PDCI}$$
$$P_3 = -K_{d2}\left(f_3 - \frac{1}{2}f_1 - \frac{1}{2}f_2\right)$$

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