Optimal Locations for Energy Storage Damping Systems in the Western North American Interconnect

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ACKNOWLEDGEMENTS

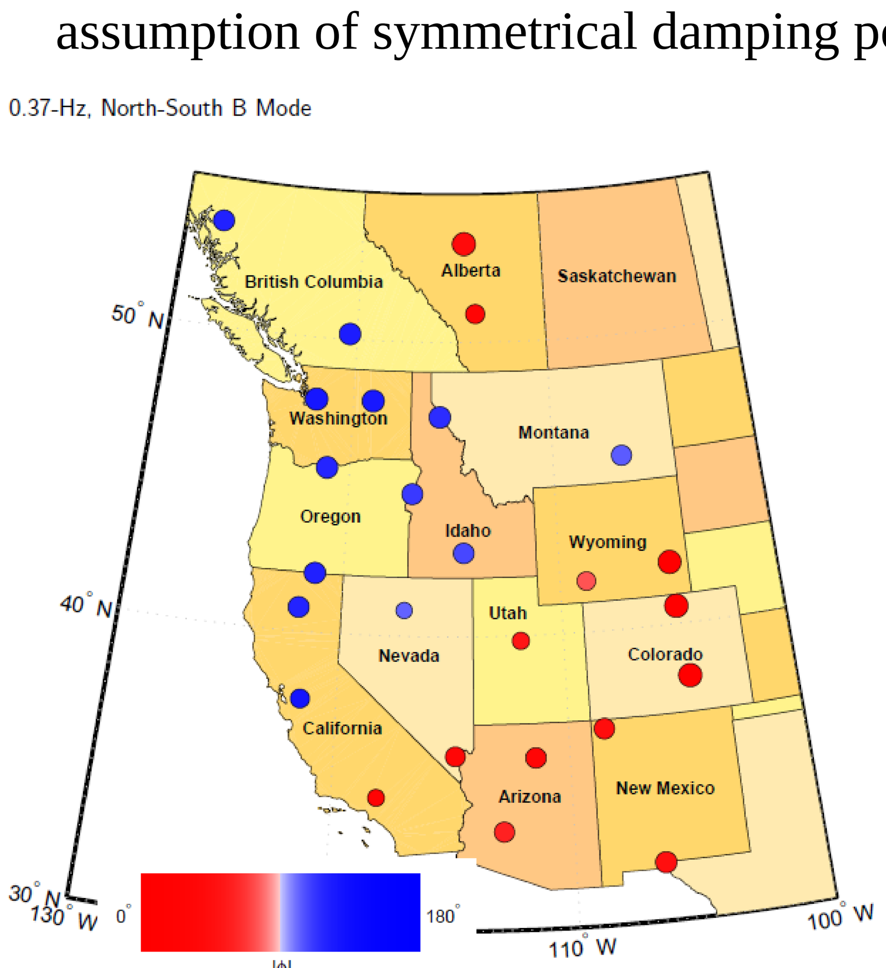
We gratefully acknowledge the support of: DOE Energy Storage Program (Dr. Imre Gyuk, PM); DOE Transmission Reliability Program (Mr. Phil Overholt, PM); and the BPA Technology Innovation Program (Dr. Dmitry Kosterev, Tech. POC, Dr. Jisun Kim, PM).

RESEARCH GOALS

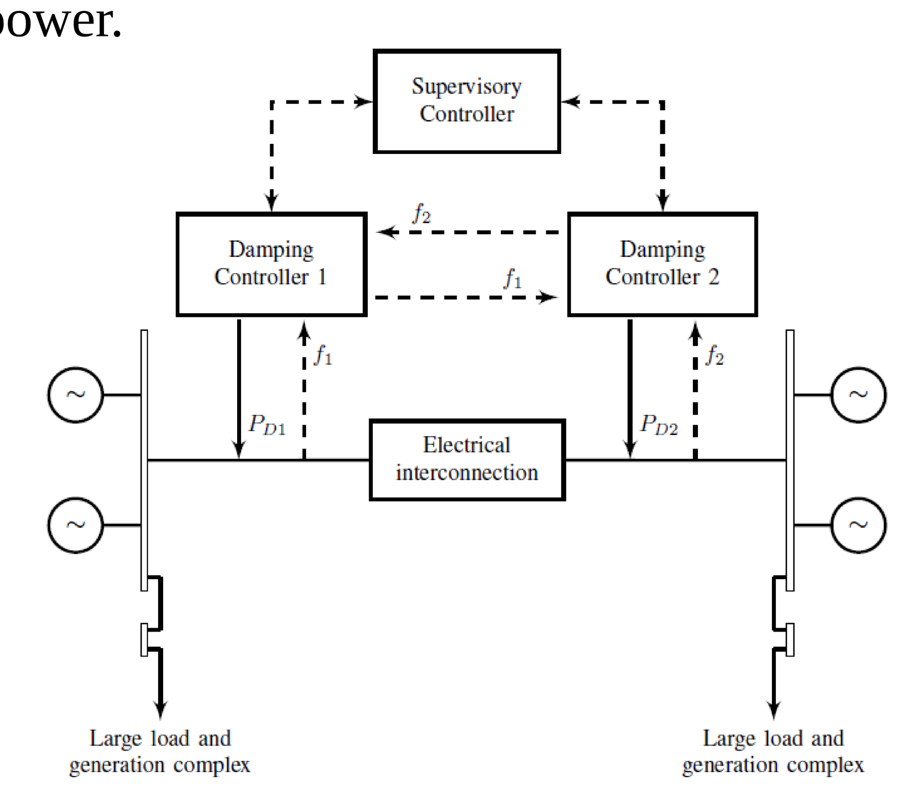
- Investigate the utility of Pacific DC Intertie (PDCI) modulation, augmented with energy storage systems, to increase damping in the western North American Power System (wNAPS)
- Determine optimal locations for the siting of energy storage systems to improve damping within the wNAPS

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 (HVDC) modulation as promising approaches to mitigate inter-area oscillations. In this work, we analyze the combination of energy storage based damping with HVDC modulation of the PDCI. Further, we devise a method for determining the optimal location of energy storage devices within a two-area system without the assumption of symmetrical damping power.



Bus	Amp.	Shape(*Deg.*)	Bus	Amp.	Shape(*Deg.*)
Ault	1.00	0.0	Monroe	0.80	126.3
Comanche	0.99	−2.1	Coulee	0.78	124.9
Laramie	0.95	2.1	Big Eddy	0.71	118.1
Genesee	0.92	−43.1	Nicola	0.71	122.4
Newman	0.66	−47.5	Taft	0.71	114.6
Moenkopi	0.58	−34.4	Malin	0.67	120.1
Four Corners	0.58	−45.6	Brownlee	0.65	110.3
Hassyampa	0.56	−60.6	Kemano	0.63	119.4
Mead	0.52	−32.7	Round Mt.	0.61	118.7
Langdon	0.45	−30.7	Midpoint	0.58	106.6
Bridger	0.42	75.9	Colstrip	0.56	102.5
Mona	0.29	52.6	Tesla	0.45	128.2
Vincent	0.27	−26.8	Valmy	0.22	101.2

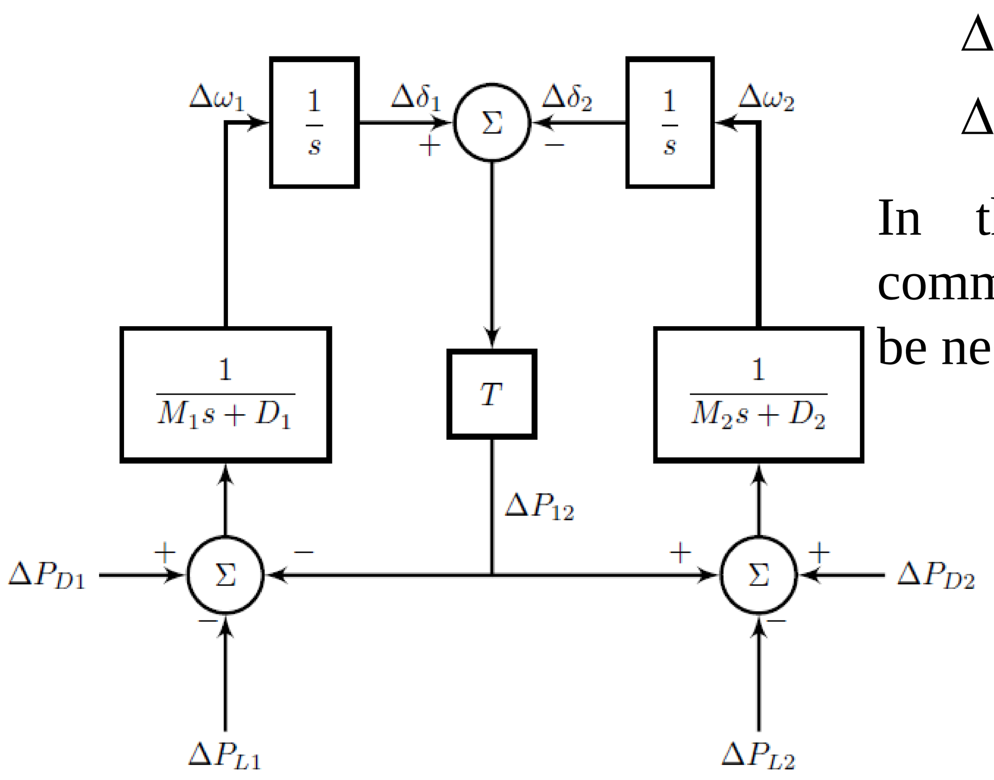


$$\Delta P_{D1} = -K\big(f_1(t) - f_2(t-\tau)\big)$$
$$\Delta P_{D2} = -K\big(f_2(t) - f_1(t-\tau)\big)$$

Low frequency oscillations are present in all large power systems

TWO-AREA SYSTEM MODEL QUANTITIES

Quantity	Description
M_i	Area i inertia
D_i	Area i damping
T	Synchronizing torque coefficient
ΔP_{Li}	Area i load variation
ΔP_{Di}	Area i damping torque
$\Delta\omega_i$	Area i change in speed
$\Delta\delta_i$	Area i change in angle



TWO-AREA SYSTEM

A simplified two-area system was considered to investigate the connection between key system parameters and the sensitivity of damping to energy storage placement. Instead of symmetrical damping power, the gains in area 1 and area 2 are varied using a parameter α.

$$\Delta P_{D1} = -K\alpha\big(f_1(t) - f_2(t-\tau)\big)$$
$$\Delta P_{D2} = -K(1-\alpha)\big(f_2(t) - f_1(t-\tau)\big)$$

In the analysis of this work, the communication latency, τ, is assumed to be negligible. Thus, when α >0.5,

$$|\Delta P_{D1}| > |\Delta P_{D2}|$$

EIGENVALUES ARE COMPUTED FOR THE 2-AREA SYSTEM

Using the simplified system, the characteristic polynomial is identified as

$$p(s) = as^4 + bs^3 + cs^2 + ds + e$$

where

$$a = M_1 M_2$$
$$b = M_1 D_2 + M_2 D_1 + M_1 K(1-\alpha) + M_2 K\alpha$$
$$c = T(M_1 + M_2) + D_1 D_2 + D_1 K(1-\alpha) + D_2 K\alpha$$
$$d = T(D_1 + D_2)$$
$$e = 0$$

The polynomial may be reduced to a third-order system may be solved symbolically in terms of the system parameters using the Ruffini-Horner method with mild assumptions, resulting in calculations for the mode damping coefficient as follows.

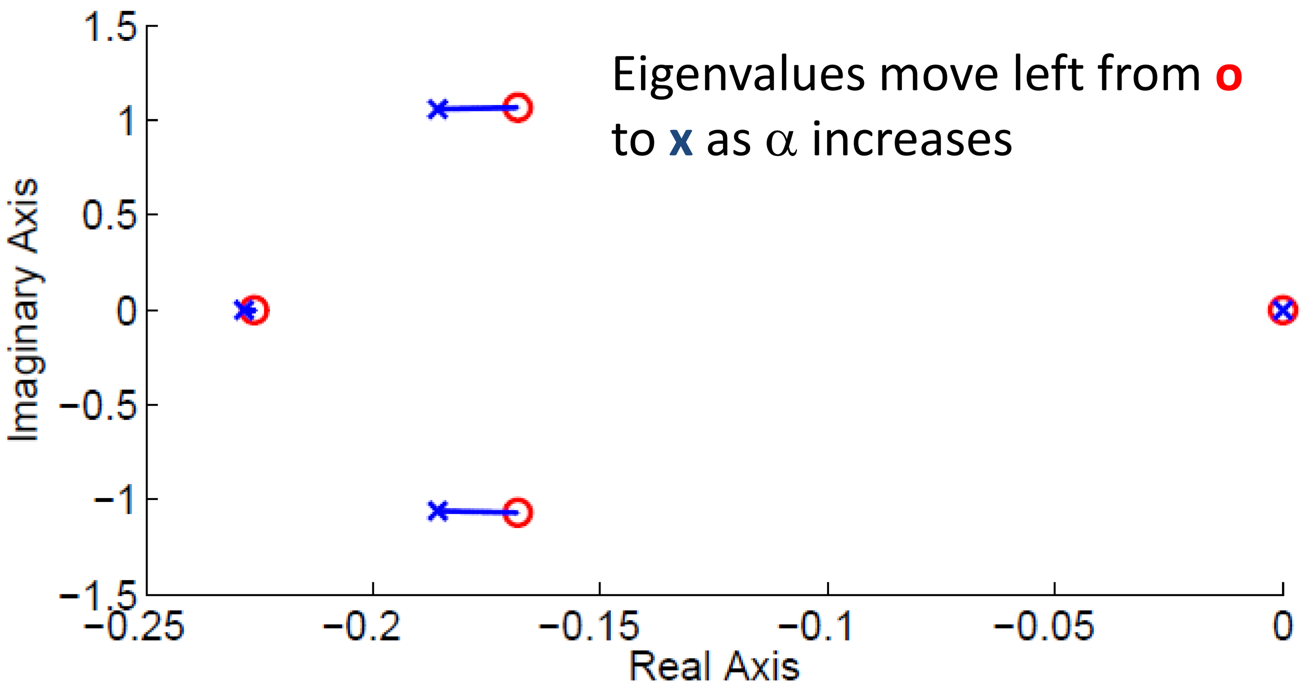
$$\zeta\omega_n \approx \frac{1}{2}\left(\frac{D_2}{M_2} + \frac{D_1}{M_1} + \frac{K(1-\alpha)}{M_2} + \frac{K\alpha}{M_1} - \frac{D_1 + D_2}{M_1 + M_2}\right)$$

OPTIMAL LOCATIONS FOR ENERGY STORAGE

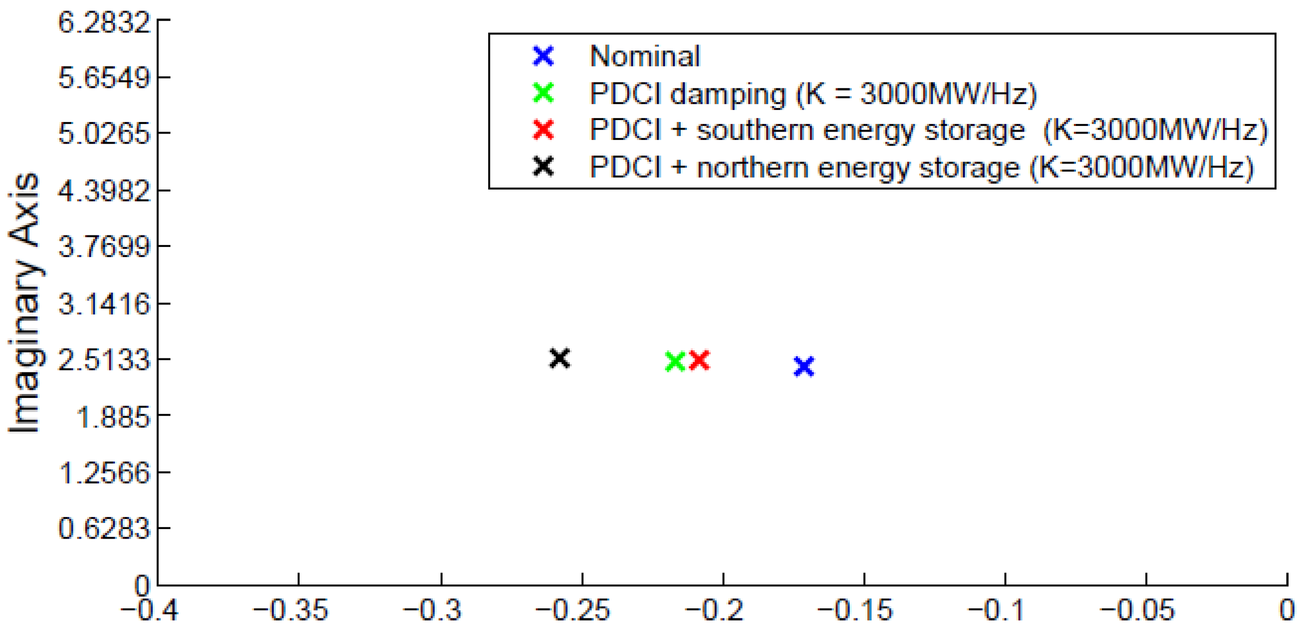
Eigen analysis and simulation of the western interconnect were utilized to investigate the sensitivity of damping to energy storage placement (i.e. value of α). In the simplified model, $M_1 < M_2$. In the simulation study, a Western Electric Coordinating Council (WECC) developed model of the western interconnect was simulated using General Electric's (GE) Positive Sequence Load Flow (PSLF) software; the base case considered was representative of the 2013 heavy summer loading condition with less mechanical inertia at the North end of the PDCI compared to the South.

Eigenvalue locations for the simplified and representative system indicate that optimal placement of energy storage resources is in the area with lower inertia.

Root locus for 2-area system; eigenvalues move left as α varies from 0 to 1



PSLF simulation results for WECC 2013 heavy summer base case. Eigenvalues are for the North-South B mode



CONCLUSION

For single mode damping control systems (e.g. two areas oscillating against each other), the optimal location for energy storage placement is in the area with the lower inertia.

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