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Open-Loop Testing Results for the Pacific DC Intertie Wide Area Damping Controller

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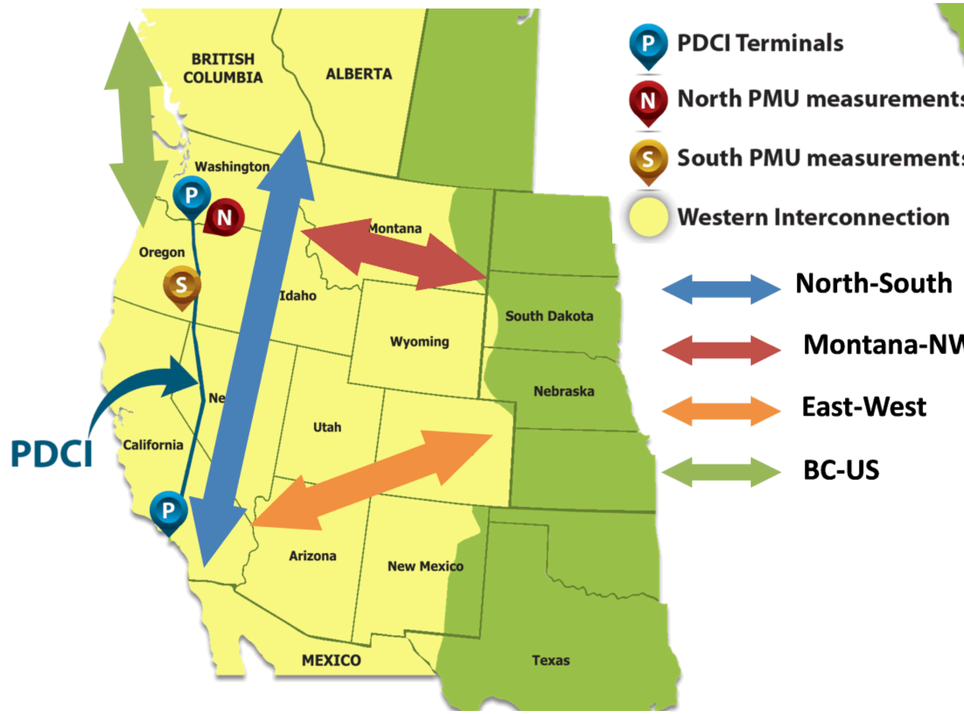
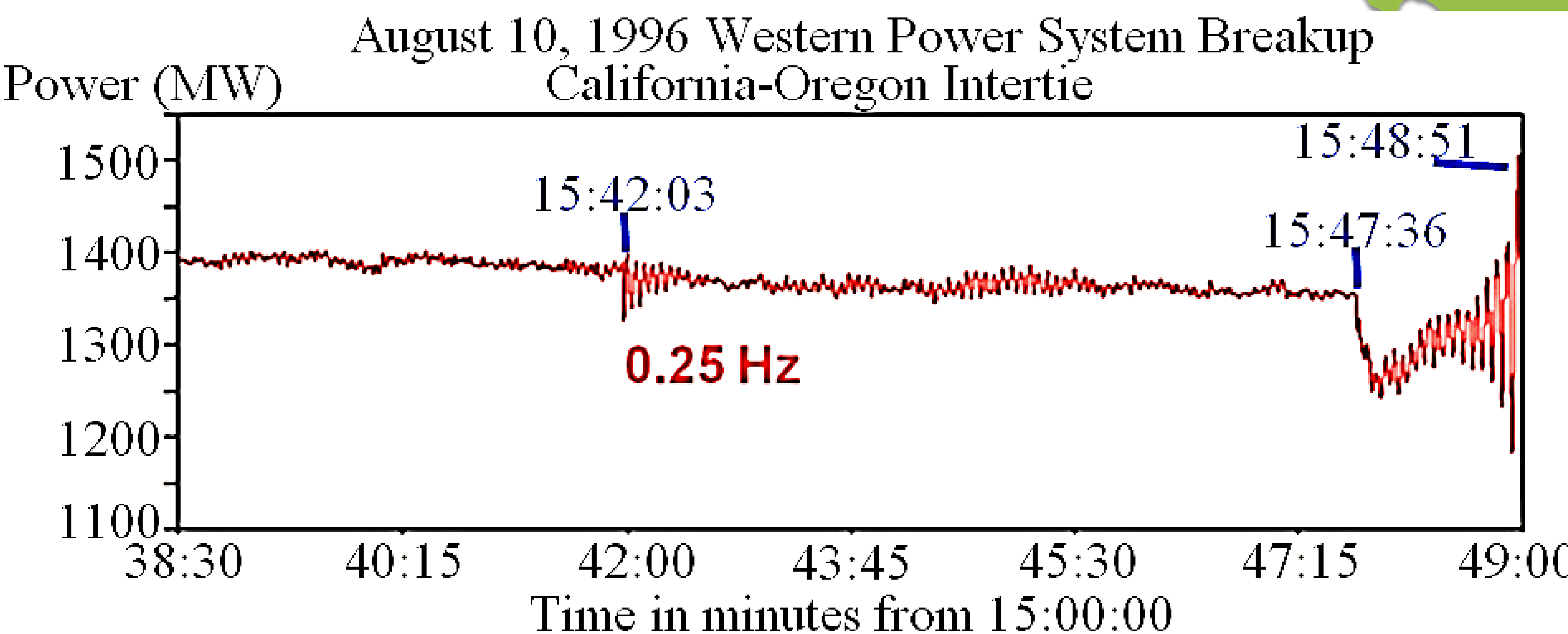
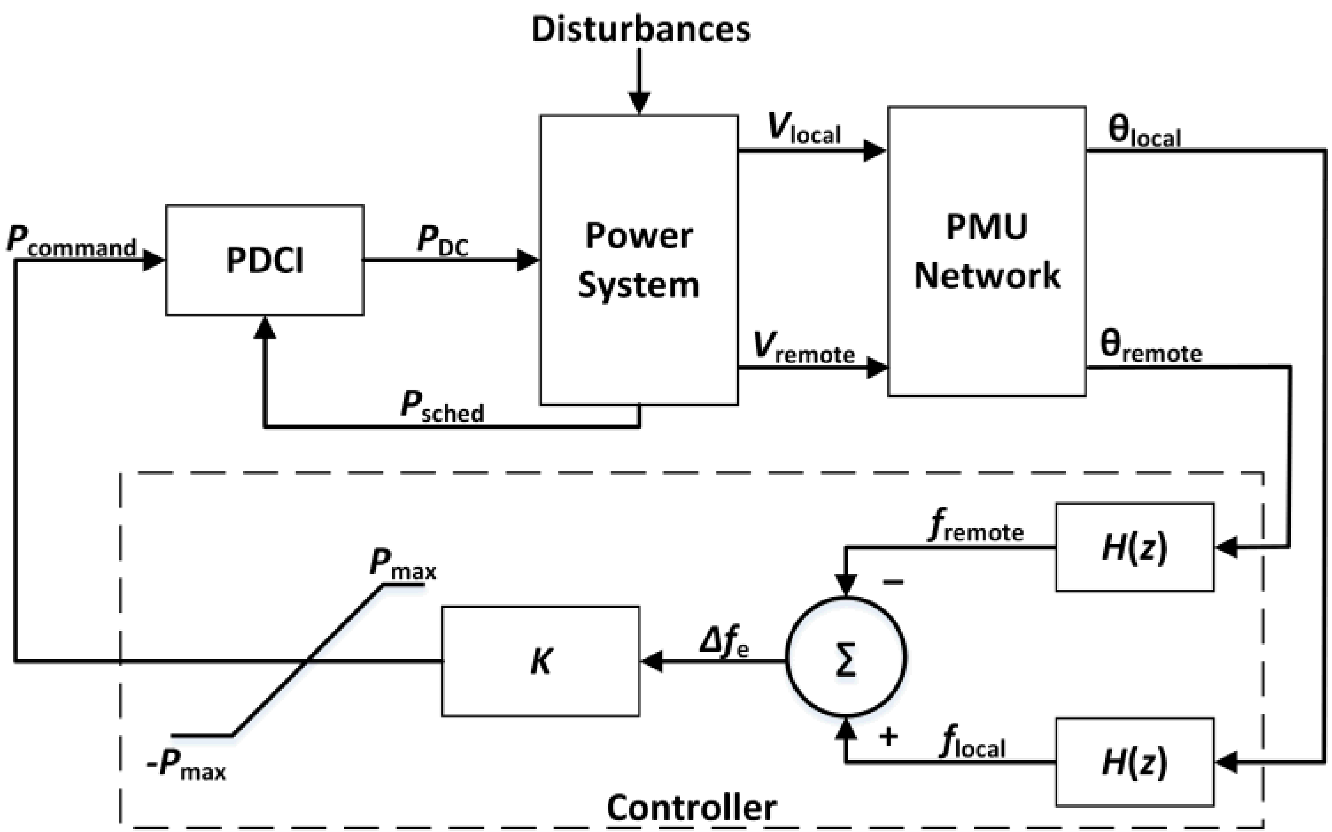
Background

- Build and test a physical controller that modulates the real power on the PDCI to improve damping of wide area oscillatory modes using real-time PMU feedback
- "Do No Harm"





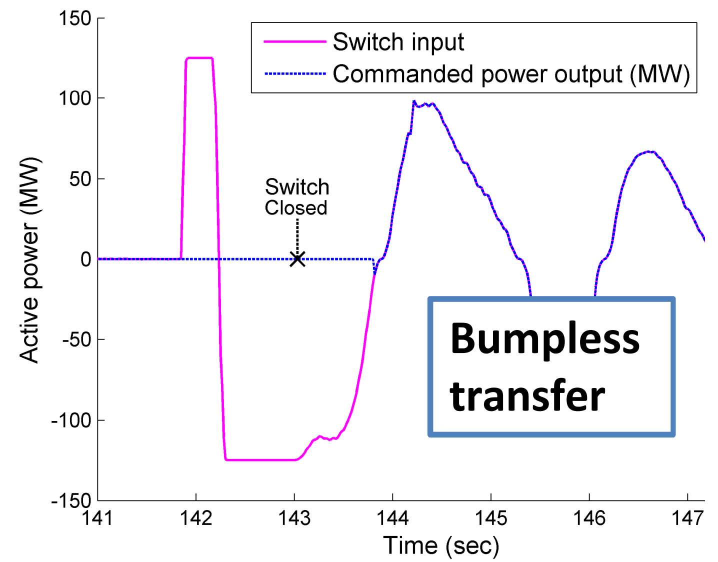
Damping controller design

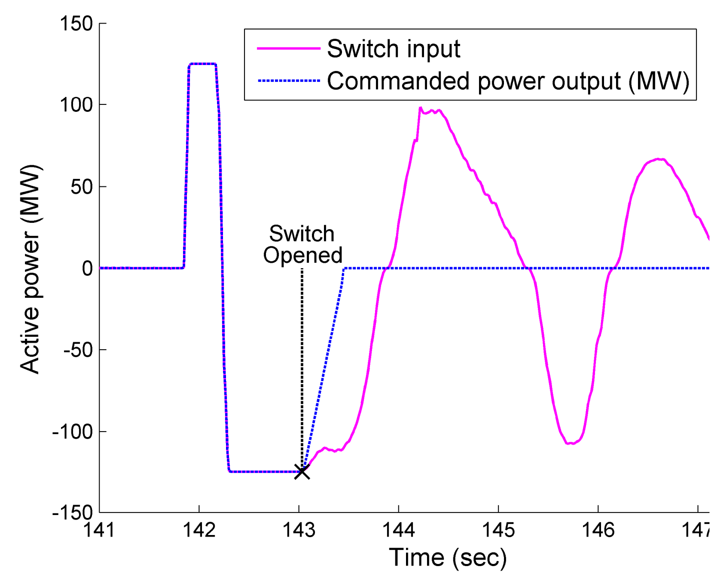


Supervisory System

- Repeated data flag
- Relative frequency flag
- Absolute frequency flag
- Angle separation flag
- Asymmetric delay flag
- Common mode delay flag
- PMU status flag
- Time quality flag
- Negative time flag
- GPS lost flag
- Data drop flag
- E-Stop Contacts flag
- And more

- Redundancy and Diversity
- 8 PMUs
- 16 prioritized real-time control instances operating in parallel
- Bumpless transfer





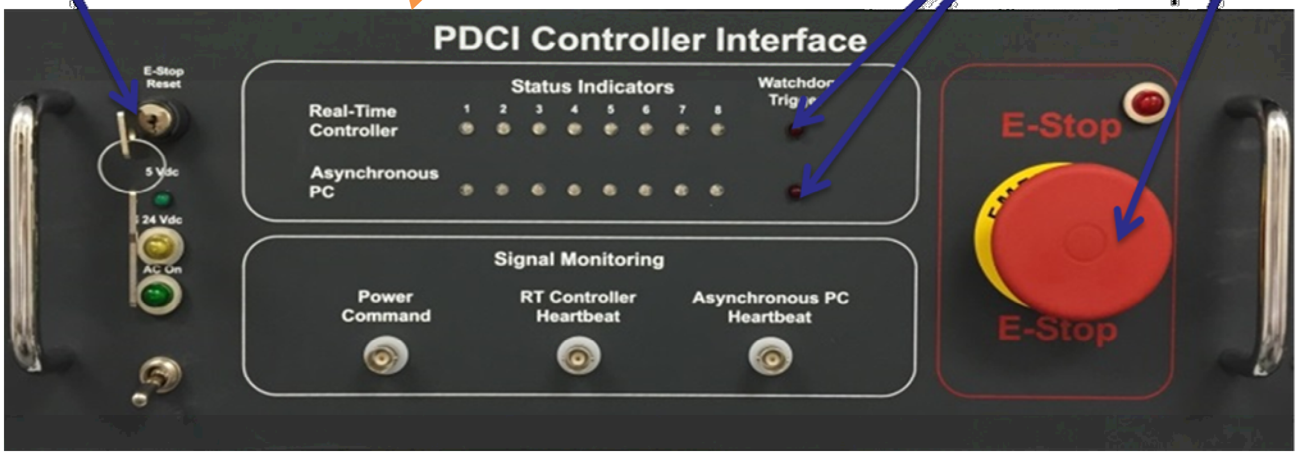
Damping Controller

Watchdog circuit module

Key switch

Heartbeat indicators

E-Stop button



Server for select supervisory functions

Real-time Control platform

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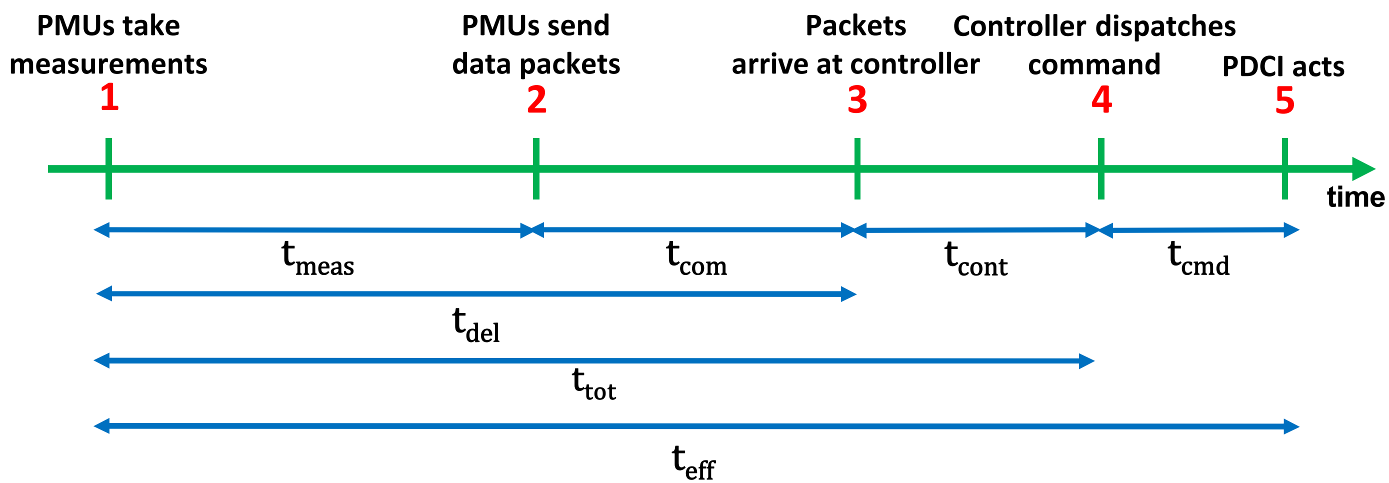
Communication and Delays

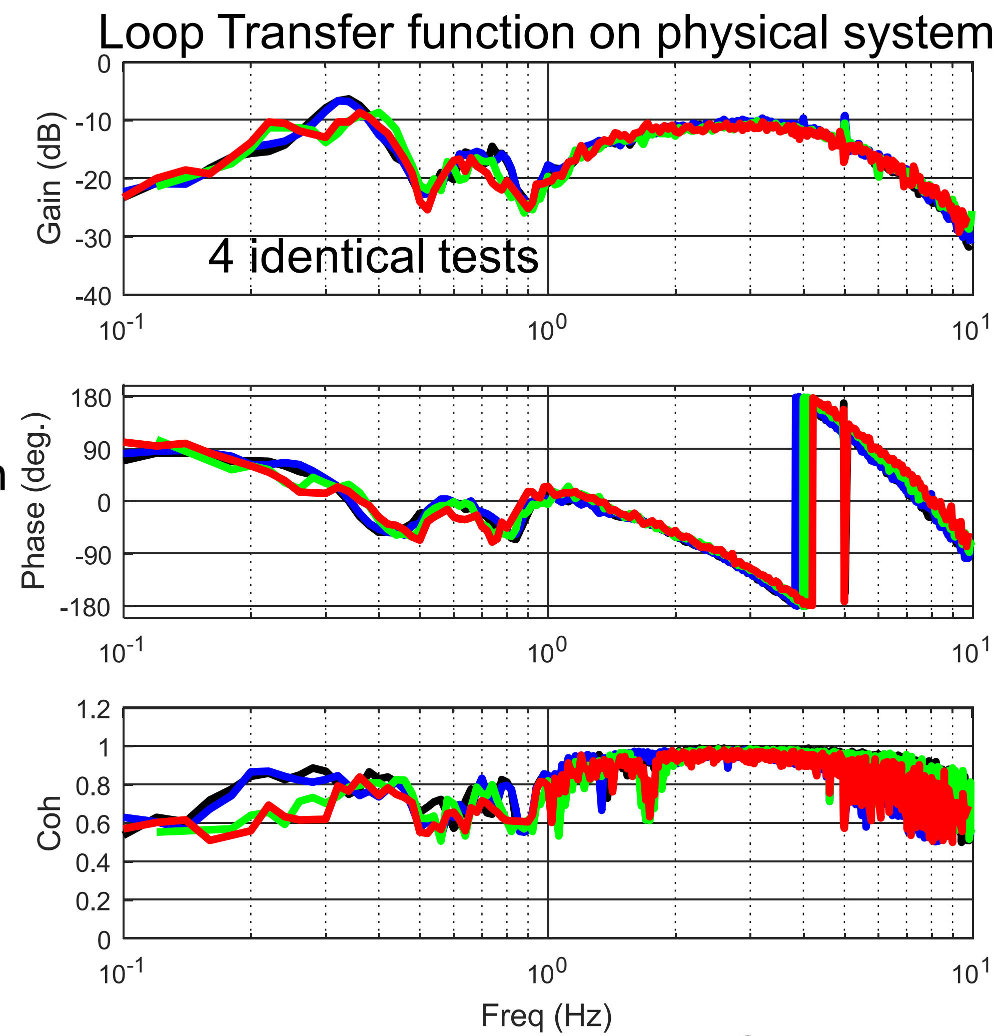


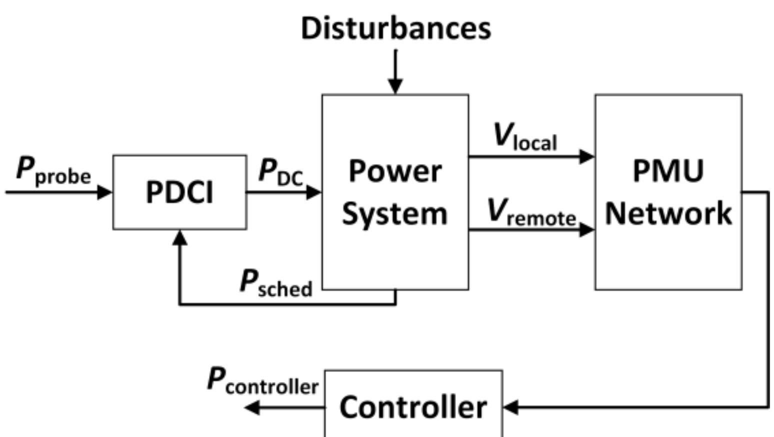
Symbol	Name	Mean	Range	Distribution
t_{meas}	PMU Delay	50 ms	Assumed fixed at 50 ms	N. A.
t_{com}	Communications Delay	10 ms	[5,38]	Heavy Tail Normal
t_{del}	Signal Delay	60 ms	[55,88]	Heavy Tail Normal
t_{cont}	Control Processing Delay	11 ms	[3,17]	Bimodal Normal with peaks at 8 & 15 ms
t_{tot}	Total Controller Delay	71 ms	[58,102]	Bimodal Normal with peaks at 66 & 73 ms
t_{cmd}	Command Delay	Estimated at 11 ms	Assumed fixed at 11 ms	N. A.
t_{eff}	Effective Delay	82 ms	[69,113]	Bimodal Normal with peaks at 77 & 84 ms

Conclusion: Average round trip time delays < 100 ms
➔ well within bounds for robust closed-loop control

Open-Loop Testing

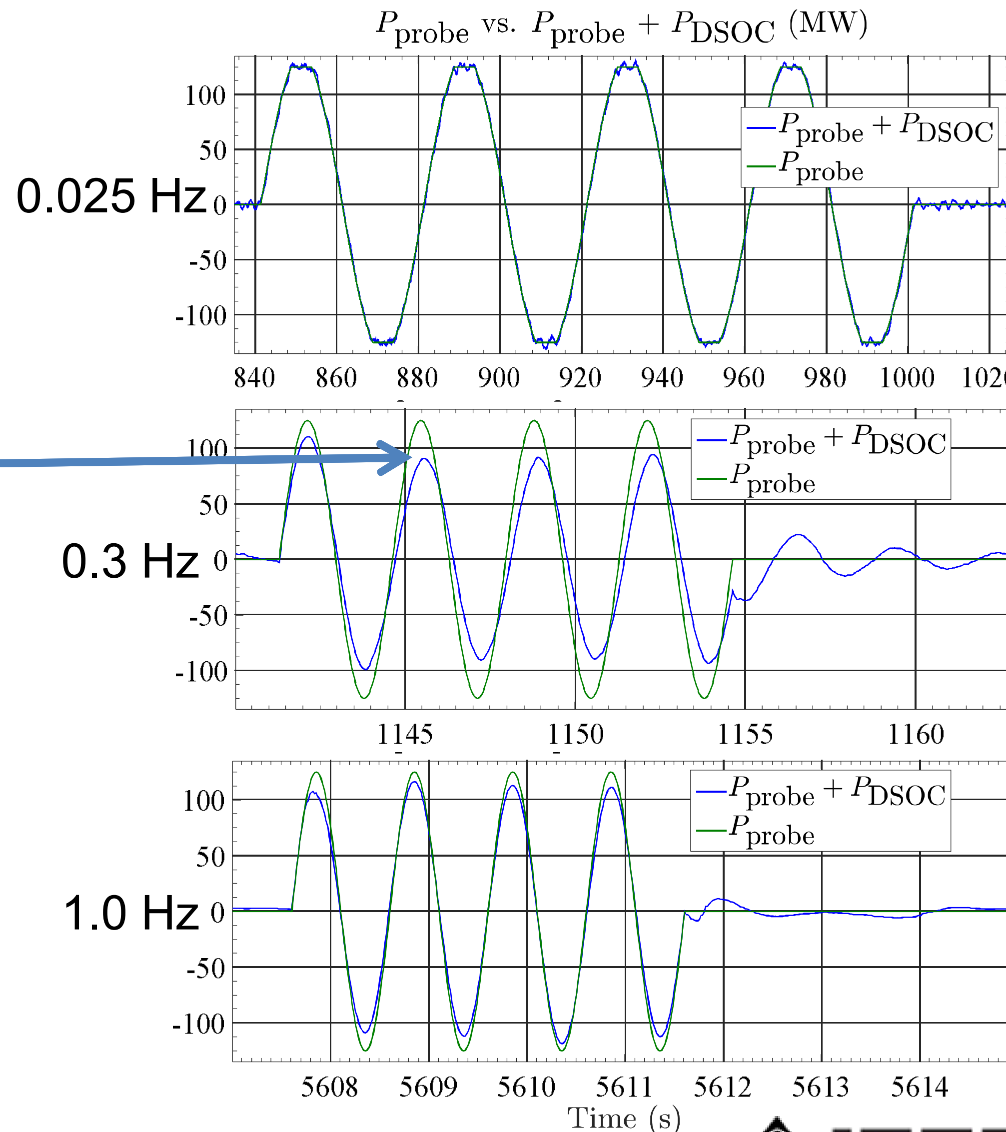
- Multi-sinusoid signal to excite system at frequencies up to 5 Hz
- Targeted maximum damping between 0.3 and 0.4 Hz
- Improvement between 0.2 and 1 Hz
- Maintain ~10 dB gain margin at ~4 Hz. DC dynamics limit the gain of the controller





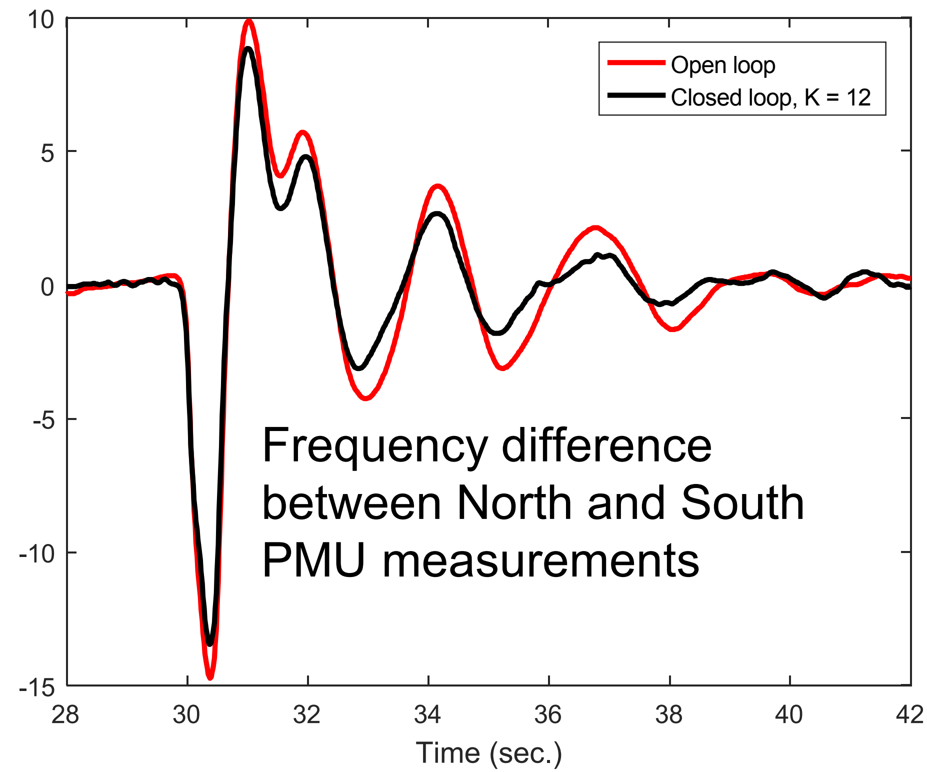
Open-Loop Testing

- Sine wave probing at 0.025 Hz, 0.3 Hz, 1.0 Hz
- The probing signal vs. the probing signal added to the command signal
- Decreased amplitude shows improved damping
- No interaction with 0.025 Hz
- Strong damping improvement at 0.3 Hz
- Slight damping improvement at 1.0 Hz



Closed-Loop Testing

- Chief Joseph Brake insertion: 1.4 GW braking resistor inserted for 0.5 seconds in Central Washington State USA
- 4-5% increase in damping from 11% to 16%
- Tests were conducted during very well-behaved system conditions
- More results to be presented at IFAC and IEEE PES General Meeting



Conclusions

- Damping controller developed using real-time PMU feedback to modulate the power on an HVDC transmission line
- Simulation results that show significant improved damping and agree with actual system tests
- Developed and tested a supervisory system to allow robust, reliable, safe performance
- Characterization of communication and delays
- Open and closed loop tests on the North American Western Interconnection