The Pacific DC Intertie Wide Area Damping Controller

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Sandia National Laboratories and Montana Tech

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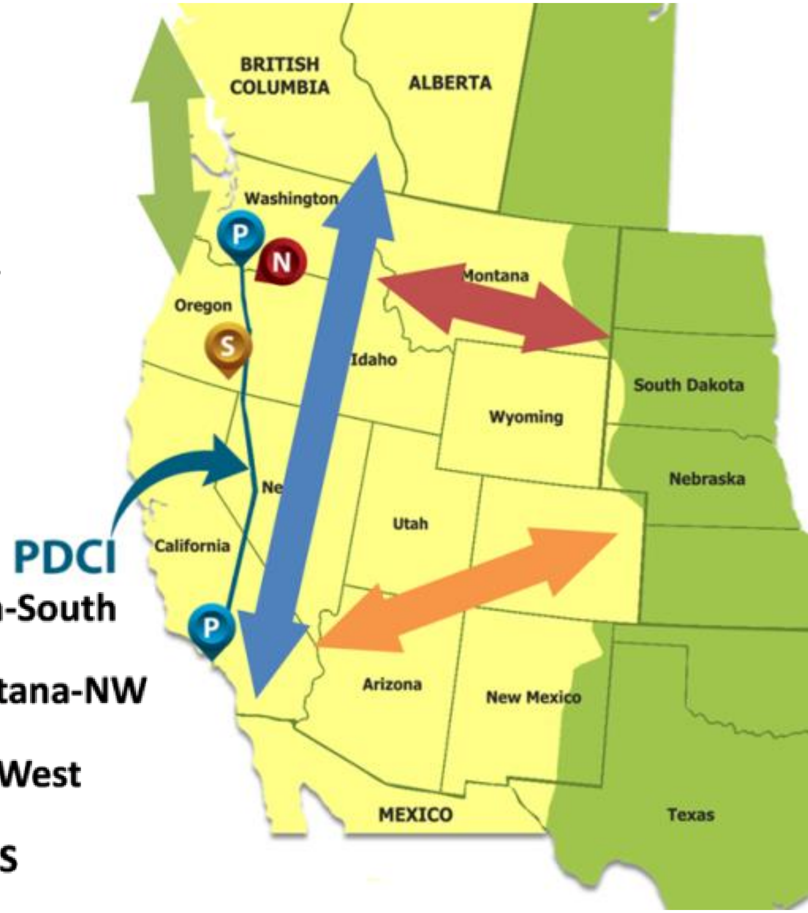
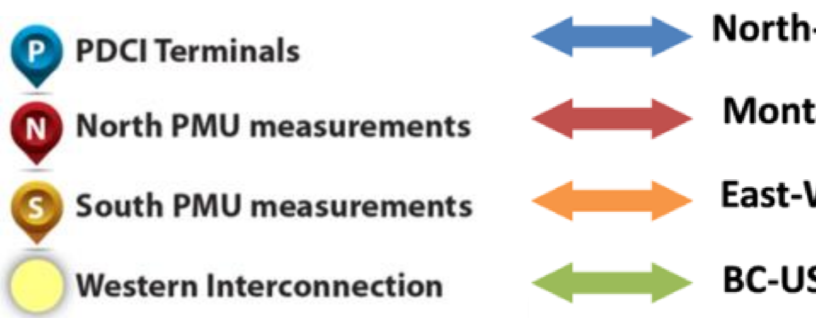
  - DOE-OE Energy Storage Program (PM: Dr. Imre Gyuk)

Modes of Oscillations in the WECC

- Generators oscillating against each other
- Occurs naturally in the system
- Low damped modes can cause system breakup and wide area blackouts

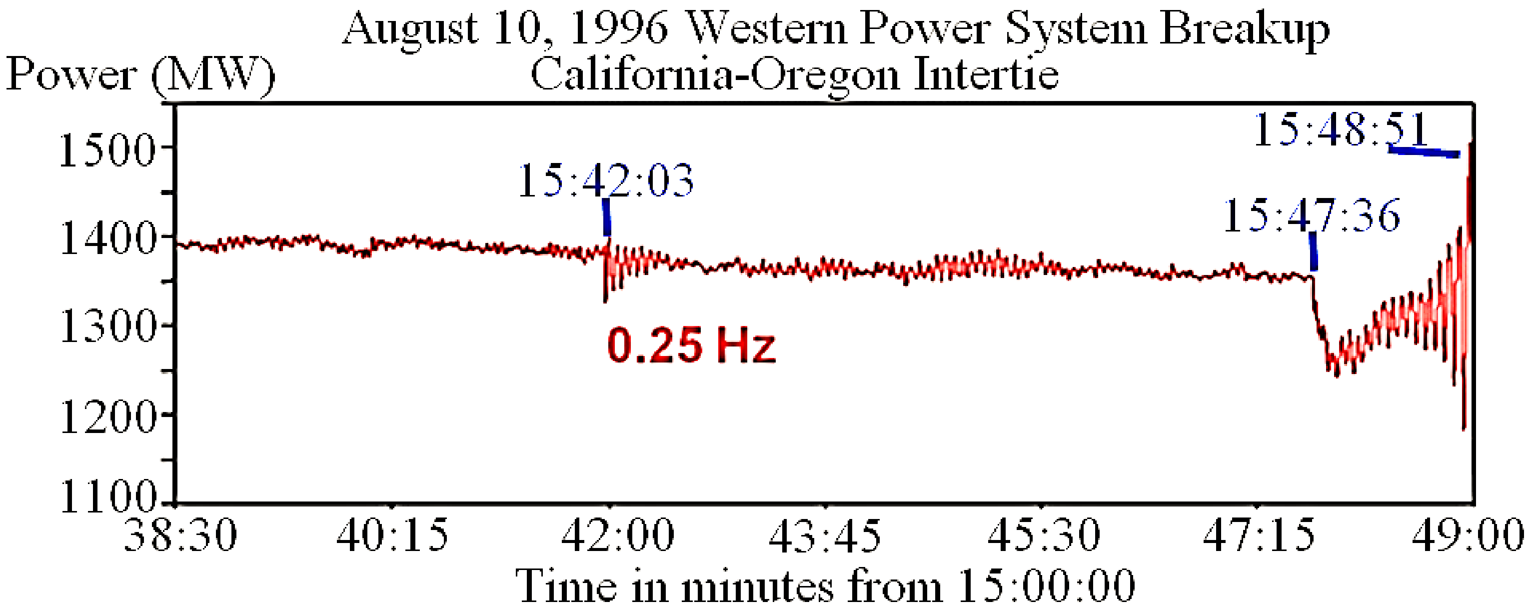
- "NSA Mode" nominally near 0.2 to 0.25 Hz;
- "**NSB Mode**" nominally near 0.35 to 0.4 Hz;
- "EWA Mode" nominally near 0.4 to 0.5 Hz;
- "BC" mode nominally near 0.6 Hz; and,
- "Montana" mode nominally near 0.8 Hz.





Anticipated Benefits from Damping Control

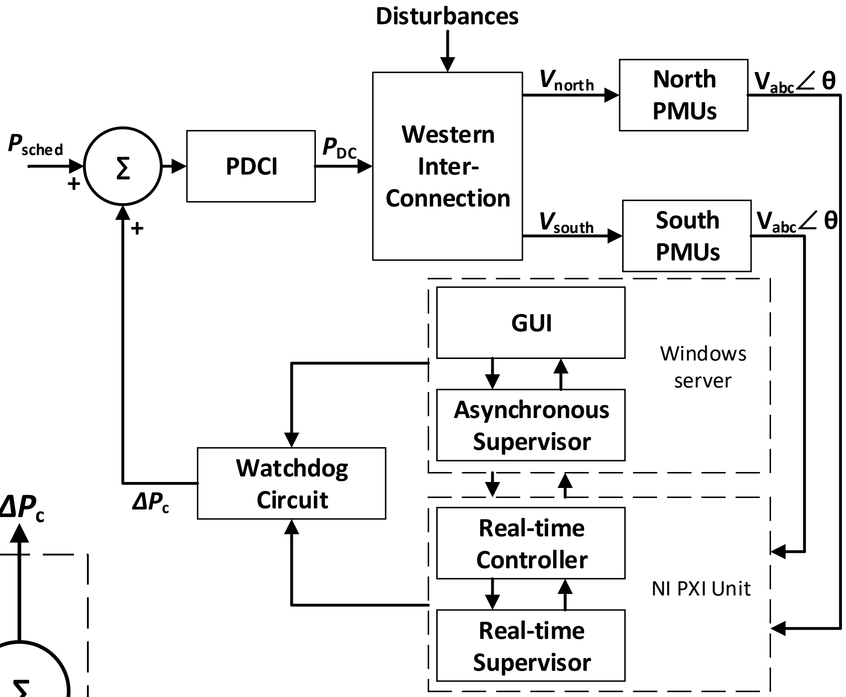
- Improved system reliability
- Additional contingency in a stressed system condition
- Increasing the power transfer of the California-Oregon Intertie (COI). Reduced need for new transmission lines (capital cost savings > $1M/mile)
- Avoidance of costs from oscillation-induced system breakups (1996 outage costs > $1B)

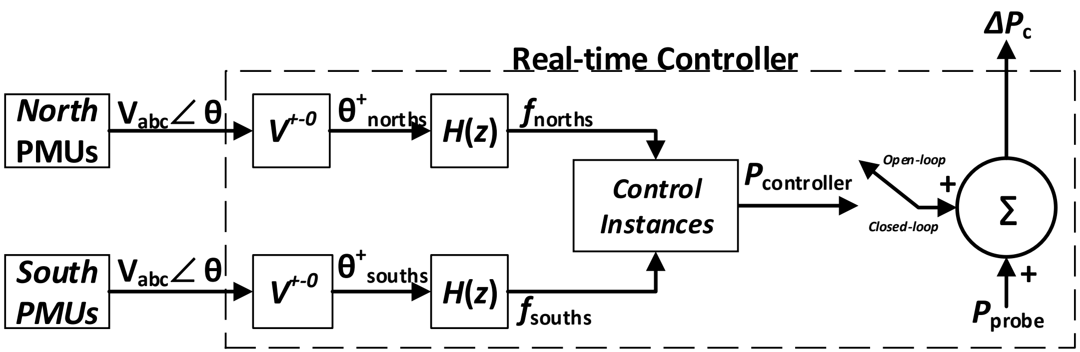


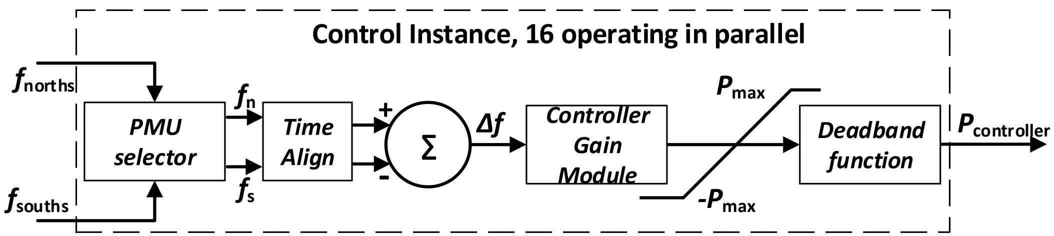
Control Strategy based on PDCI Modulation

Control Objectives:

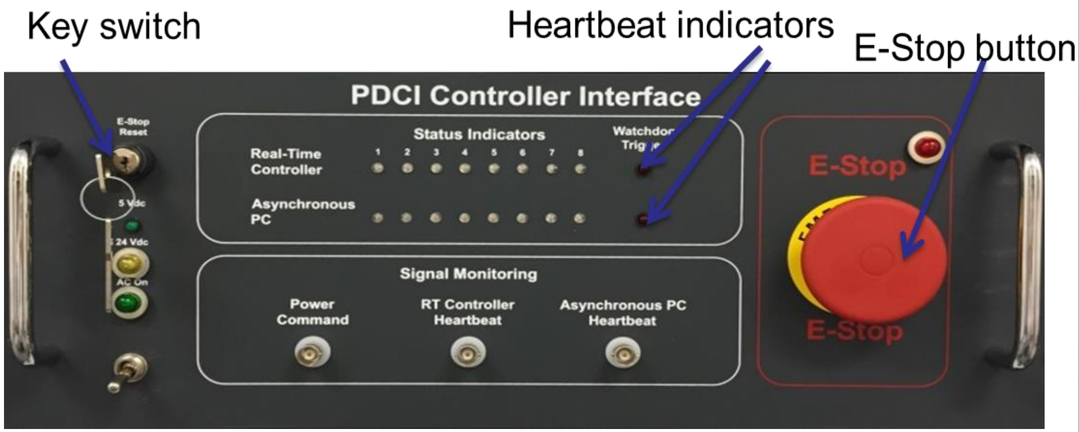
- Dampen all modes of interest for all operating conditions w/o destabilizing peripheral modes
- Do NOT worsen transient stability (first swing) of the system
- Do NOT interact with frequency regulation







Damping Controller Hardware



Three primary components

1. NI PXI real-time unit
2. Windows server
3. Watchdog circuit

Supervisor Control Design Philosophy

Design was driven by the need to detect and respond to certain system conditions in real-time as well as asynchronous monitoring functions at slower than real time

Supervisor

Asynchronous Control Loop

- Automated probing
- Transfer function estimation
- Gain and phase margin estimation
- PDCI monitoring

Real-time Control Loop

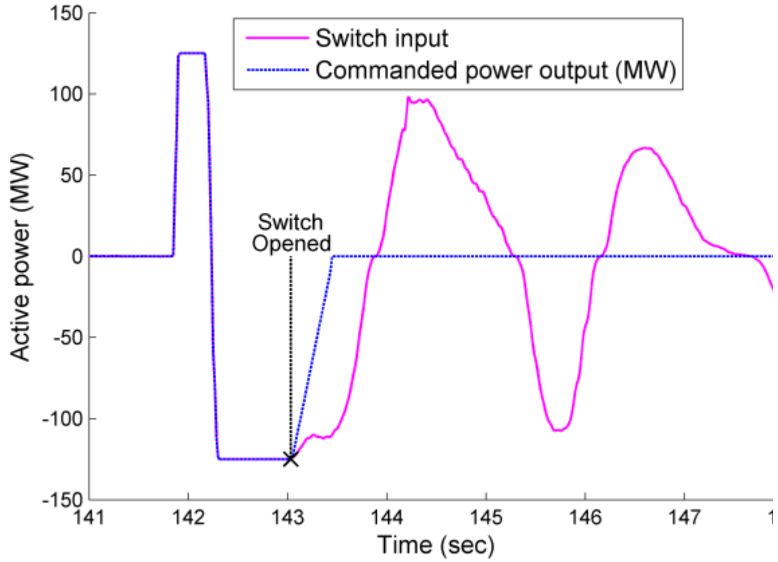
- State machine arch.
- Bumpless transfer (SW)
- Oscillation detection
- Separation detection
- Frequency tol. detection

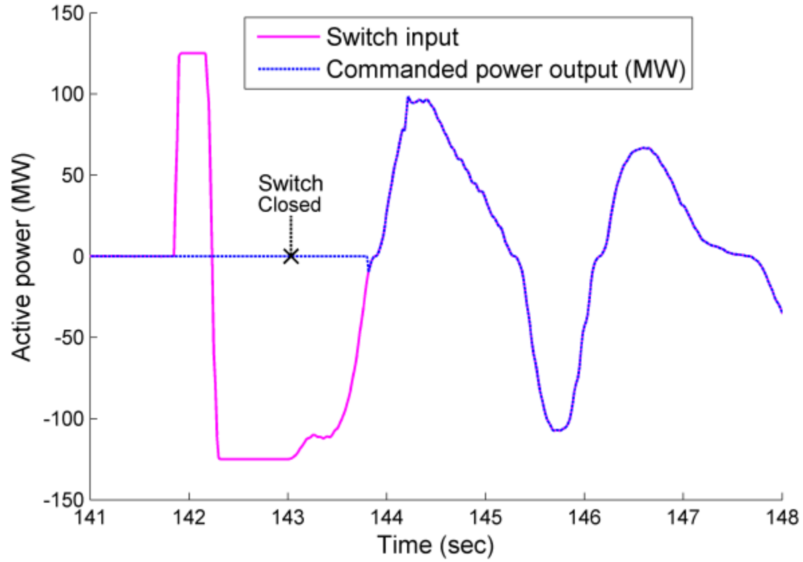
Watchdog Circuit

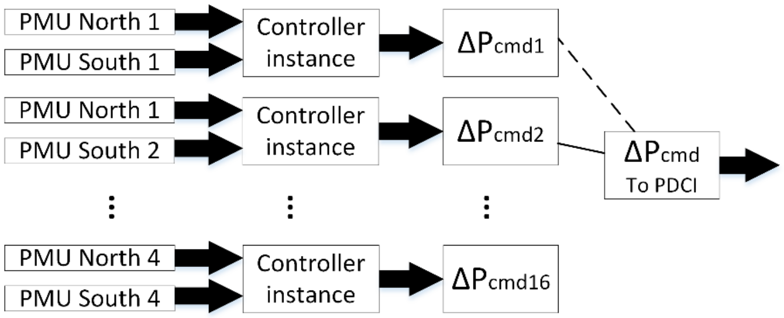
- Watchdog circuit for async. and RT loops
- Emergency stop button
- Bumpless transfer (HW)
- Reinitialization procedure

Bumpless Transfer

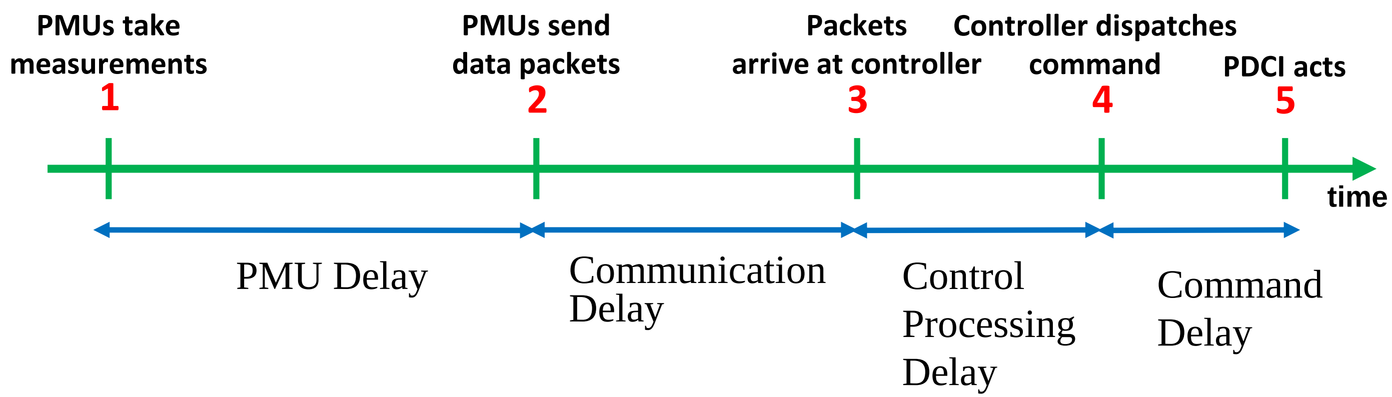
Seamlessly switch between system states as to not inject step functions into the system







Communication and Delays

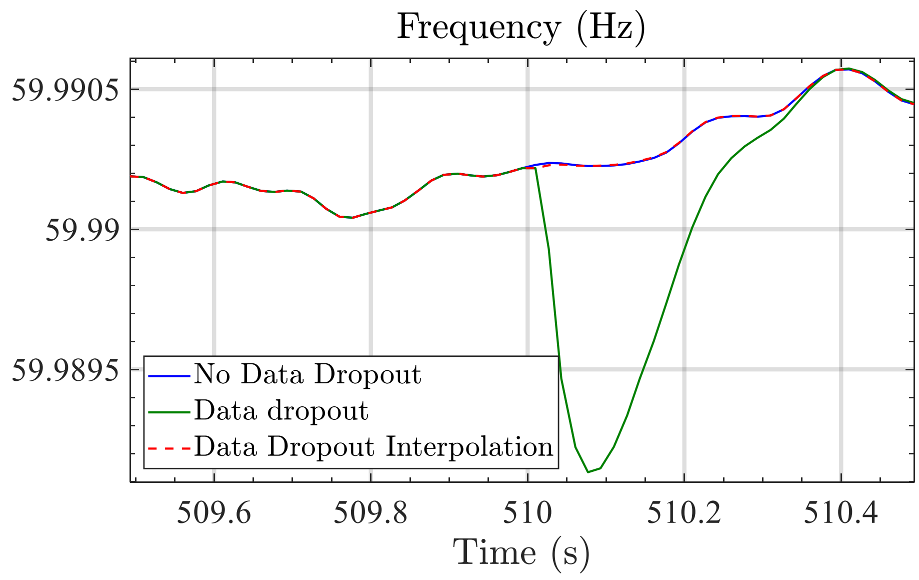


Name	Mean	Range	Note
PMU Delay	44	40 – 48	Dependent on PMU settings. Normal distribution.
Communication Delay	16	15 – 40	Heavy tail
Control Processing Delay	11	2 – 17	Normal around 9 ms, but a peak at 16 ms due to control windows when no data arrives (inconsistent data arrival)
Command Delay	11	11	Tests were consistent, fixed 11 ms
Effective Delay	**82**	**69 – 113**	**Total delay**

Delays well within our tolerance

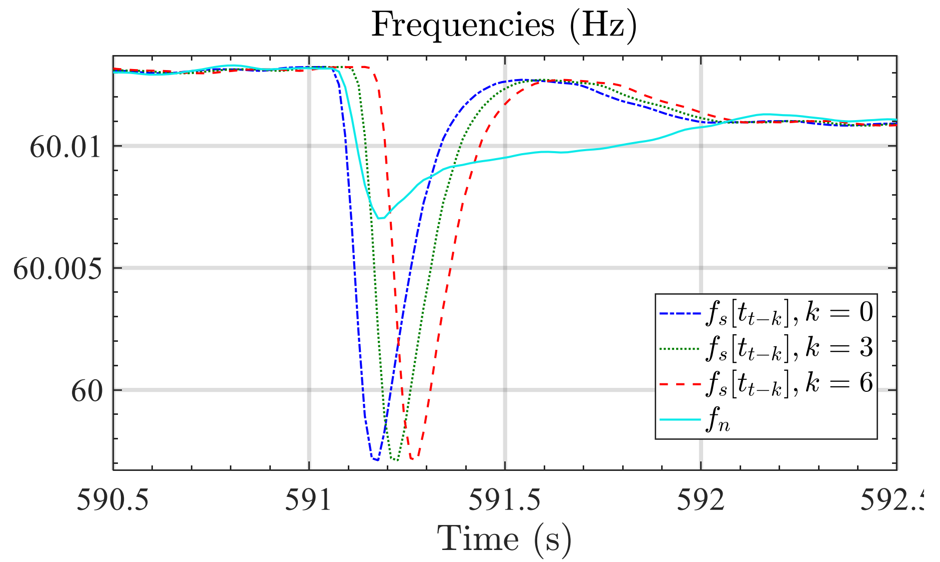
Data considerations – Data dropout

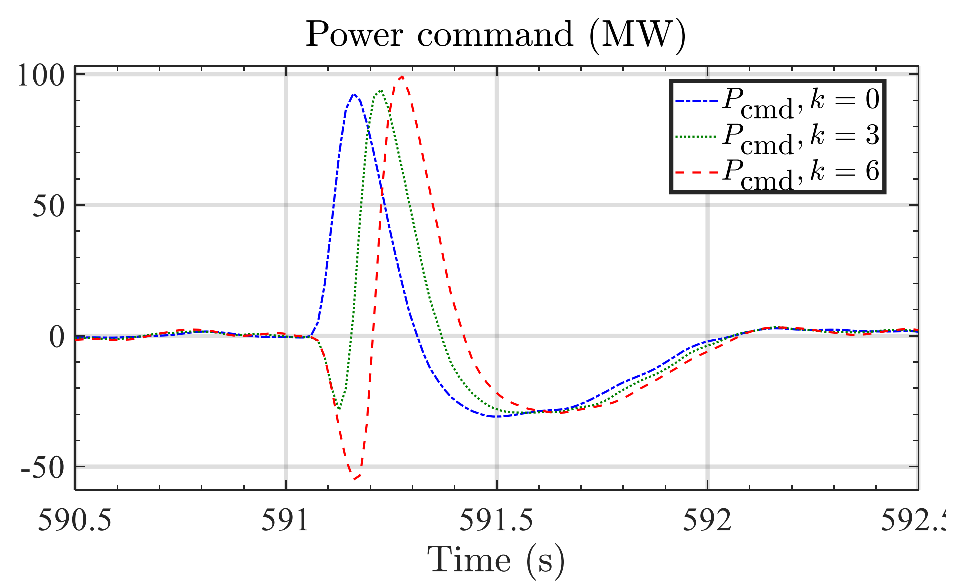
- PMUs on the BPA network rarely have data dropouts, but the controller must account for these.
- Supervisory system catches data dropouts and disables that controller instance (16 total)



Data considerations – Time alignment

- The North and South measurements need to be from the same PMU timestamp.
- Supervisory system time aligns the data. If data is too far apart, the control instance is disabled



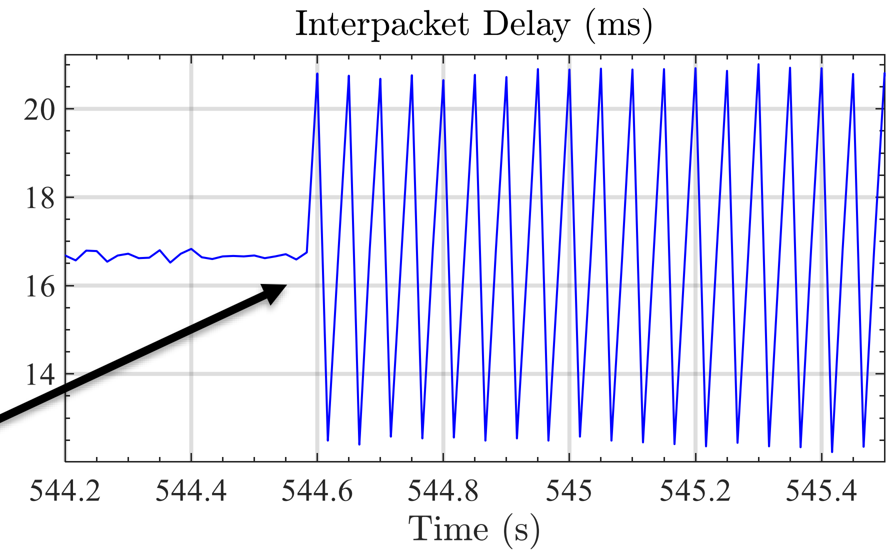


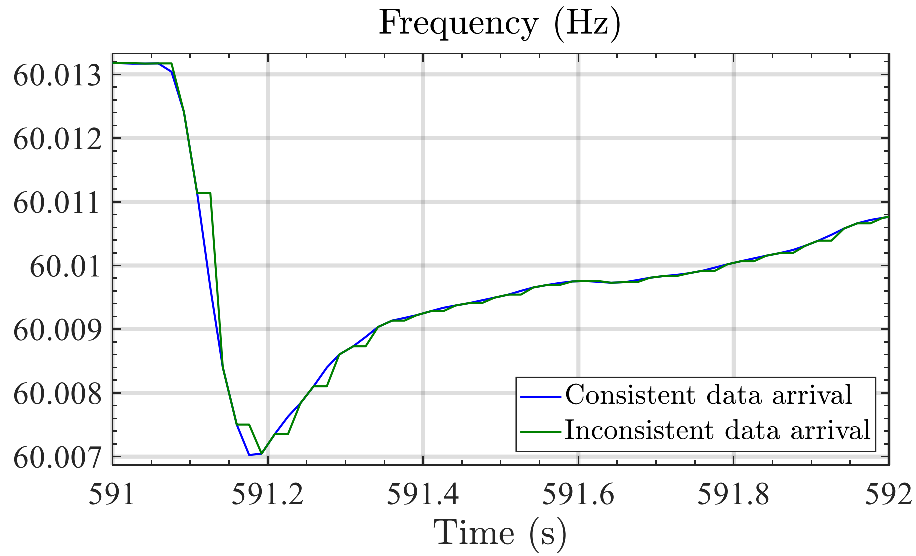
Data considerations – Inconsistent data arrival

- PMUs have consistent average reporting rates, set to 60 Hz for BPA's system

- However, the actual data leaving the PMU is not always every 16.6667 ms.

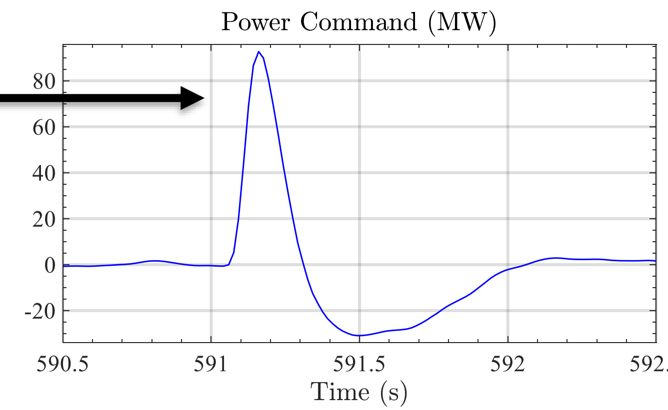
- Inconsistent data must be handled properly.



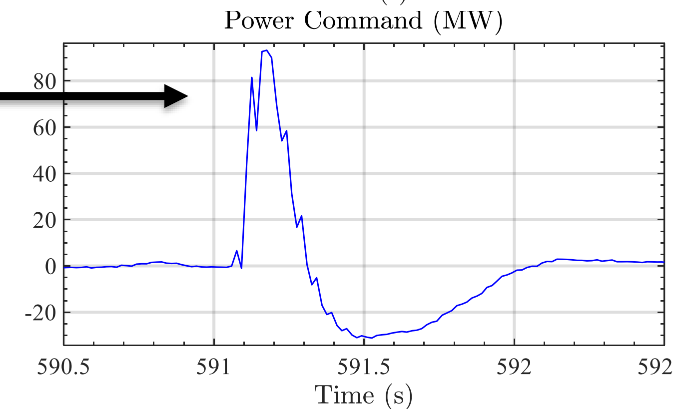


Data considerations – Inconsistent data arrival with time-alignment

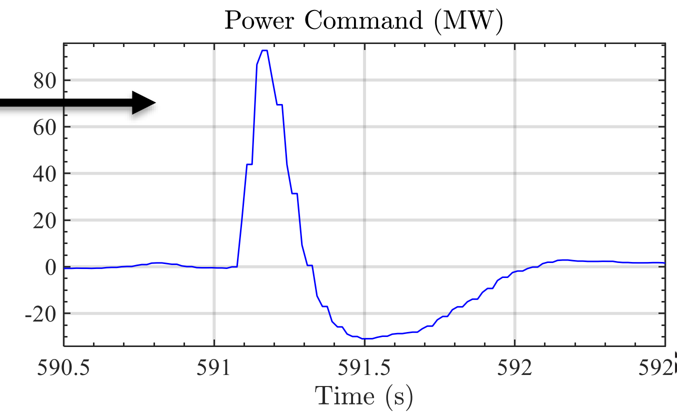
- Ideal case



- Worst case, inconsistent data arrival without time-alignment.



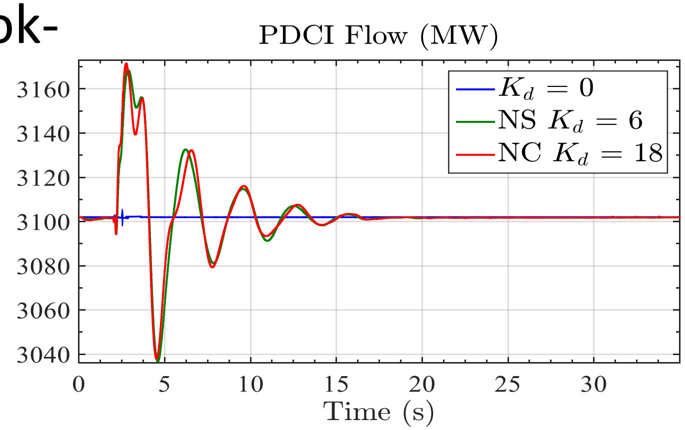
- Inconsistent data arrival with time-alignment.

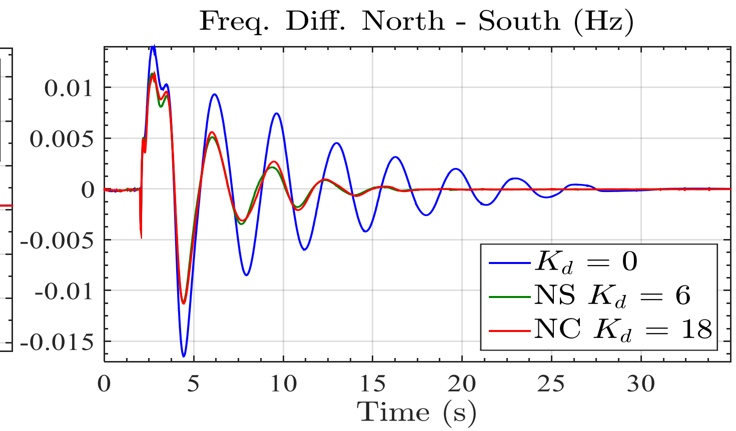


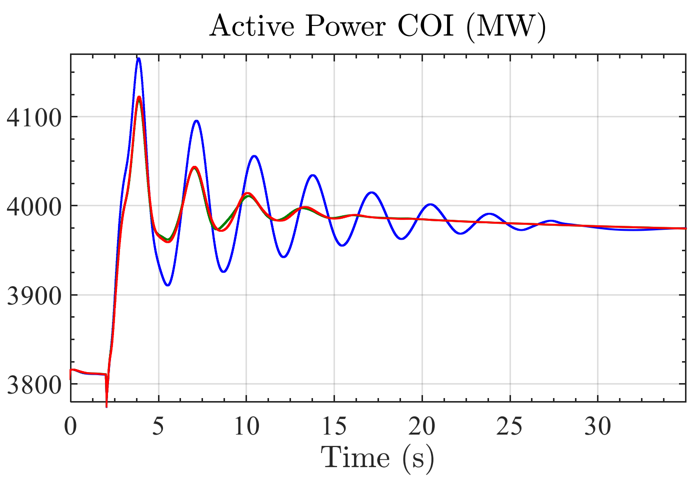
PMU-based Feedback Control has the Potential to Significantly Improve Oscillation Damping

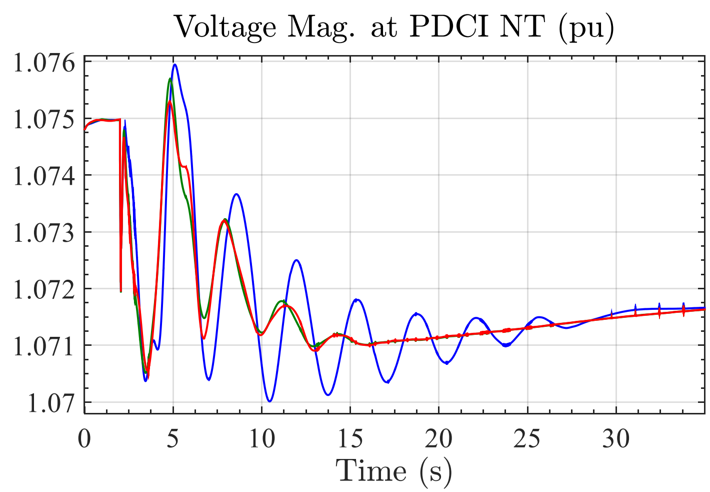
Simulation of BC-Alberta separation (Cranbrook-Langdon intertie)

- With damping control, the oscillations decay very quickly.



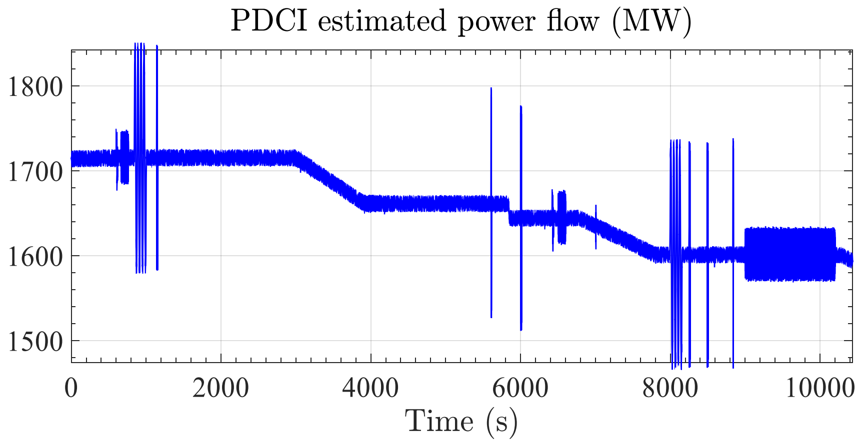


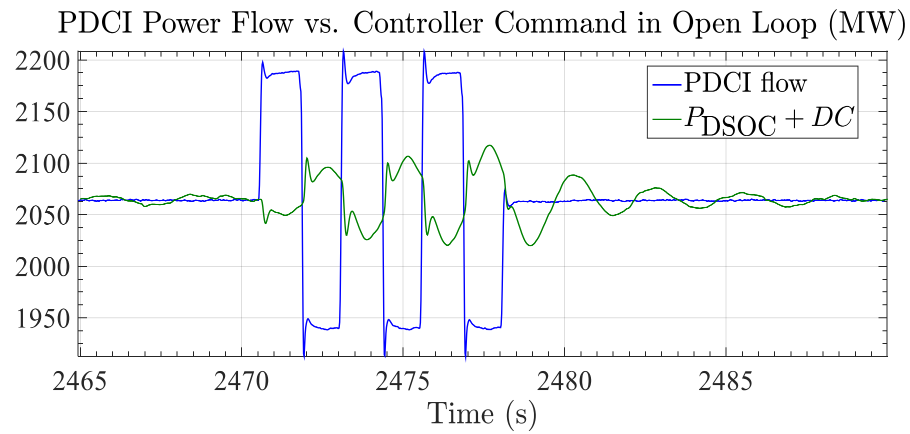




First North America Tests using PMU Feedback Control: Open-Loop

- Open-loop probing tests: Controller injects a power command to disturb the system.
- Test if the controller responds to the disturbance correctly

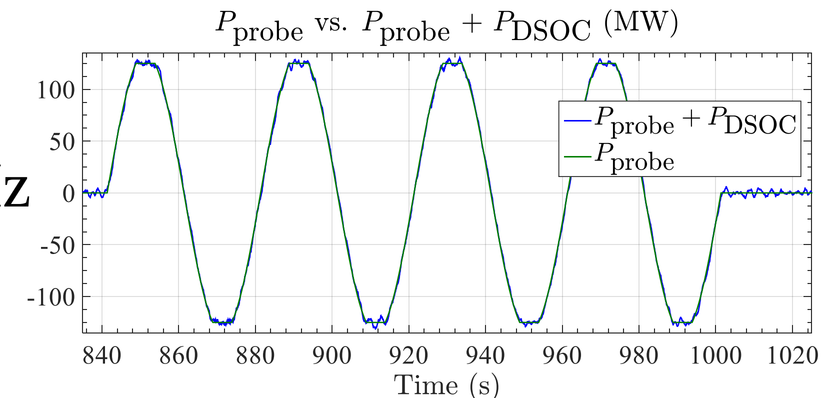




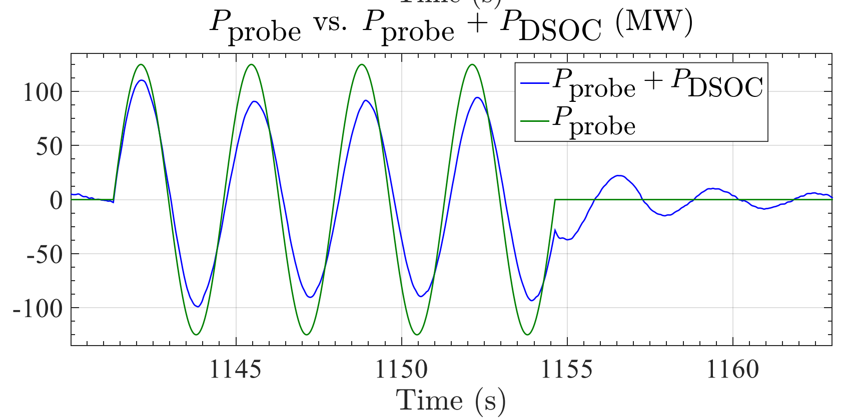
Open-Loop Forced Oscillation Tests

- The controller injects a forced oscillation, and measure the controllers output.
- Traces on top of each other mean no interaction.
- As expected controller interacts and improves forced oscillations in the inter-area frequency range

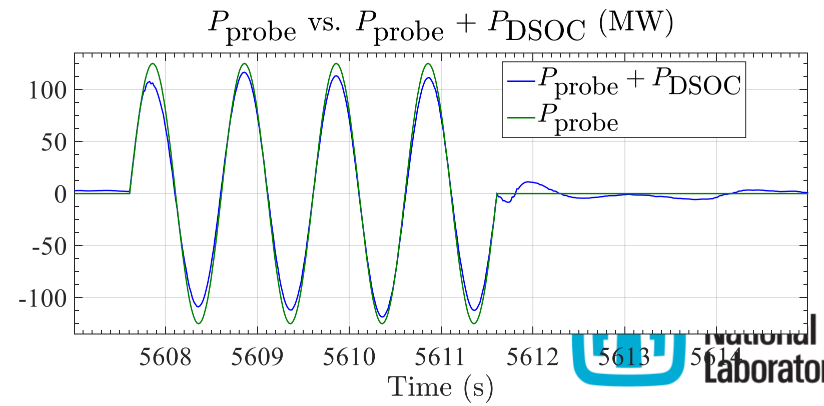
0.025 Hz



0.3 Hz

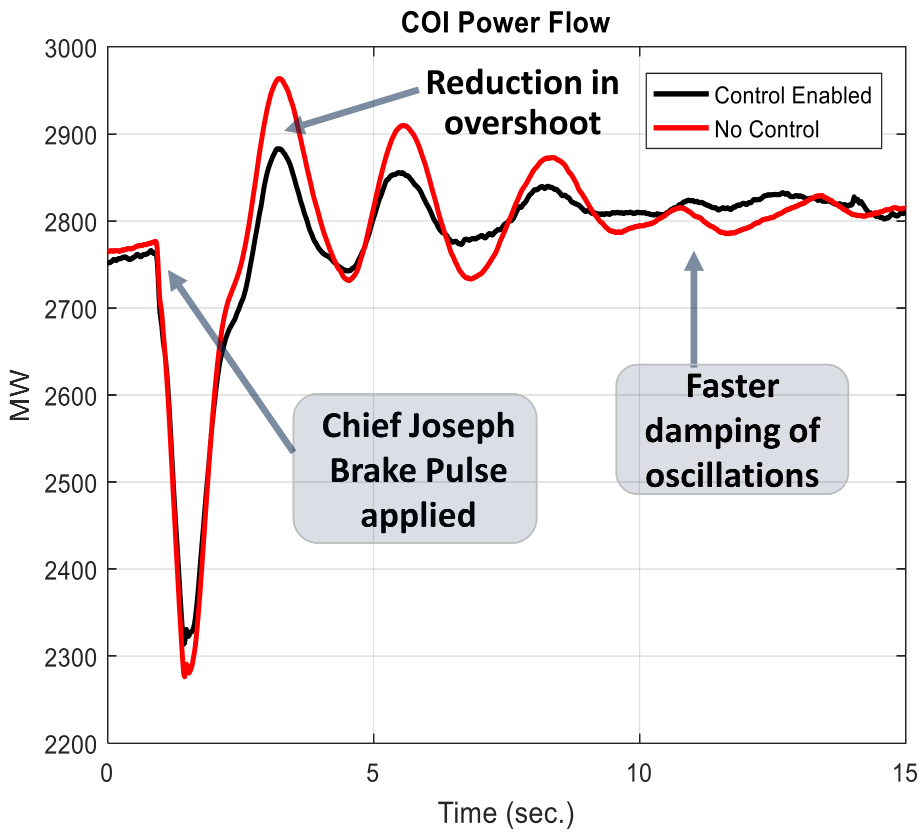


1.0 Hz

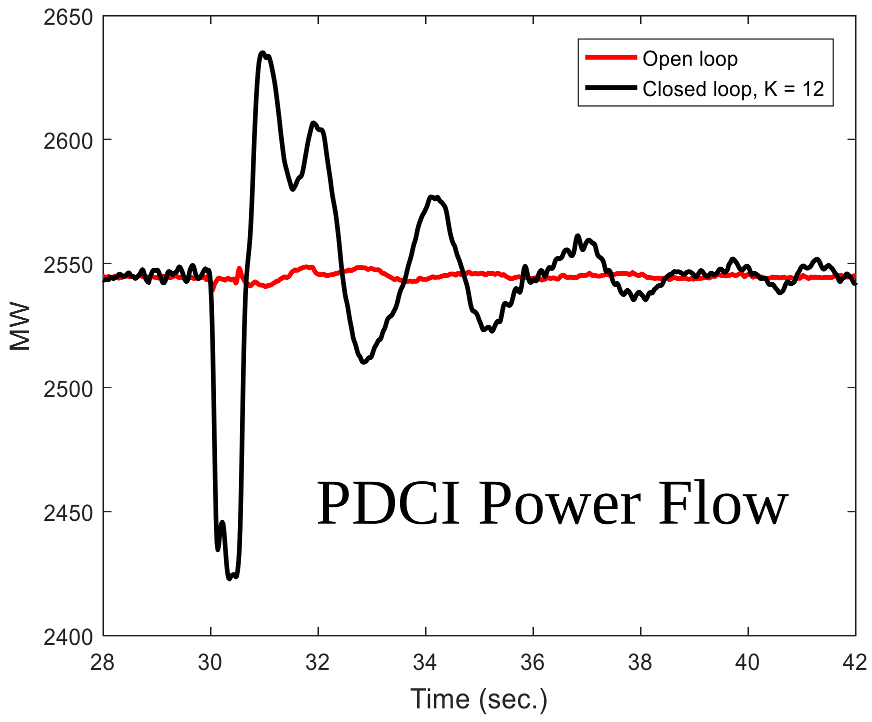


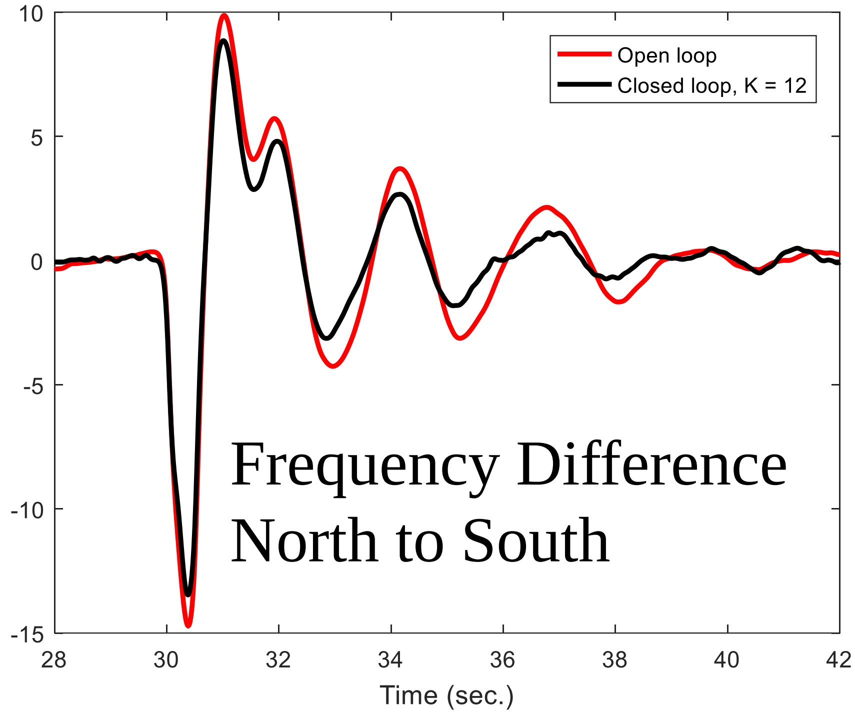
First North America Tests using PMU Feedback Control: Closed-Loop

- Closed-Loop Chief Joe Brake Test
- Adding a 1400 MW load in central Washington State.
- Test if the controller improves damping and does no harm to the system
- Improved damping of 4-5%

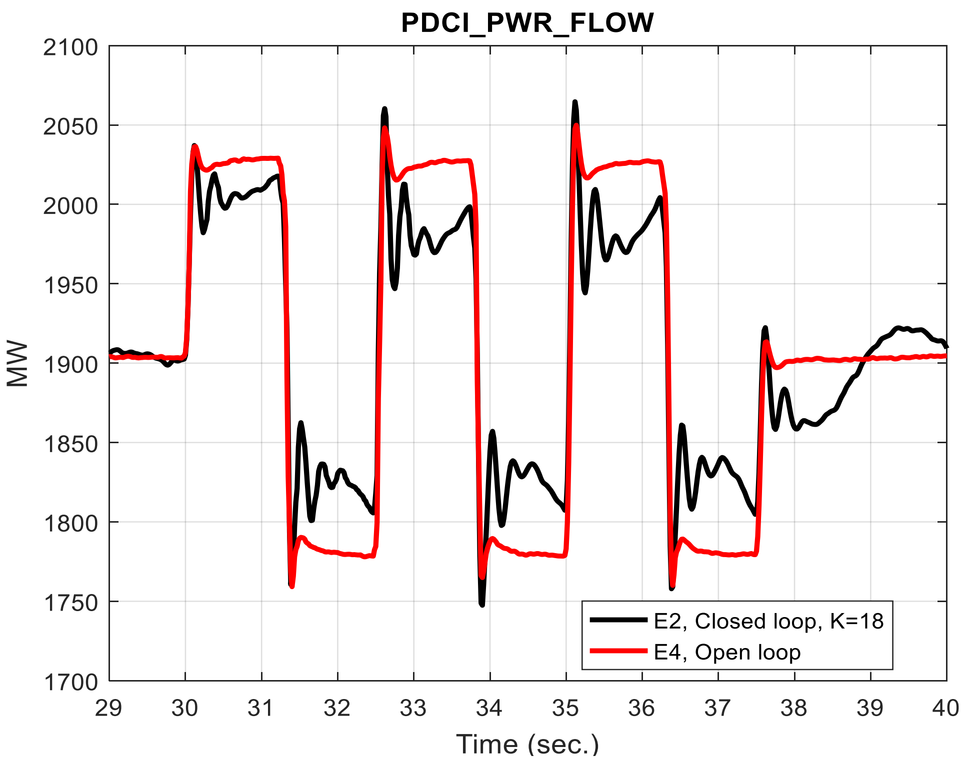


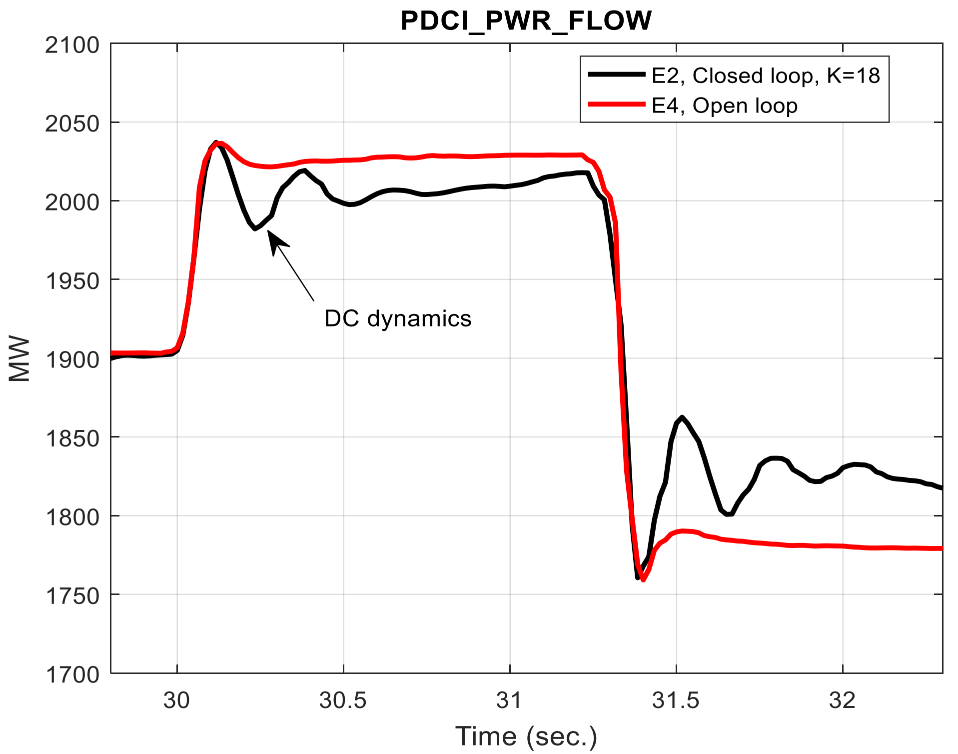
First North America Tests using PMU Feedback Control: Closed-Loop





May 16, 2017 Tests, Square Wave Response, Gain = 18 MW/mHz





Test results indicate gains in 9 - 12 MW/mHz range are a good tradeoff in damping performance vs. excitation of DC dynamics

Conclusions

- Theory → working prototype < 2 years
- Two phases of tests conducted on PDCI (Sept 2016 and May 2017) have shown significant improvement in N-S B mode damping
- Test results have shown no degradations in damping of peripheral modes
- Test results have consistently confirmed the findings of simulation studies
- Supervisory system has performed exactly as expected
- Results in all facets have been very encouraging