# Inter-Area Oscillation Damping by PDCI Modulation from PMU Feedback

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U.S. DEPARTMENT OF ENERGY

# Project Team

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- **DOE-OE Energy Storage Program – PM: Imre Gyuk**
- **BPA Technology Innovation Office – Project # 289**

# Project Overview

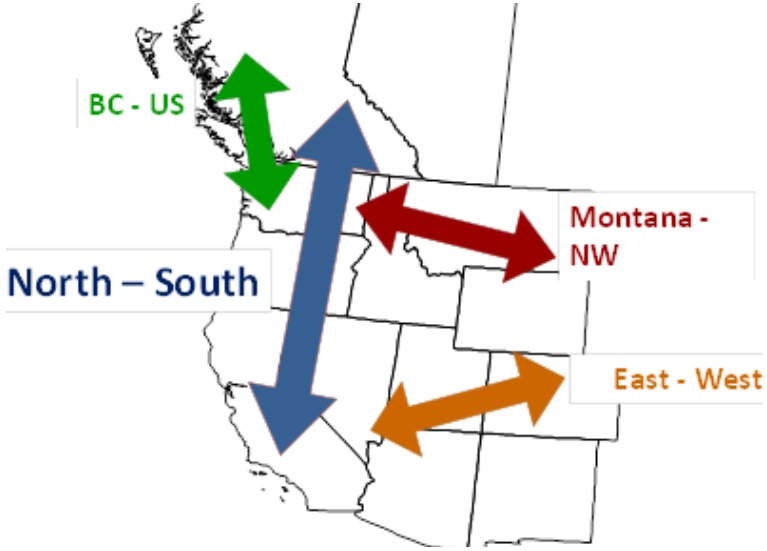
- Objectives:

1. Design and construct a prototype control system that uses real-time PMU feedback and HVDC modulation to damp inter-area oscillations.
2. Demonstrate the performance, reliability, and safety of this prototype control system by conducting closed-loop tests on the PDCI.

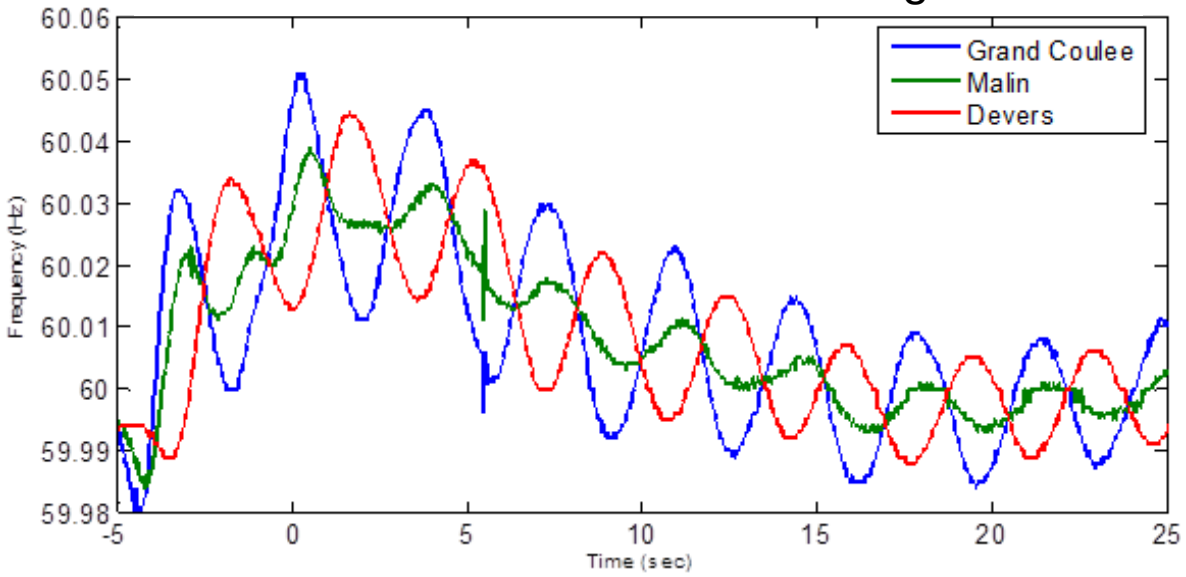
- Status:

1. A prototype control system has been developed, which modulates active power through the Pacific DC Intertie (PDCI) and uses frequency information from BPA-based PMUs for real-time feedback control.
2. The development of the prototype control system is on schedule and is rapidly progressing towards closed-loop demonstration in summer 2016.

# Modes of Inter-Area Oscillations in the West



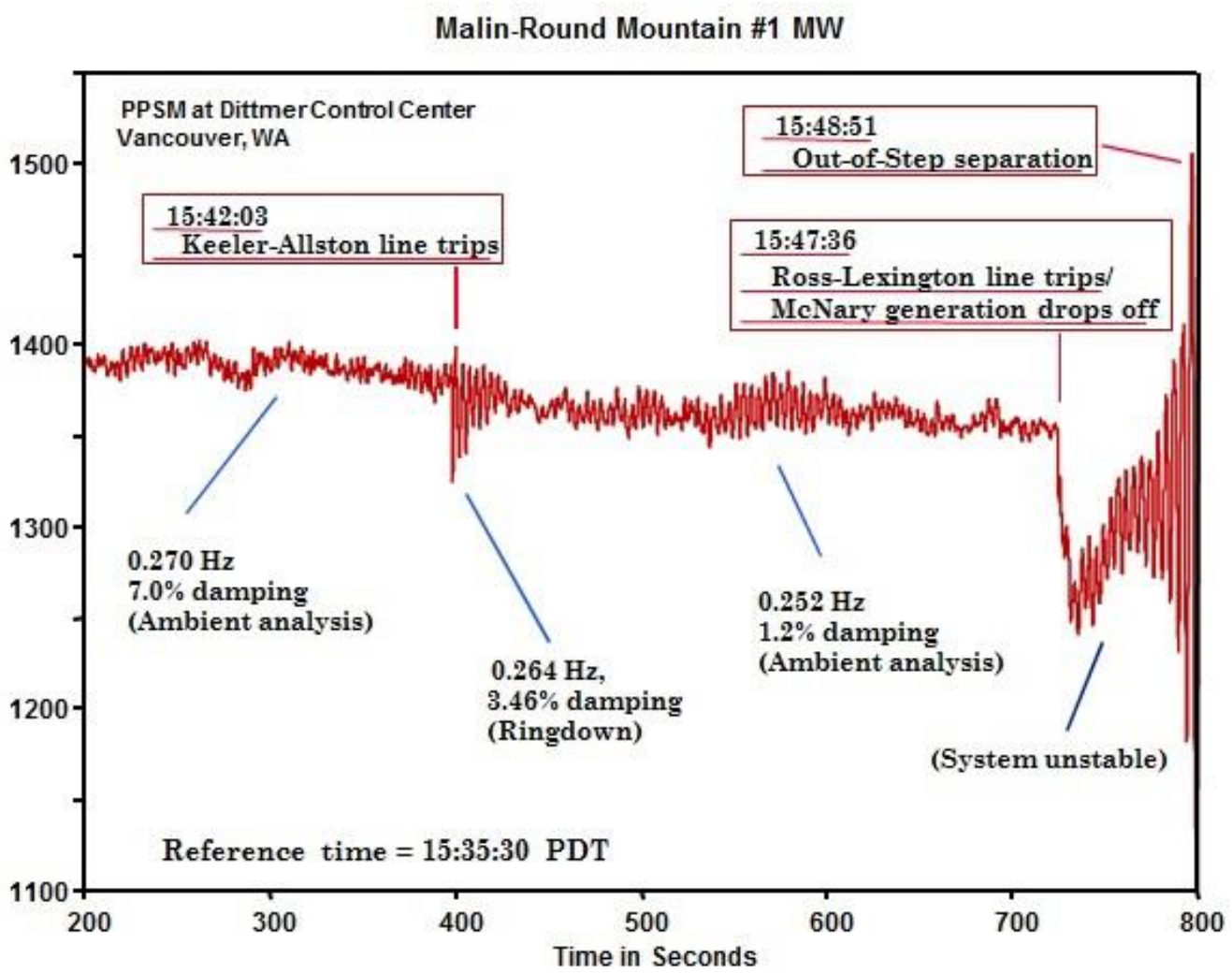

North-South Oscillation Event in August 2000



# Inter-Area Oscillations Jeopardize Grid Stability

- Large generation and load centers separated by long transmission lines can develop inter-area oscillations
- Present approach to mitigate this scenario is to maintain large headroom in power flow
- More efficient mitigation strategy is active power injectior using PDCI modulation

August 10, 1996 Western Power System Breakup

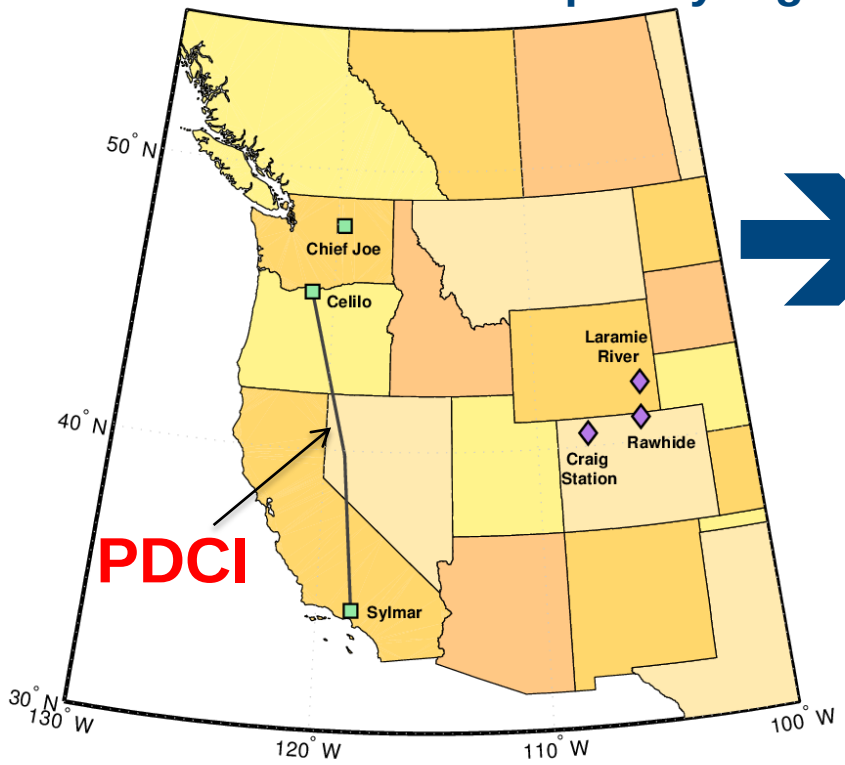


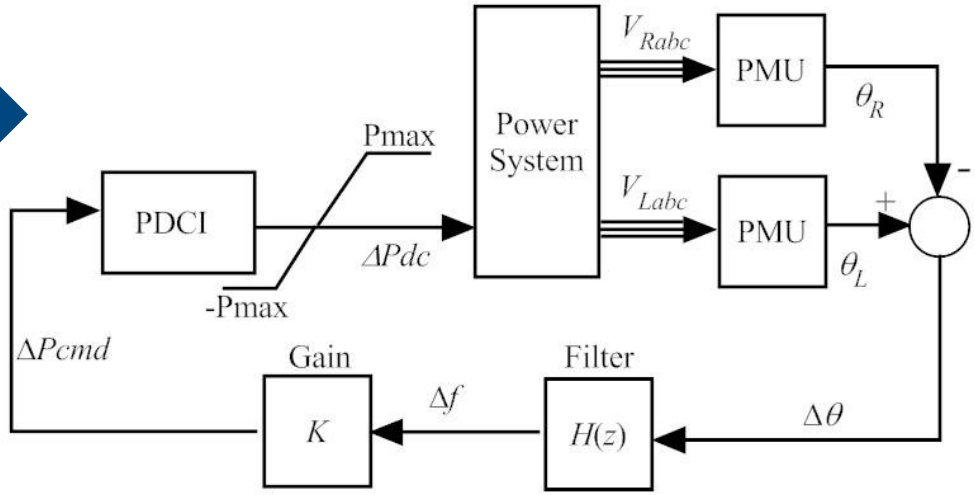
# Design Objectives for PDCI-based Controller

**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

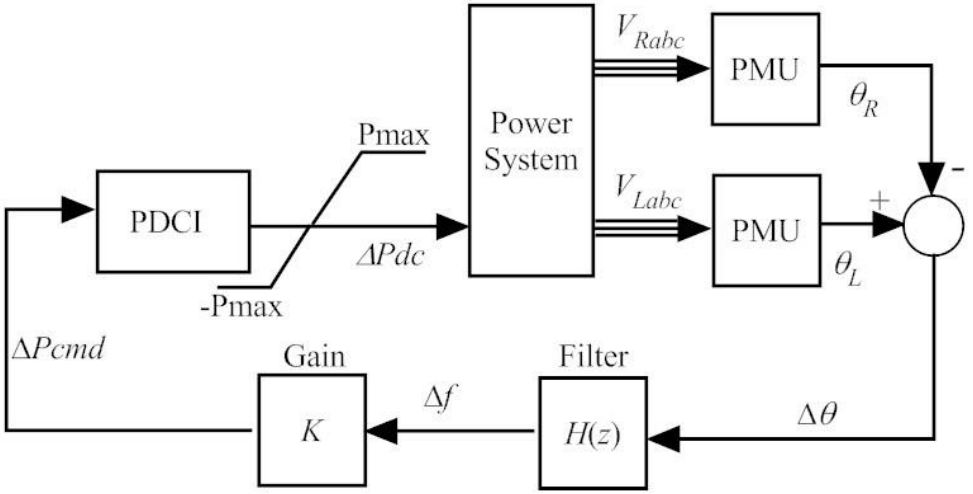
**Feedback control signal should be proportional to the frequency difference between the two areas (Local minus Remote)**



# Final Controller Design

- Based on
  - Extensive control theory analysis
  - Many simulation cases
  - Many years of actual-system probing tests
- Local Location = Lower Columbia basin.
- Remote Location = COI.
- $\boldsymbol{H(z)}$ = "Customized" Bessel derivative filter.
- $\boldsymbol{K}$ = 5 to 15 MW/mHz
- Pmax ≈ 25 MW

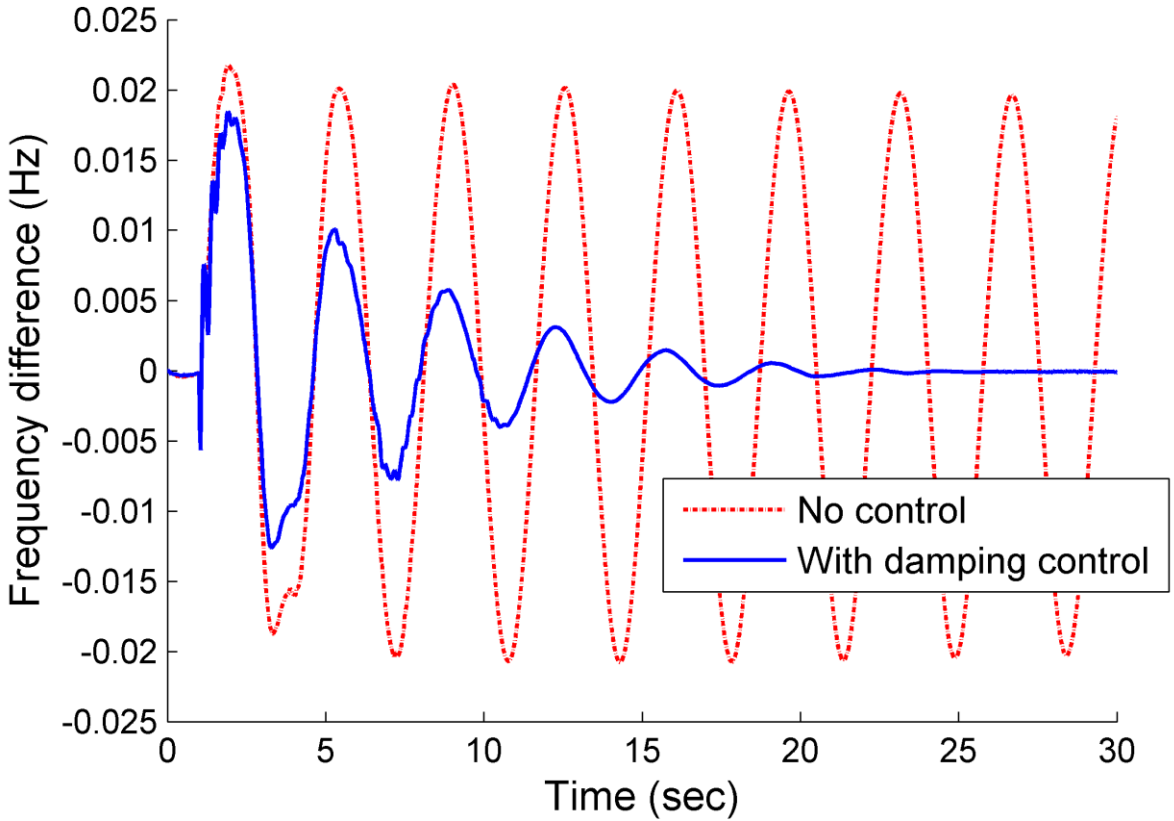



References:

1. D. Trudnowski, D. Kosterev, J. Undrill, "PDCI Damping Control Analysis for the Western North American Power System," Proceedings of the *IEEE PES General Meeting*, July 2013.
2. D. Trudnowski, "2014 Probing Test Analysis," Report for BPA project TIP-289, Jan. 2014.

# Expected Benefits

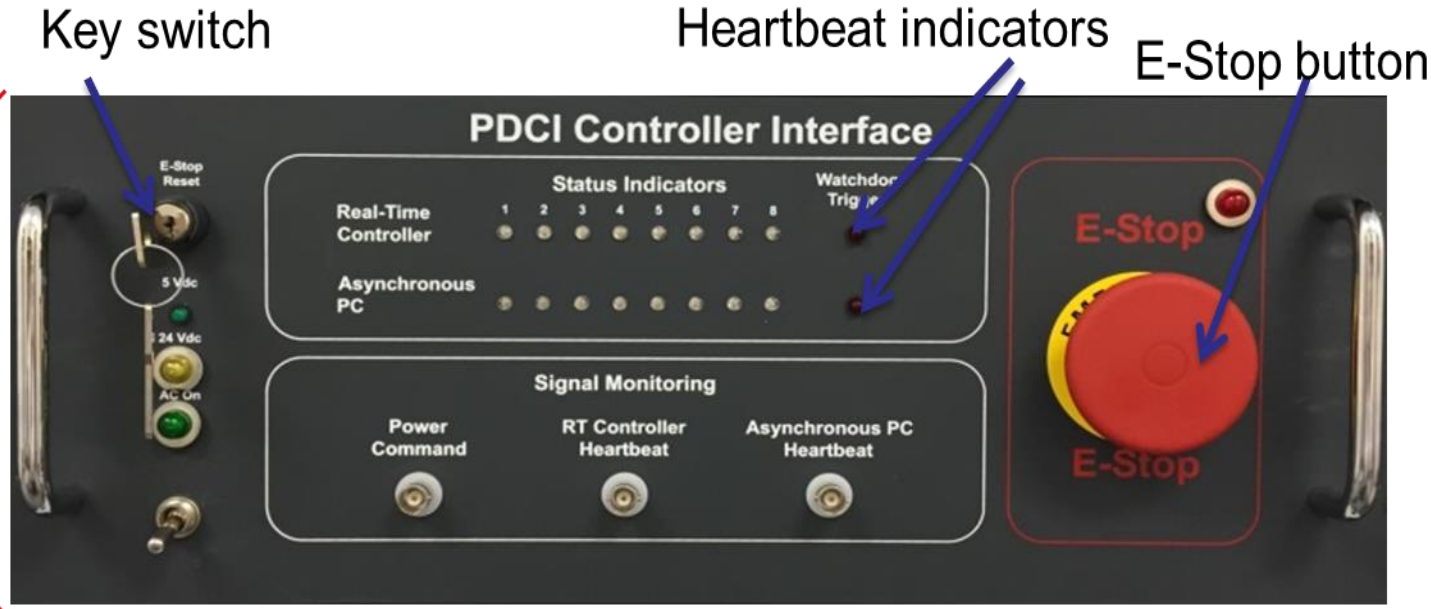
- Improved system reliability
- Increased flexibility
- Economic benefits:
  - Avoidance of costs from an oscillation-induced system breakup (1996 outage costs>$2B)
  - Reduced need for new transmission capacity (capital cost savings > $1M/mile)




PSLF simulation of control system response to BC-Alberta separation (outage of Cranbrook-Langdon intertie)

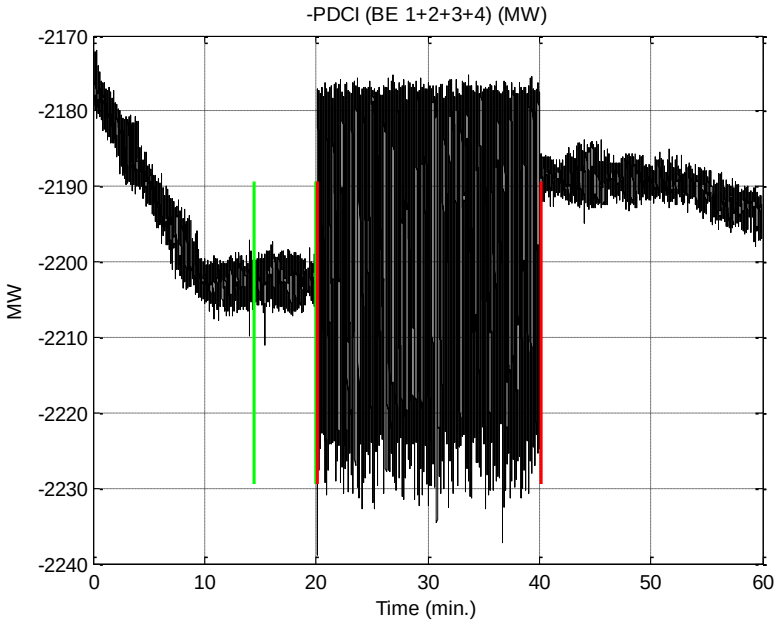
# Do No Harm

- "Watch Dog" circuit installed at BPA on June 22, 2015
- Overriding design philosophy was to make the system "failsafe" – failure of any component would safely disconnect the control system
- "Asynchronous Supervisor" ensures controller is not destabilizing other modes

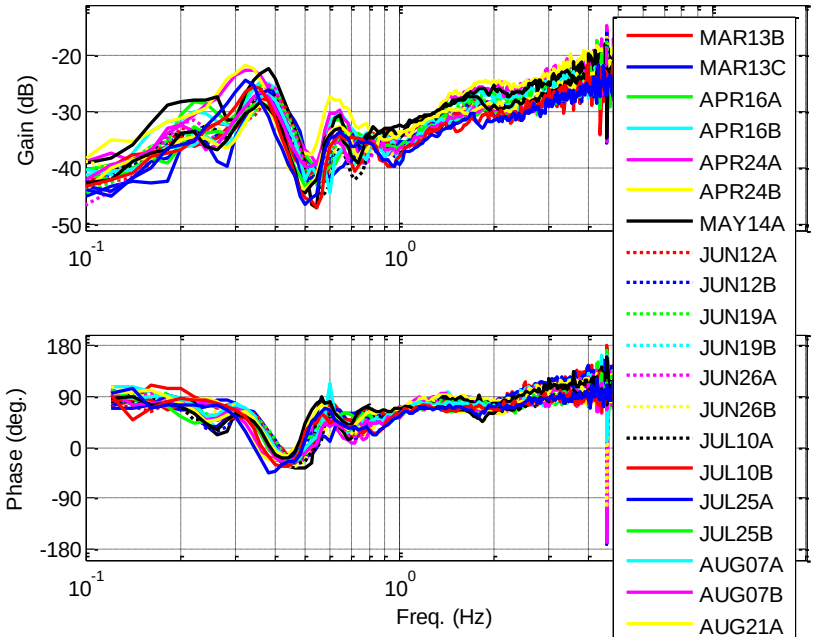



# PDCI Probing Tests

- **Low frequency** probing test (2009-2014) modulates PDCI by +/- 20 MW from 0.02 Hz to 5 Hz
- **High frequency** probing test (2014) modulates PDCI by +/- 5 MW from 1 Hz to 28 Hz

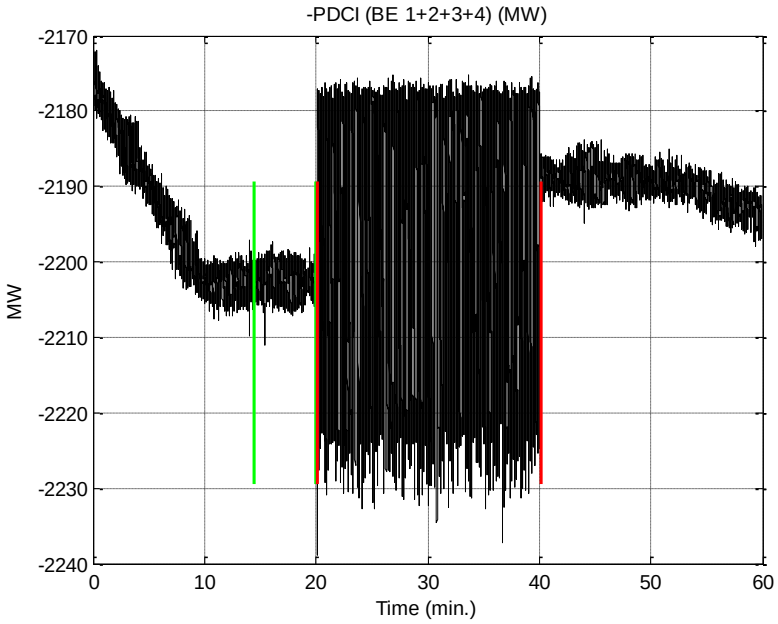


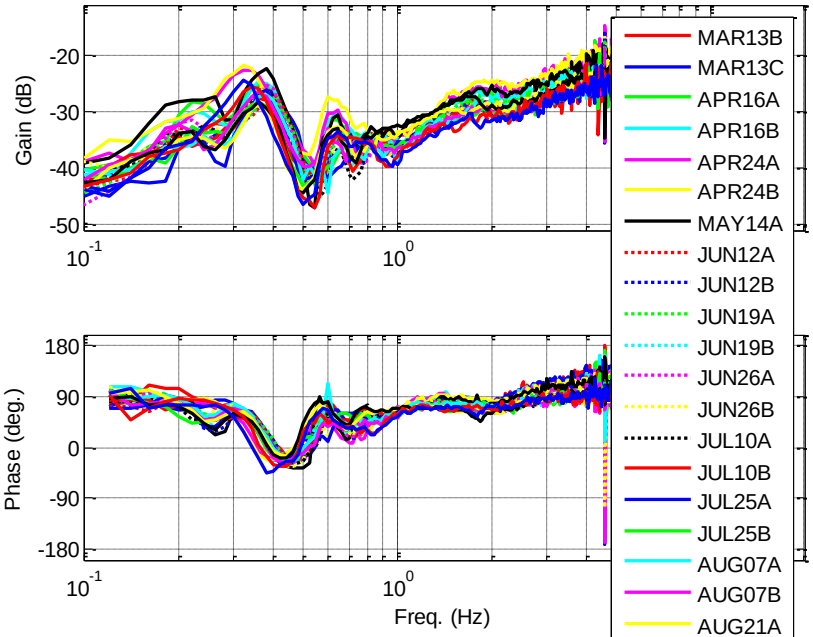

- The goal of the **low frequency** tests is to excite the 0 to 5 Hz range of oscillations in WECC
- The goal of the **high frequency** tests is to evaluate the dynamics of the PDCI system



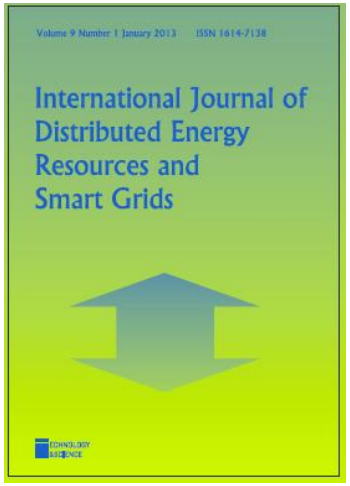
# PDCI Probing Tests

- What we've learned
  - Why this control didn't work in 1970s
  - New theory supported by tests
  - Identified optimal feedback signal locations (local and remote)
  - Feedback gain of 5 to 10 MW/mHz will provide **SIGNIFICANT** damping
  - PDCI has adequate bandwidth
  - Optimal design of feedback filter
  - We need to further test and fine-tune PMUs (on going)



# Project Publications

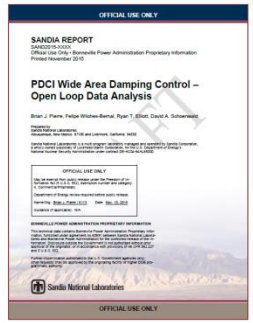



- Journal Paper: *International Journal of Distributed Energy Resources and Smart Grids*, vol. 11, no. 1, pp. 69-94, 2015.

- IEEE PES General Meetings: 2013 – 2016

- Electrical Energy Storage Applied Technologies (EESAT) Conference: 2013, 2015

- Project Reports: Open-Loop Data Analysis, Quick Start Guide, Telecom Requirements, Phase I Final Report, I/O Data Requirements



# Conclusions

- Theory → working prototype in 2 years
- Results in all facets of control system design and simulation studies have been very encouraging
- Open loop tests have been successful

- Plans for FY16 and FY17 closed-loop demonstration are being carefully coordinated with Celilo staff & BPA telecom experts

# QUESTIONS?