Integrated Information for Large Power Grids: Experience in the Western Interconnection

A Summary Presentation for the PMU Pioneers Panel

John F. Hauer
Pacific Northwest National Laboratory
Richland, WA 99352

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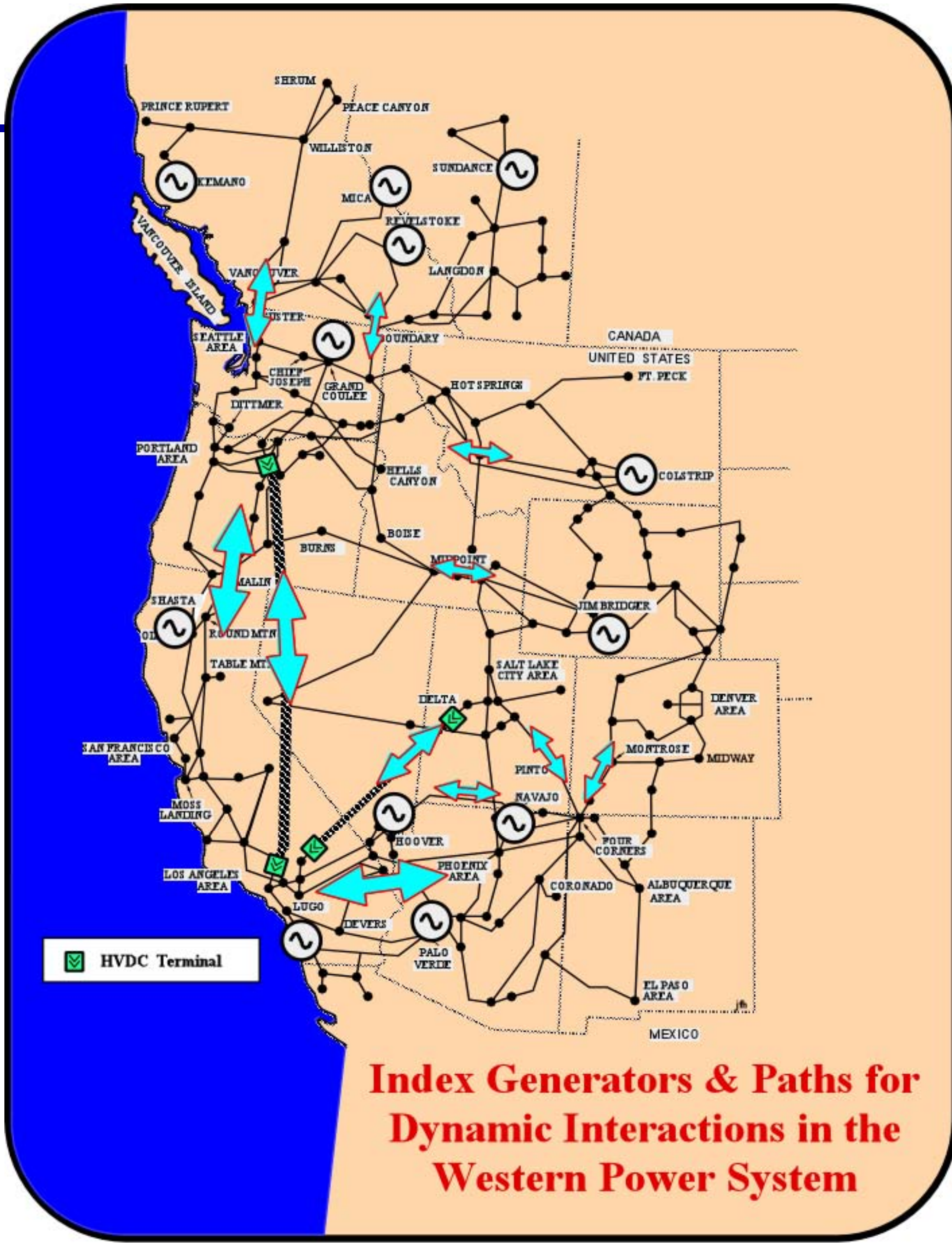


Index Generators & Paths for Dynamic Interactions in the Western Power System

The Western Power System:

A challenge in dynamic complexity

Source Materials: Projects & Documents

[1] **"Reactive Power Control as a Means for Enhanced Interarea Damping in the Western U. S. Power System—A Frequency-Domain Perspective Considering Robustness Needs,"** J. F. Hauer. *Application of Static Var Systems for System Dynamic Performance*, IEEE Publication 87TH0187-5-PWR, pp. 79-92, 1987. (***launched SOWG and WSCC WAMS, effort later reinforced by DOE and EPRI***)

[2] **"Square Butte HVDC Modulation Field Tests,"** C. E. Grund, J. F. Hauer, L. P. Crane, D. L. Carlson, and S. E. Wright. IEEE Trans. Power Delivery, pp. 351-357, January 1990. **(*confirmed WSCC experience*)**

[3] **Eigenanalysis and Frequency Domain Methods for System Dynamic Performance,** IEEE Publication 90TH0292-3-PWR, 1990 (***many WSCC results from SOWG***).

[4] **"Extending the Realism of Planning Models for the Western North America Power System,"** J. F. Hauer and J. R. Hunt in association with the WSCC System Oscillations Work Groups. V Symposium of Specialists in Electric Operational and Expansion Planning (SEPOPE), Recife (PE) Brazil, May 19-24, 1996.

[5] **Validation of Phasor Calculation in the Macrodyne PMU for California-Oregon Transmission Project Tests of March 1993**," J. F. Hauer. **IEEE Trans. Power Delivery**, vol. 11, pp. 1224-1231, July 1996 .

[6] **Integrated Monitor Facilities for the Western Power System: WAMS Analysis in 2005**, J. F. Hauer, W. A. Mittelstadt, K. E. Martin, J. W. Burns, and Harry Lee. Interim report of the WECC Disturbance Monitoring Work Group, December 2005. (To appear in **The Electric Power Engineering Handbook**, edition 2, L. L. Grigsby ed., CRC Press, 2007)

[7] **Use of the WECC WAMS in Staged System Tests for Validation of System Performance and Modeling: Summary Report for September 2005–August 2006,** J. F. Hauer, W. A. Mittelstadt, J W. Burns, K. E. Martin, Harry Lee, and D. J. Trudnowski**.** Report of the WECC Disturbance Monitoring Work Group, draft of April 24, 2007 . (***most recent progress report by DMWG***)

Wide Area Control:

A definitive sufficiency test of grid management resources

Evolution of the WECC WAMS:

Ripple effects of the Celilo Damper Project – Lessons Learned

Celilo Damper (1975- 1989)

- ***wideband controller modulating the PDCI, control law similar to PSS***
- ***designed to damp North-South mode, but influenced all others***
- ***performance tracked with a succession of central BPA monitors plus accessory tests and recorders***

Immediate lessons from the Celilo Damper Project

- ***PDCI modulation affects all generators on the grid (as intended)***
- ***Planning models could neither replicate nor predict modulation effects***
- ***Measurement facilities did not provide an adequate view of modulation effects***
  - ***transducer technology was inadequate***
  - ***monitor data was sparse, and not easily shared***
- ***The controller environment was far more variable and complex than computer models could represent (many implications for controller design and operation)***

Evolution of the WECC WAMS:
Ripple effects of the Celilo Damper Project – Collective Actions

Actions deriving from the Celilo Damper Project

- ***system tests and research projects for robust damping control (BPA/PNNL, others)***
- ***improved technologies for measurements and analysis (many participants)***
- ***collective WSCC/WECC efforts for***
  - ***validation and refinement of planning models***
  - ***development of a wide area measurement system (WesDINet/WAMS)***

System Oscillations Work Groups (SOWG) (1987-1995)

1. Collect and analyze system monitor data
2: Calibrate planning models against actual system response
3: Assist other Work Groups for improving models & data
4: Develop tools for analysis and mitigation of system oscillations
5. Conduct workshops/seminars for frequency domain tools
6. Enhance/refine tools for modal analysis of system oscillation records
7. Encourage the application of frequency domain methods
8. Provide technical review of proposed controllers [*and new construction*] that can have significant impact on system damping

WesDINet, WAMS, and Synchronized System Measurements

WesDINet = **Western Dynamic Information Network (redefined as WAMS)**

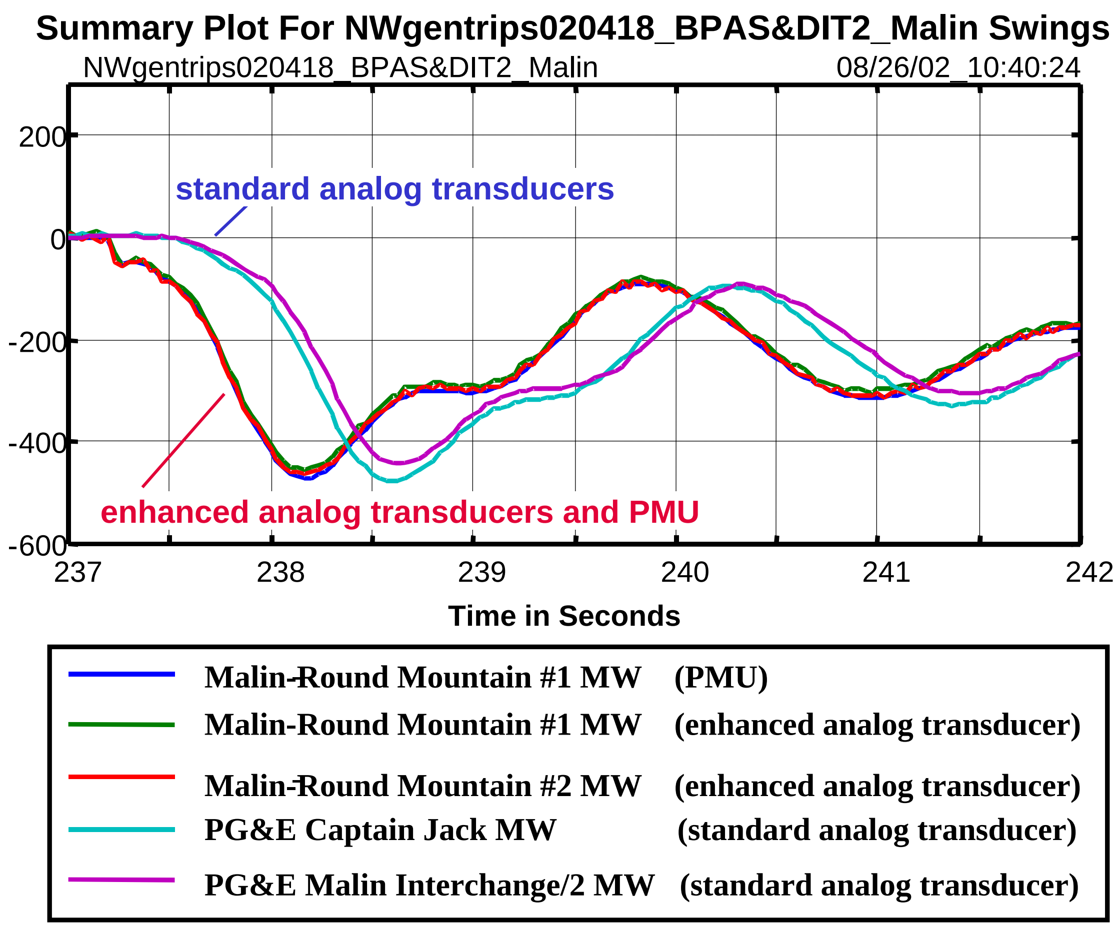
WAMS = **Wide Area Measurement System**

SSM = **Synchronized System Measurements**

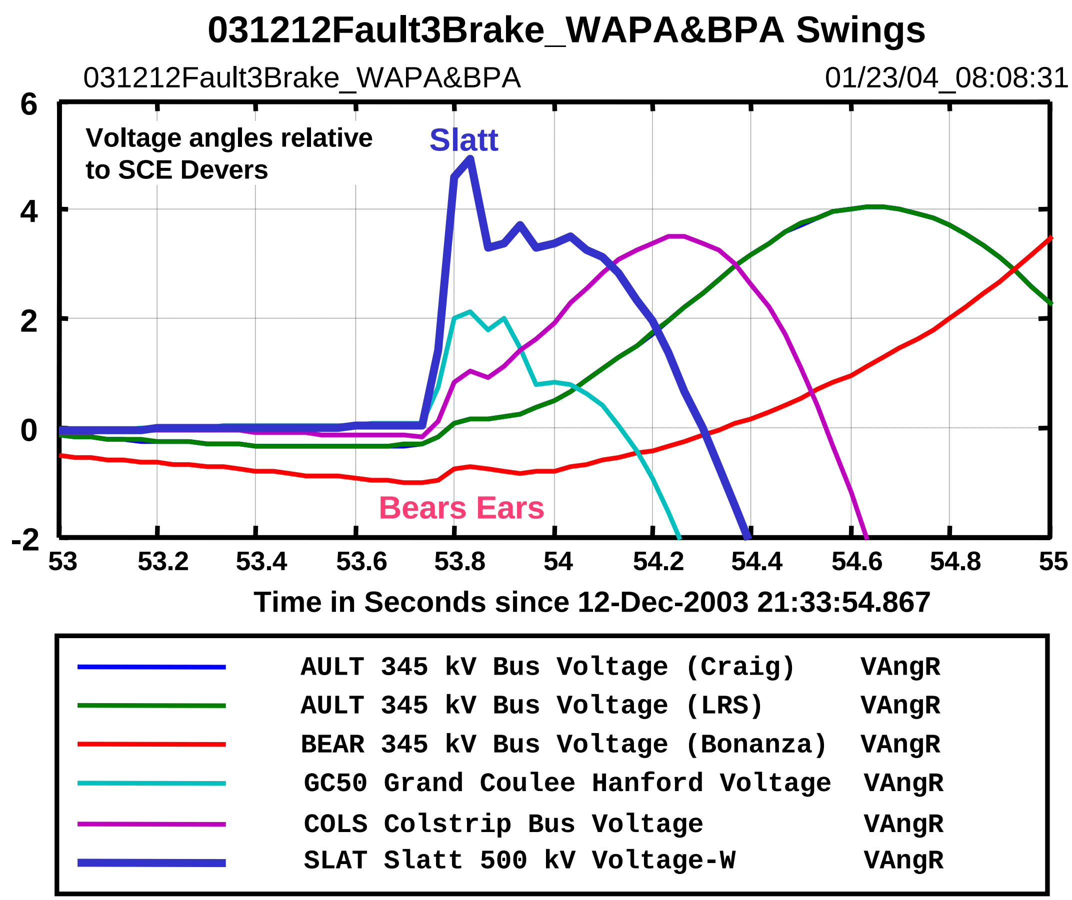
SPM = **Synchronized Phasor Measurements (subset of SSM)**

- **WAMS describes an advanced technology infrastructure that is designed to *develop and integrate measurement based information into the grid management process*.**
- **WAMS infrastructure encompasses *measurement facilities*, *operational support*, and *data utilization*.**
- **WAMS measurement facilities augment those of conventional SCADA, and are expressly designed to enhance the "situational awareness" that is necessary for safe and reliable operation .**

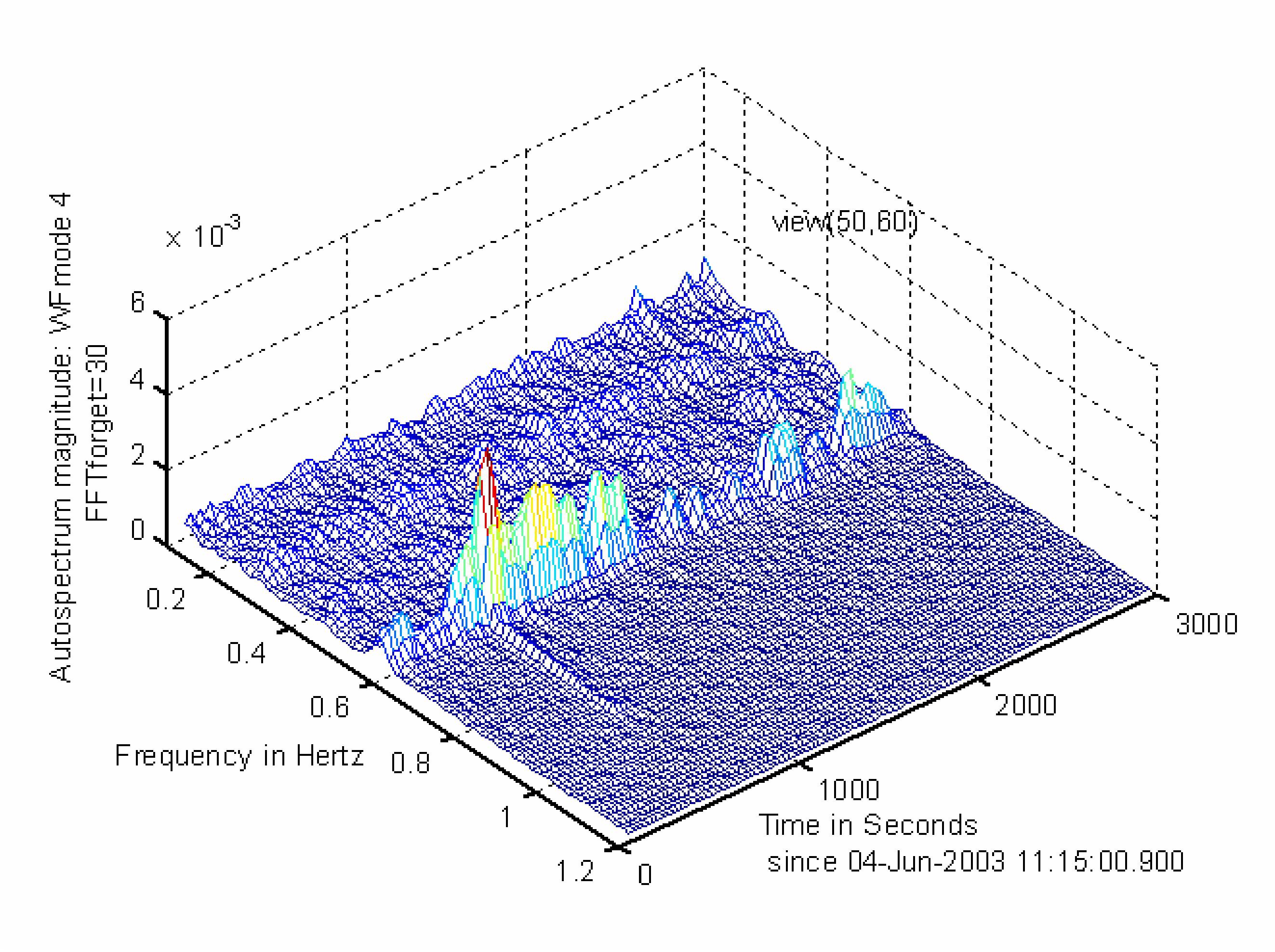
Inconsistencies in Malin Area Transducer Signals: NW Generation Trip Event of April 18, 2002



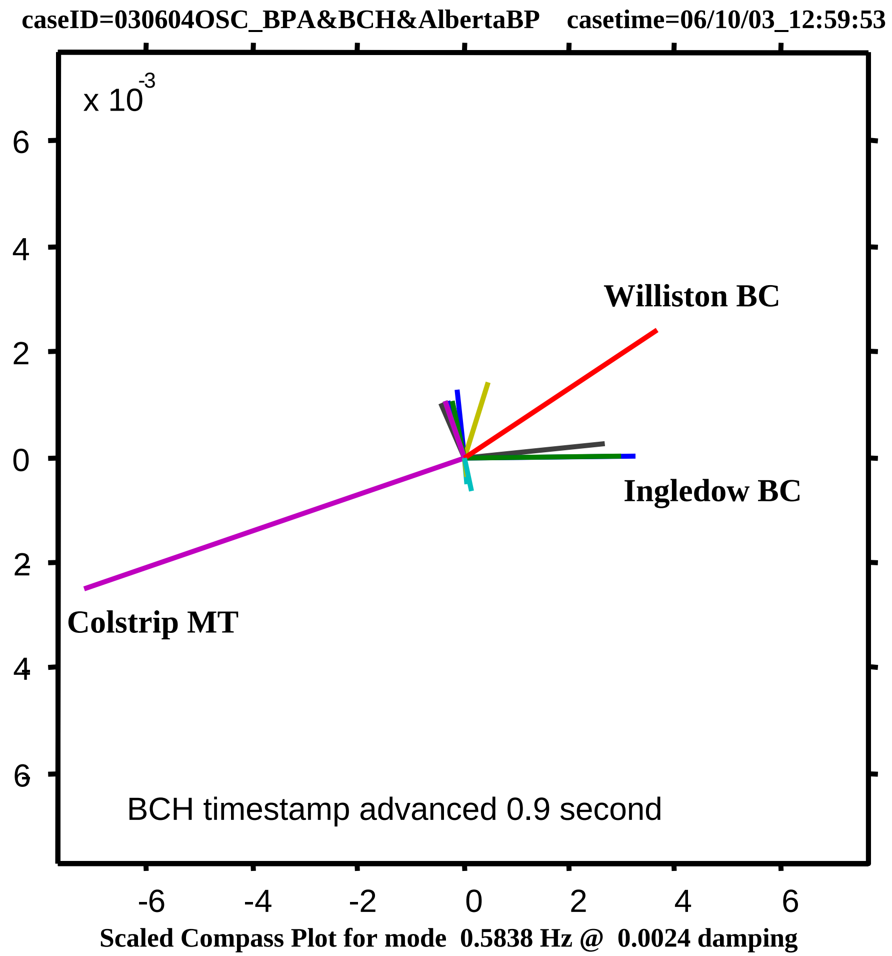
Transients in voltage angles relative to SCE Devers: Malin fault on December 12, 2003



Waterfall plot for NW oscillation event on June 4, 2000: local frequency at Williston, BC



Mode shape for 0.584 Hz oscillation in local frequency: NW oscillation event on June 4, 2003



Situational Awareness: *"Where's the Edge?!"*

"Everyone wants to operate the power system closer to the edge. It's a good idea. But to do that we should know

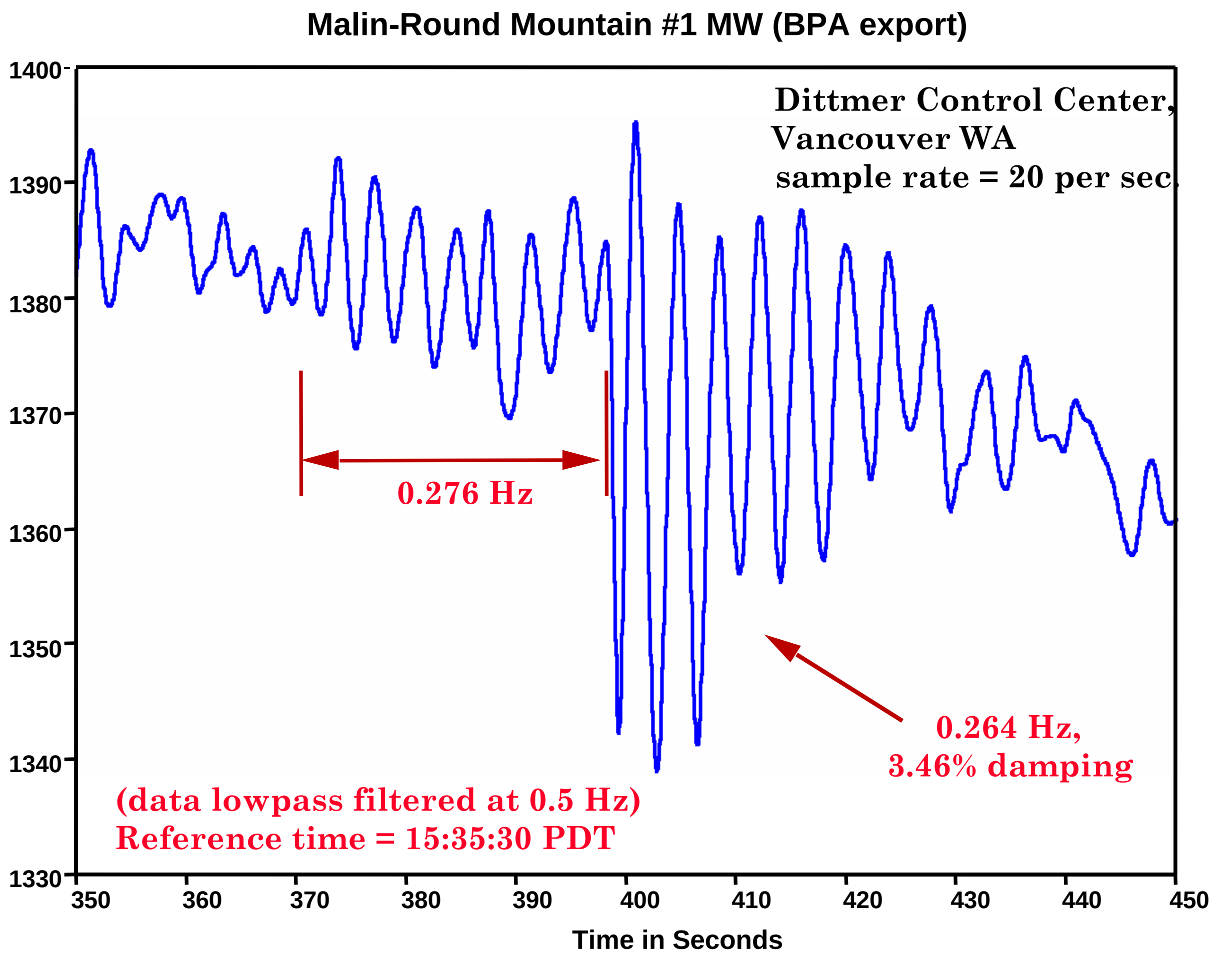
- ***where the edge is*, [knowledge base from overall experience & analysis]**

and

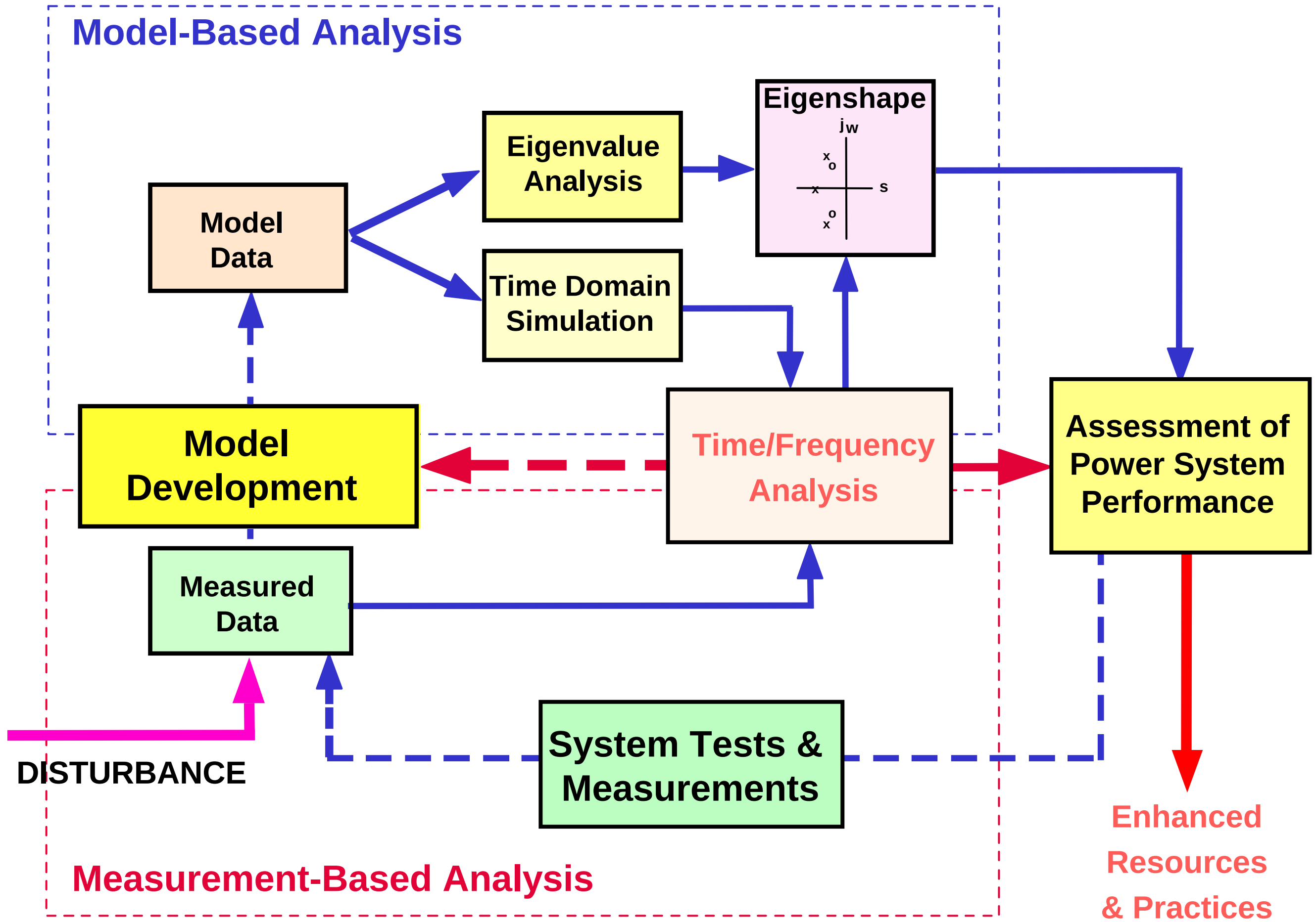
- ***how close we are to it*." [real time observations compared against knowledge base]**

Comment by a veteran engineer with TransAlta Utilities to the WSCC System Oscillations Work Group, 1992.

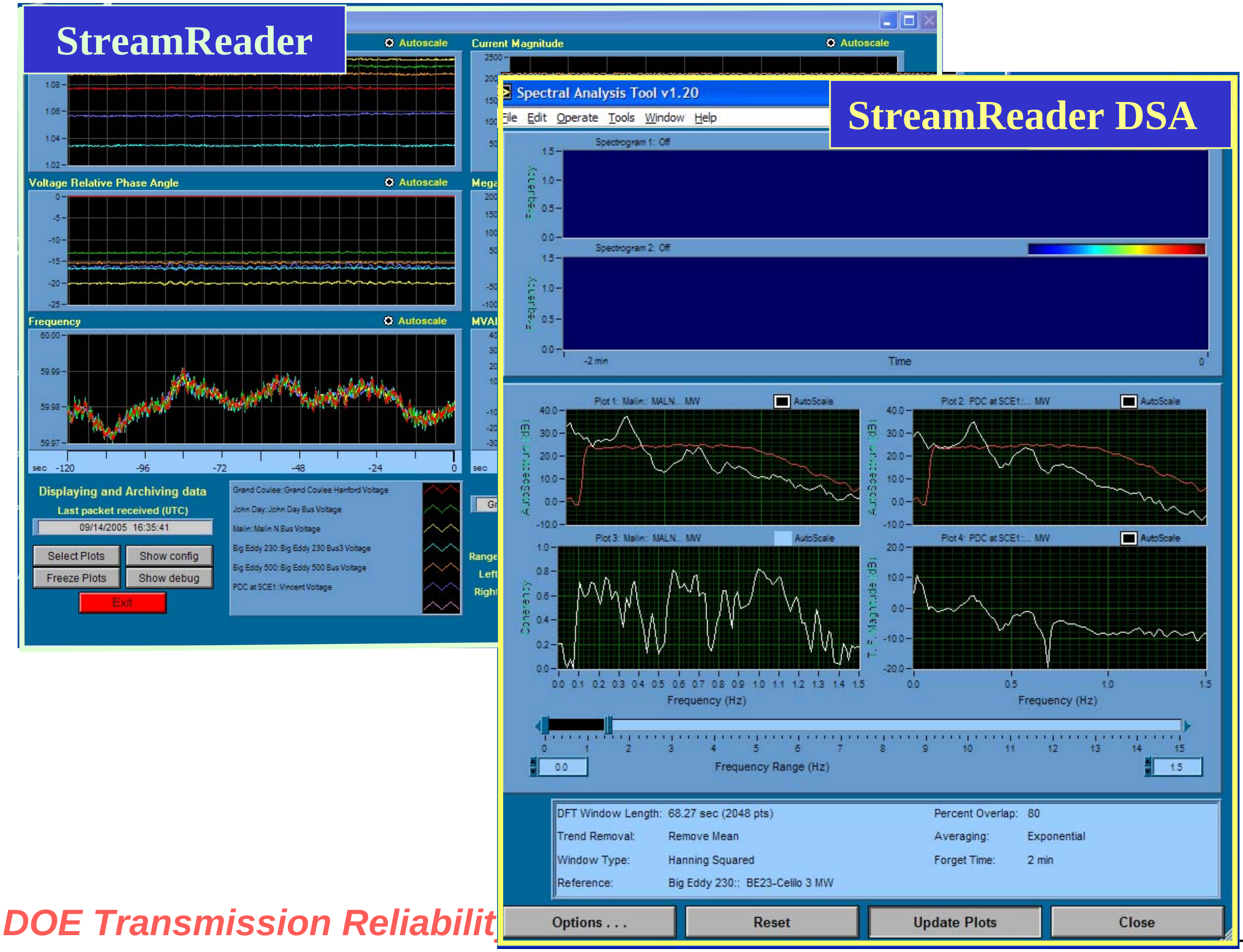
Shift of Western System Dynamics with loss of Keeler-Allston line: Breakup of August 10, 1996



Validation of System Performance & Modeling (workflow of WSCC SOWG, 1987-1995)



StreamReader Tools for Real Time Correlation Analysis
Test StepC3 on September 14, 2005: Noise probing @ 20 MW



Description of System Dynamic Performance Tests: 2005-2006

Test Objectives:

A. ***Obtain seasonal benchmarks*** **for dynamic performance of the WECC system**

B. ***Develop comparative data*** **to evaluate and refine the realism of WECC modeling tools**

C. ***Refine and validate methods*** **that identify power system dynamics with minimal or no use of probing signals**

Test Activities:

- **energizations of the Chief Joseph dynamic brake (1400 MW pulse)**
- **modulation of the Pacific HVDC Intertie:**
  - **brief sine waves and square waves (± 120 MW)**
  - **sustained random noise (± 25 MW)**
- **analysis of ambient system activity**

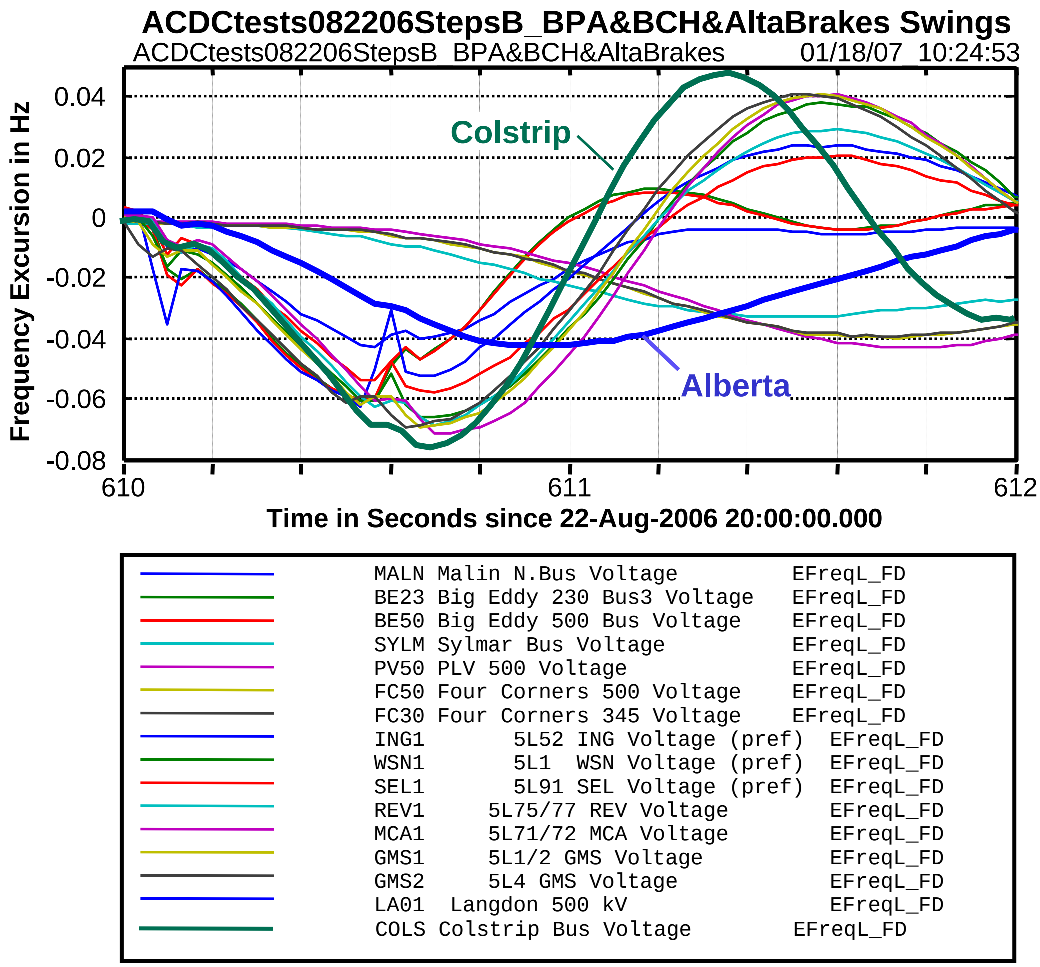
Ambient damping of WECC interarea modes is very good – *when the transmission network is intact!*

Primary modes from Test Brake Insertions, 2005-2006*

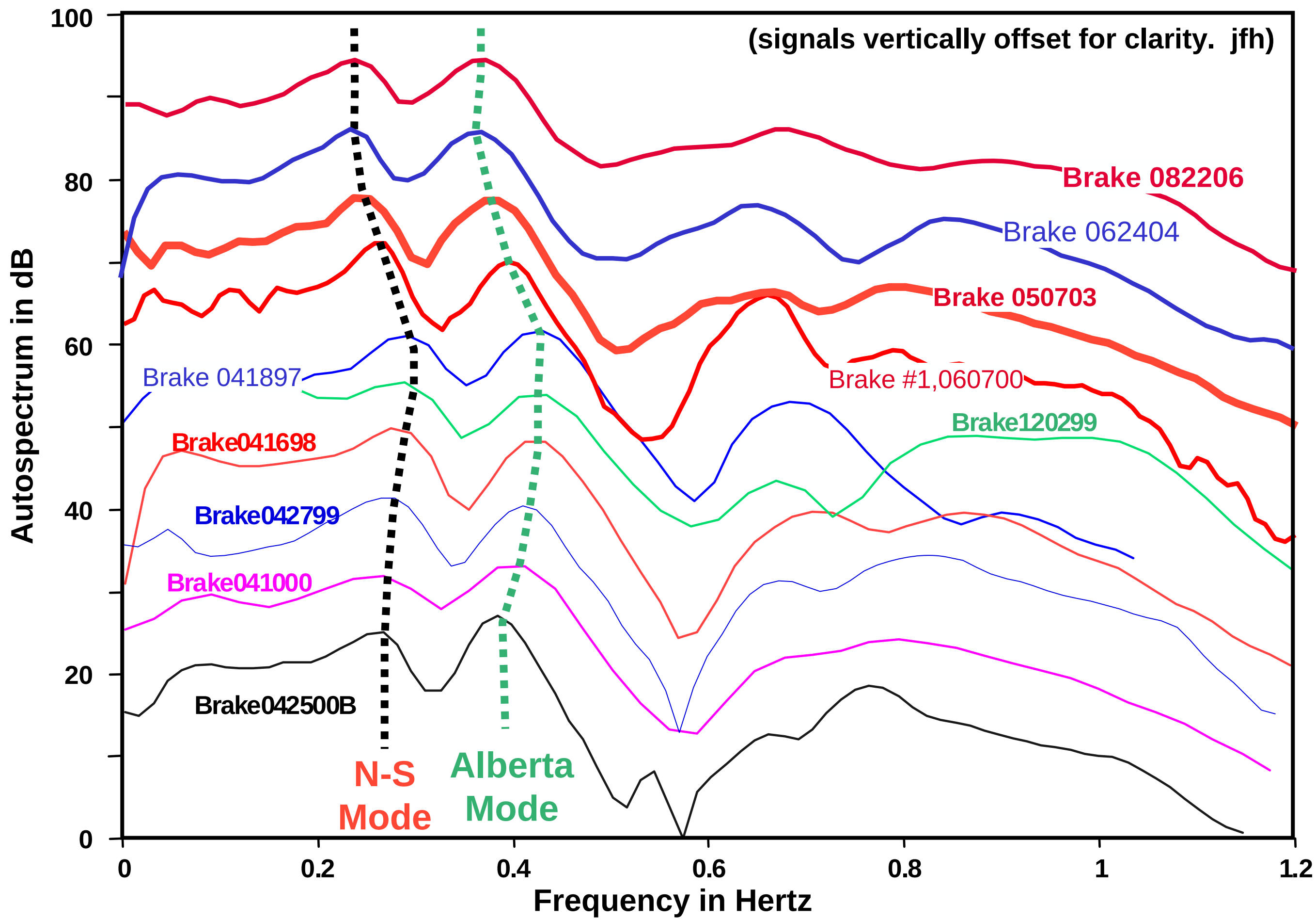
Mode	D1 on 09/14/05	B1 on 06/13/06	B1 on 08/22/06
North-South	0.318 Hz @ 8.3%	0.244 Hz @ 9.1%	0.244 Hz @ 9.6%
Alberta	(not present)	0.376 Hz @ 9.1%	0.373 Hz @ 8.1%
Kemano	0.626 Hz @15.4%	0.620 Hz @ 8.8%	0.642 Hz @ 9.9%
Colstrip	0.720 Hz @22.5%	0.776 Hz @10.2%	
	0.889 Hz @10.7%	0.830 Hz @10.9%	

These values are typical of the past decade.

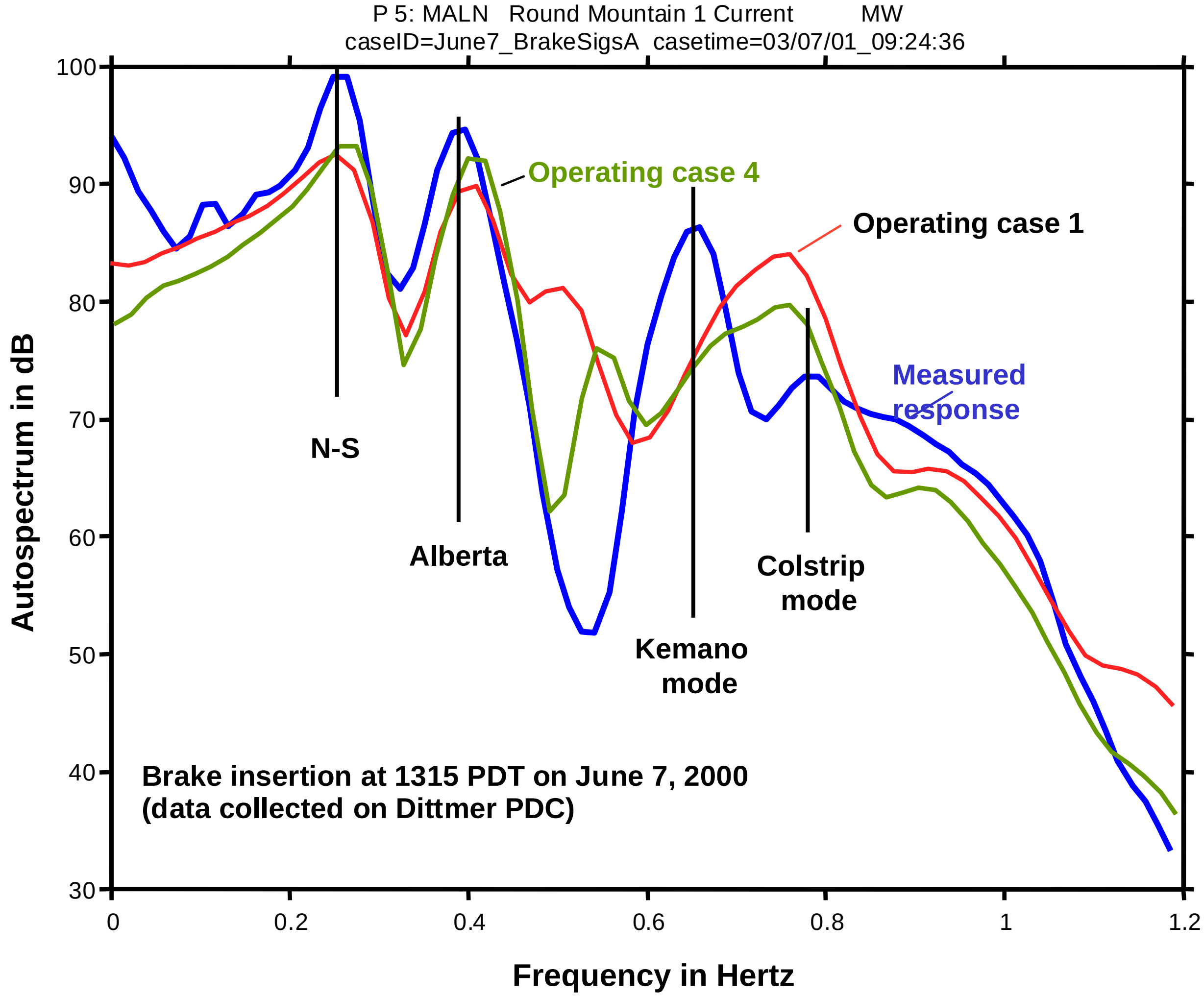
Timing Checks: Brake Insertion Event B1, 082206



Ringdown signatures for recent insertions of the Chief Joseph dynamic brake (Alberta strongly connected)



Comparing Models Against Historical Records for Malin Ringdown Signatures



Modeling Criteria for Oscillatory Dynamics

A fully realistic model for wide area oscillation dynamics must, *for all important modes*, replicate and predict actual system behavior in the following respects:

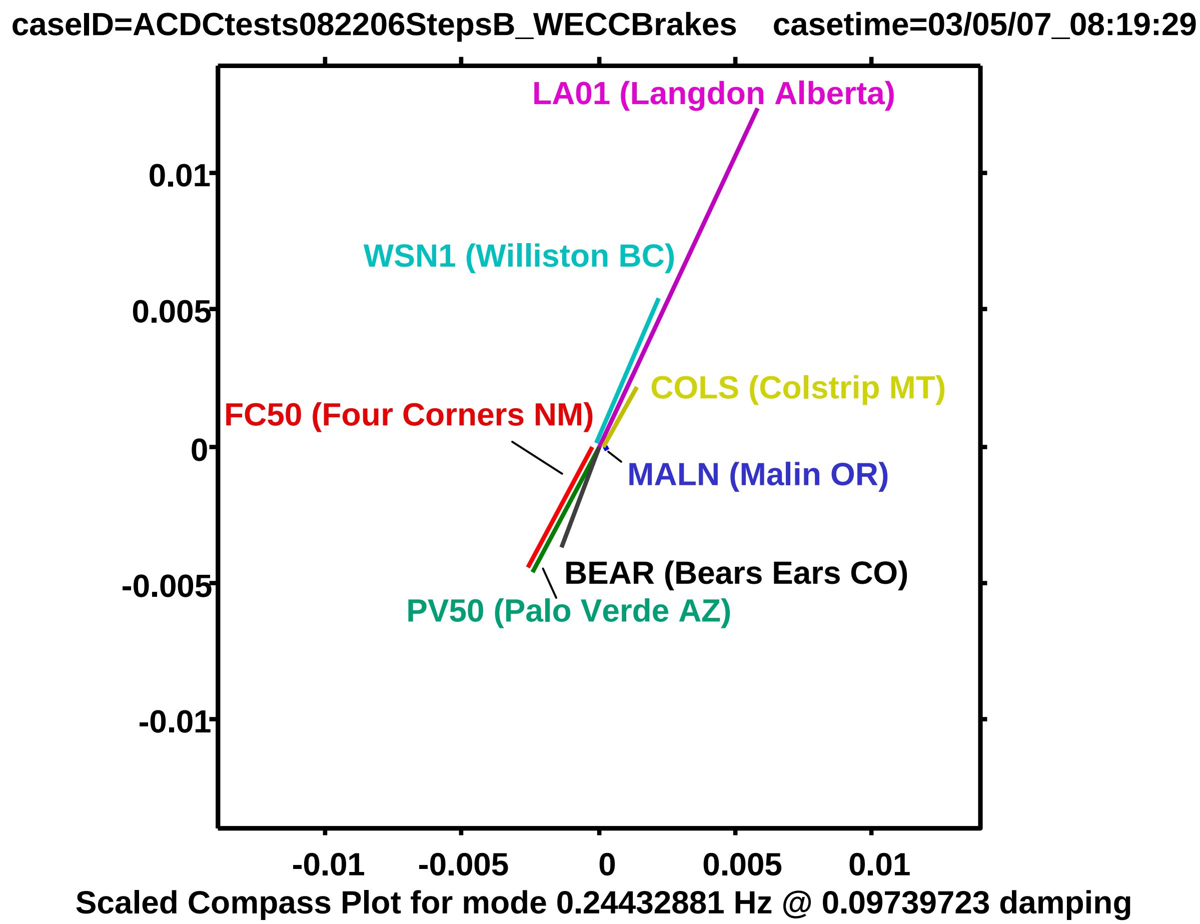
a) **Mode parameters** (eigenvalues). Usually characterized in terms of frequency and damping.

b) **Mode shape** (eigenvectors). Characterized by the relative phasing and strengths of generator oscillations for each mode.

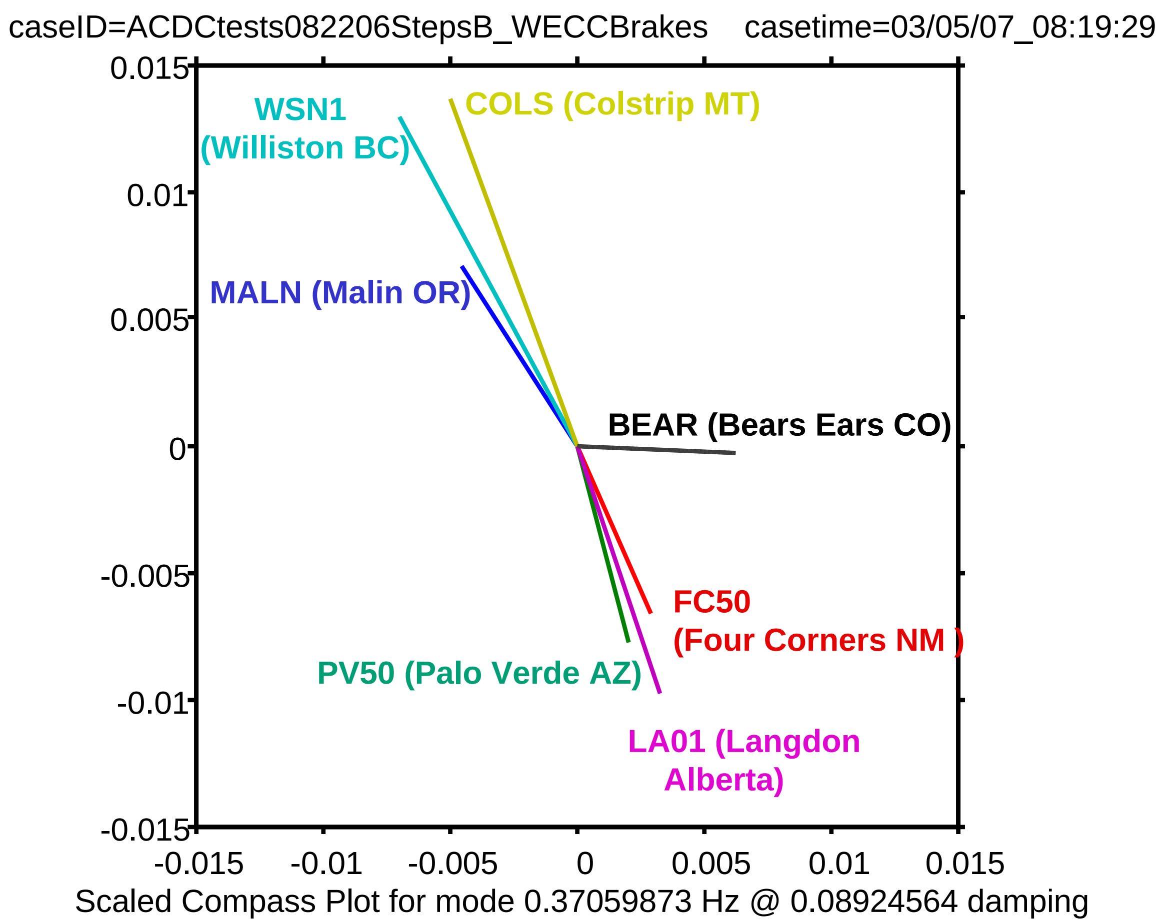
c) **Interaction paths**. The lines, buses, and controllers through which generators exchange energy during oscillatory behavior.

d) **Response to control**. Modification of oscillatory behavior due to control action, including changes to network parameters and load characteristics.

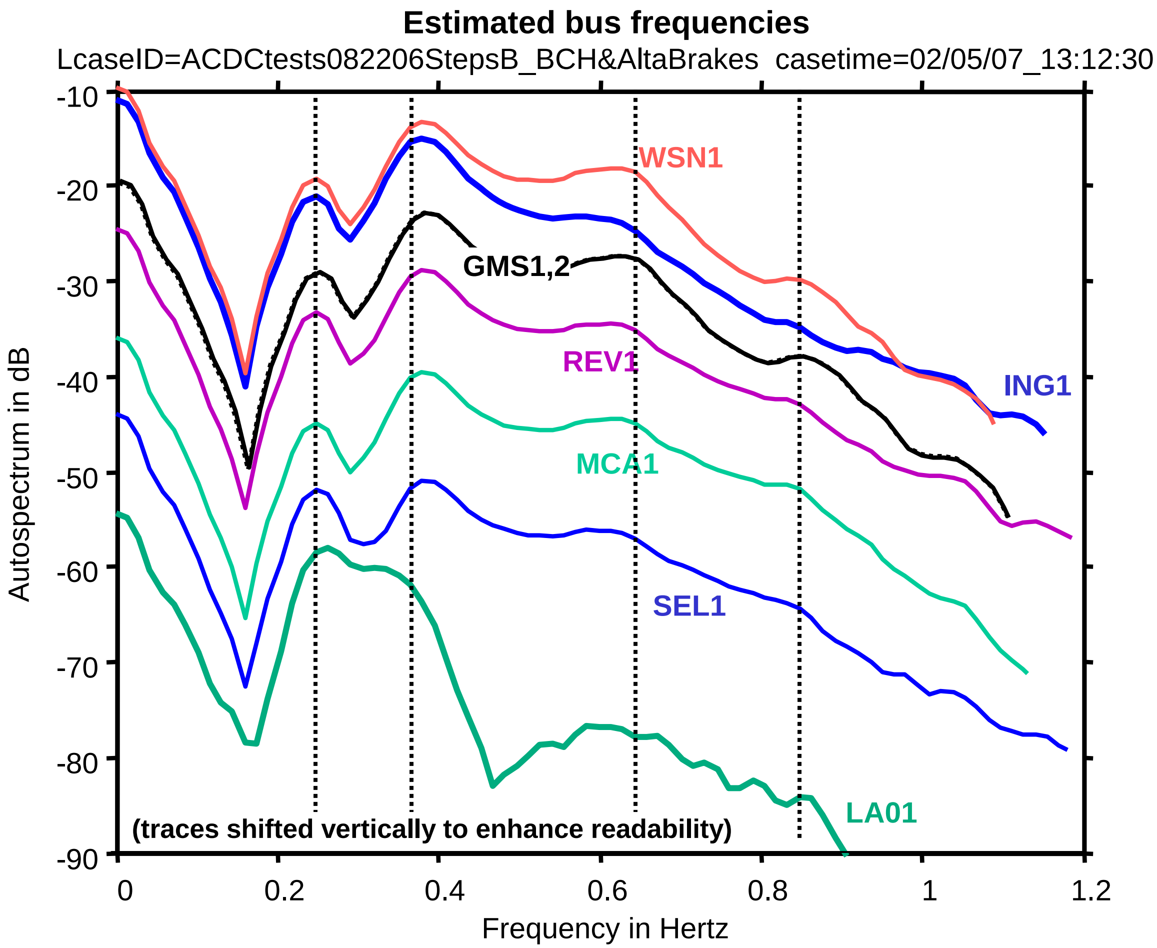
Brake event B1 – WECC Pattern for North-South Mode (poles from relative angle fit, new data from bandpassed EFreqL)



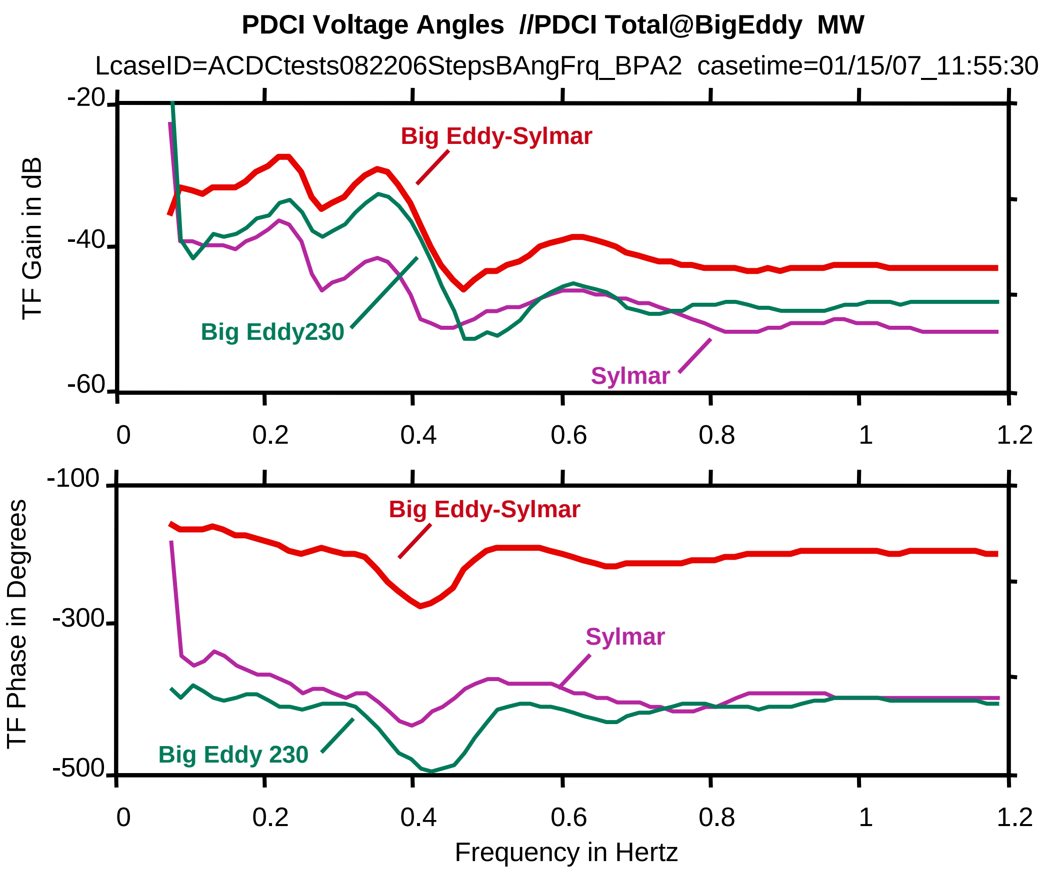
Brake event B1 – WECC Pattern for Alberta Mode (poles from relative angle fit, new data from bandpassed EFreqL)



BCH Bus Frequency Signatures for Brake Event B1, 082206 (frequencies estimated from angles)



Transfer function for PDCI terminal angles vs. ±25 MW PDCI probing noise (step B3 on 08/22/06)



Are Bus Angles Robust for HVDC Damping??

Conjecture:

Relative bus angles *MAY* provide the long awaited robust signal for HVDC Modulation, but *local angles & frequencies are not* (see Square Butte damper project)

Measurement issues to resolve:

- **PMU vulnerability to harmonic inputs and out-of-band dynamics**
- **Parasitic oscillations originating within some PMUs**
- **Time delays in feedback loops**

System issues to resolve:

- **Risk of NMP zeros (many studies with validated models)**
- **Parameter scheduling of control law vs. status of Alberta connection**
- ***Controller certification procedures!***

jfh Bio

John Hauer (F'90) started his engineering career with the General Electric Company in 1961. This was followed by industrial work at Boeing Aerospace, a Ph.D. at the University of Washington, and a faculty position at the University of Alberta.

In 1975 he joined the Bonneville Power Administration and began a long involvement with identification, analysis, and control of power system dynamics. In 1994 he stepped down as BPA Principal Engineer for power system dynamics, and assumed technical leadership of the power systems group at the DOE's Pacific Northwest National Laboratory in Richland, Washington. He is a Laboratory Fellow at PNNL, a Life Fellow of the IEEE, and a professional engineer licensed in the State of Oregon.

While Dr. Hauer retired in 2005, he continues to find amusement in serving as a general irritant and provocateur to the power industry.