Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Mode Meter Development

Presented by: Ning Zhou

Pacific Northwest National Laboratory

June 12th, 2012

Washington DC

Work Team

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

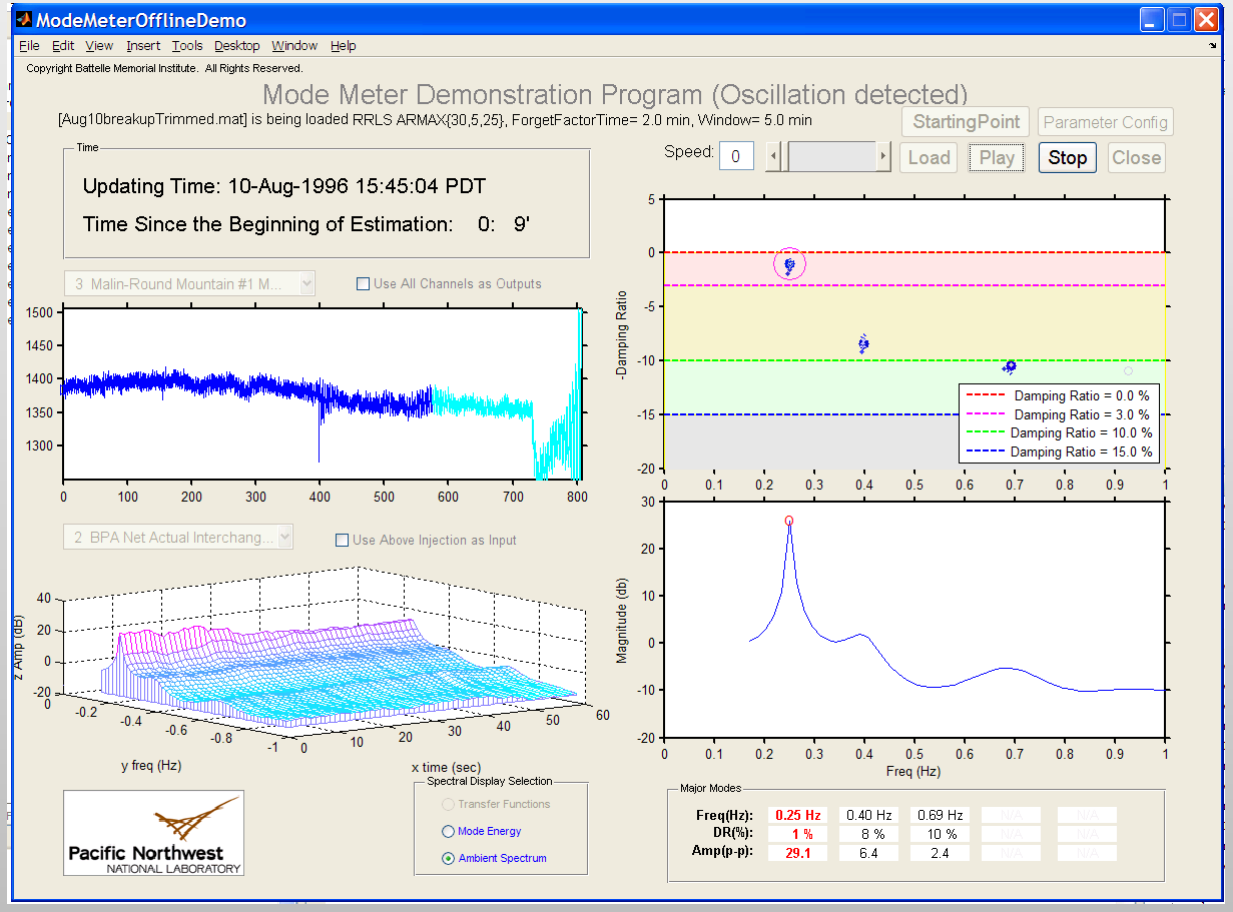
- PNNL team:
  - Ning Zhou
  - Pengwei Du
  - Jim Follum (summer intern)
- The work under this project closely aligns and collaborates with the research under the TRP project "**Measurement Based Stability Assessment**" being conducted by:
  - Dan Trudnowski, Montana Tech
  - John Pierre, University of Wyoming
  - Louis Scharf, Colorado State University (Retired)
  - Many graduate students

Project Objective:

Real Time Mode Identification

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965



Goal:

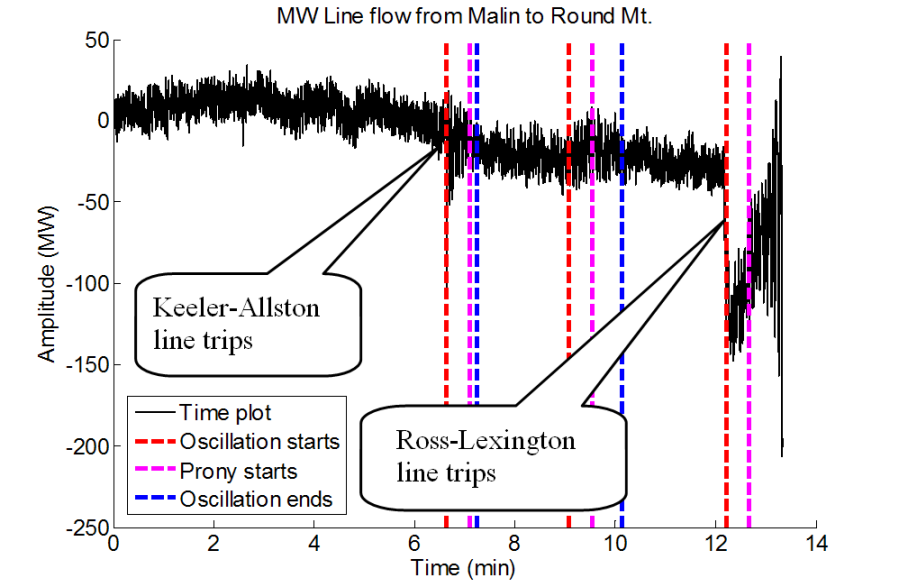
Enhance the power system reliability by **estimating oscillation modes** from PMU data in near **real time**.

Modal Analysis from Ringdown Data

- Applicable after significant transient;
- Quick detection of light damping modes;

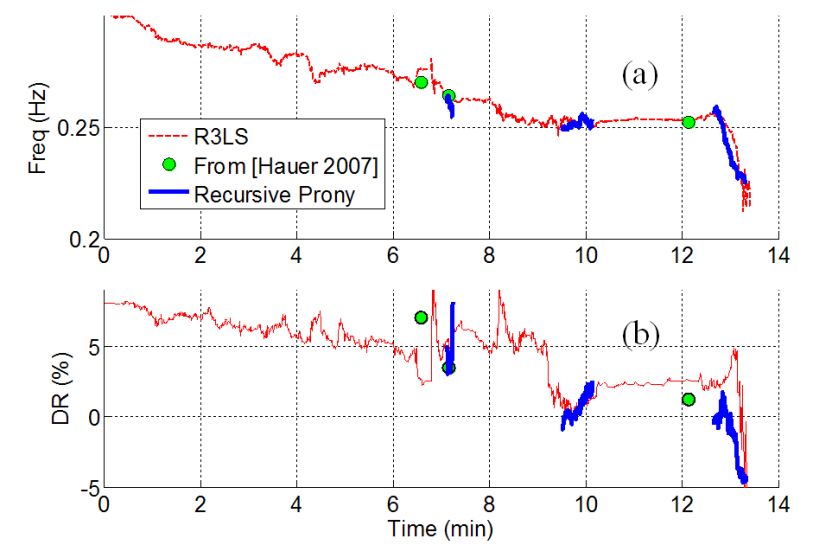
1. Detect Ringdown
2. Select Channels
3. Modal Analysis
4. Select Dominant Modes
5. Quantify the Uncertainty

Detect Ringdown



Recorded real power flow from Malin to Round Mountain (Reference time: Aug 10th, 1996, 15:35:30 Pacific Daylight Time)

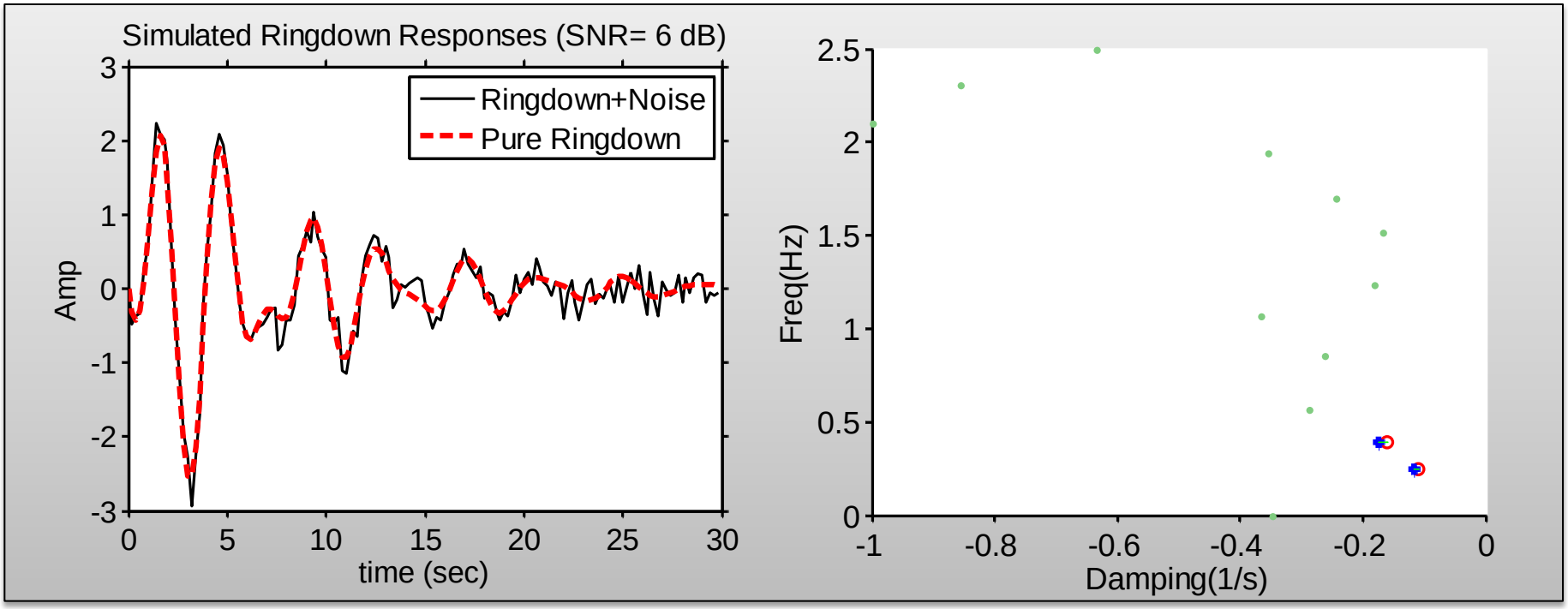
Mode estimation by R3LS, Off-line study, and ringdown analysis.



* Ning Zhou, Zhenyu Huang, Francis Tuffner, John Pierre, and Shuangshuang Jin, "Automatic Implementation of Prony Analysis for Electromechanical Mode Identification from Phasor Measurements," 2010 IEEE PES General Meeting, July 25-29, 2010

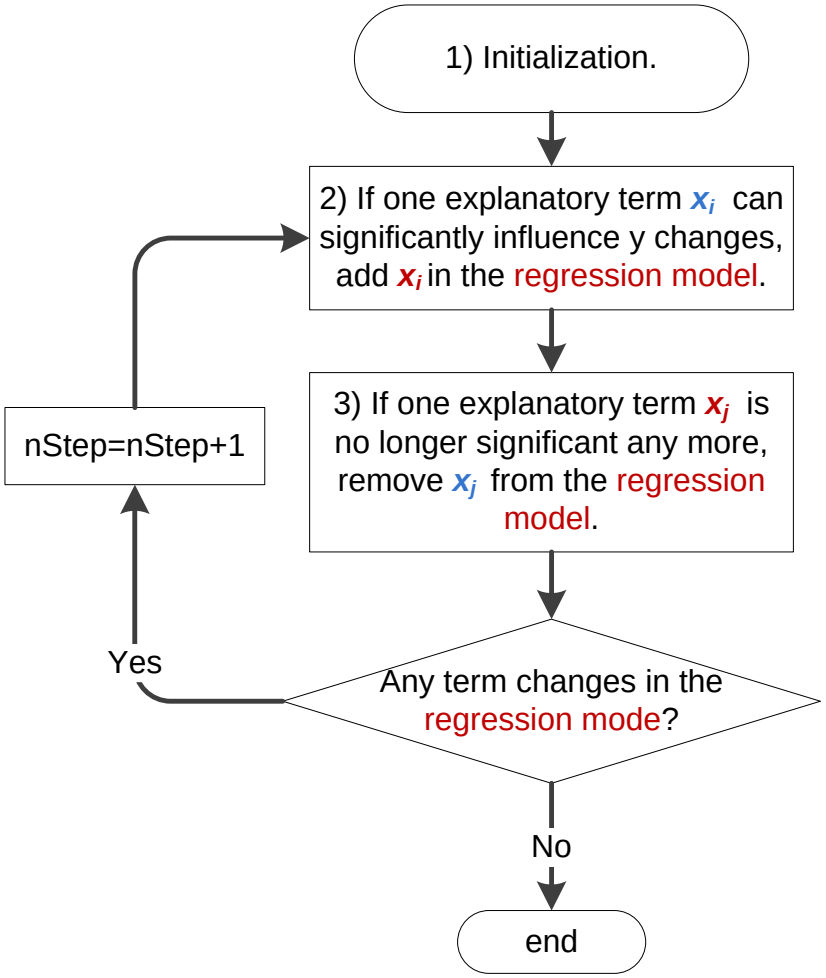
Select Dominant Modes (Goal)

- **Target**: separate dominant modes and trivial modes.
  - ***Dominant modes*** represents the dynamic feature of a power system.
  - ***Trivial modes*** are artificially added to suppress the noise and improve estimation accuracy.
- **Motivations**: reduce the rate of false alarms.



Select Dominant Modes (Approach)

- **Empirical Study**: Sorting Energy.
- **Proposed Method:** Stepwise regression**.**



- The stepwise-regression method provides a **systematic way** of identifying the dominant modes in a statistical framework, which takes a noise model into consideration.
- **Significance:** Is β_i close to 0 enough? (t-test).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i + \cdots + \beta_m x_m + e$$

Select Dominant Modes (Simulation Example)

Fig. 7. Instance of combined ringdown responses and ambient data.

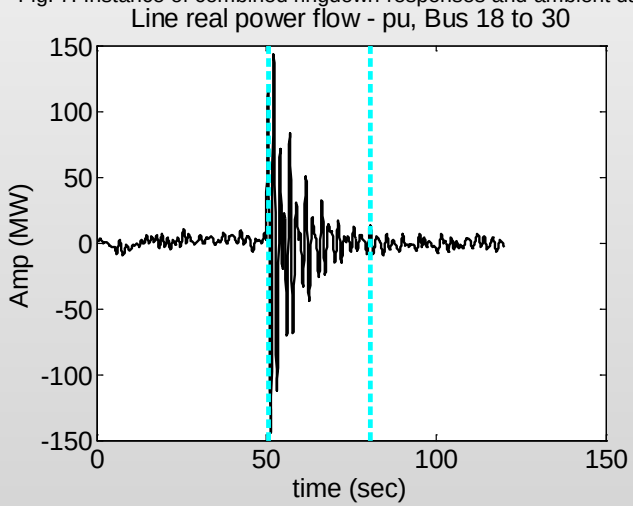
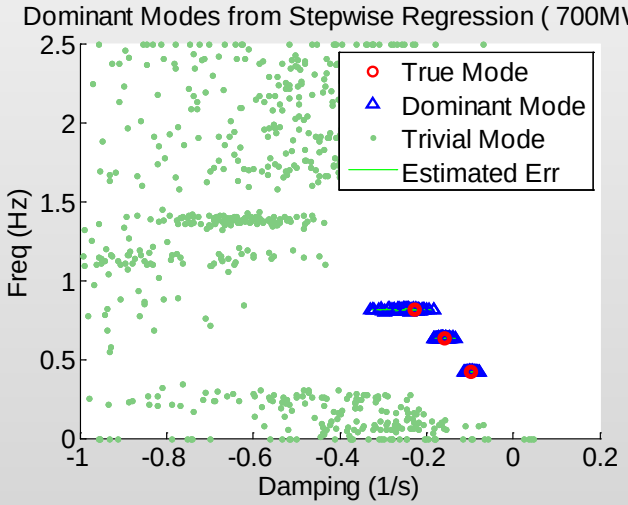
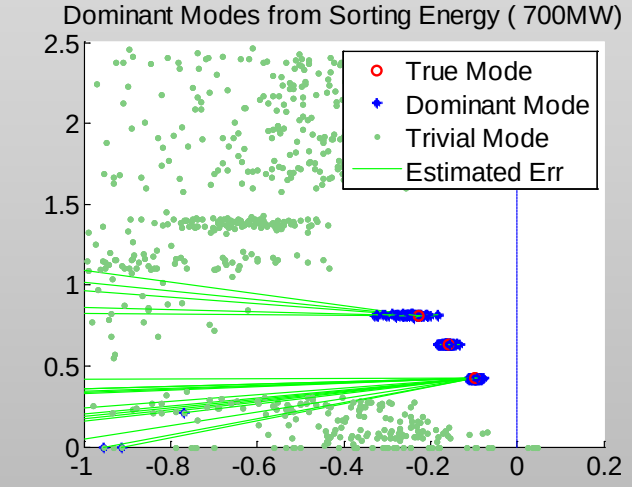


Table V. The Number of Outliers for the Identified Dominant Modes from 100 Monte Carlo Simulations Using the 17-Machine Model

Insertion Amp (MW)	*Outliers Using Energy Sorting*	*Outliers Using Stepwise-regression*
2800	2	0
1400	6	0
700	20	0
350	42	8

N. Zhou, J.W. Pierre, D.J. Trudnowski, "A Stepwise Regression Method for Estimating Dominant Electromechanical Modes," IEEE Transaction on Power Systems, vol. 27, no. 2, pp. 1051-1059, May 2012.





Select Dominant Modes (1996 Example)

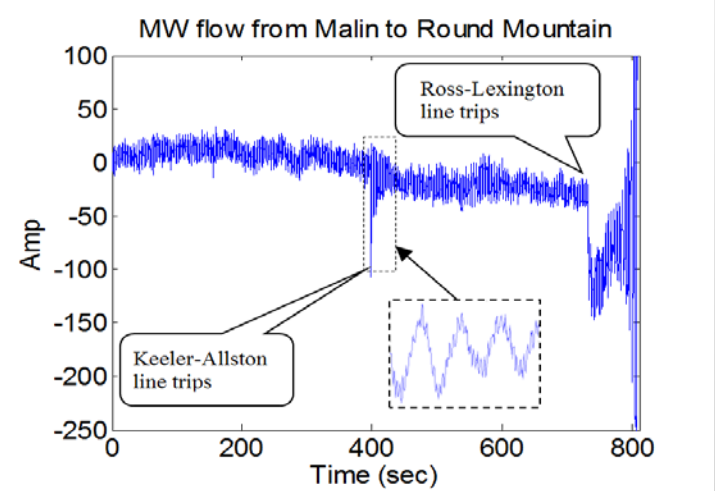


Fig. 9. Recorded real power flow from Malin to Round Mountain with detected oscillation. (Reference time: August 10, 1996, 15:35:30 PDT).

Number of Outliers for the Identified Dominant Mode from 100 Monte Carlo Simulations For Measurement Data

SNR (dB)	*Energy Sorting*	*Stepwise-regression*
10	1	0
6	7	0
3	13	0
1	21	0
0	27	1

Energy Levels and *P*-Values from Studying the Ringdown Responses.

Mode Index	*Mode Freq (Hz)*	*Mode DR (%)*	*Energy Level*	*p-Value*
1	0.270	3.59	111.0	$1.8X10^{-39}$
2	0.032	70.48	19.5	$7.2X10^{-6}$
3	0.652	5.93	12.0	0.46
4	0.805	4.90	9.2	0.81
5	0.483	19.71	8.5	0.25
6	1.955	2.95	7.7	0.84
7	1.398	6.86	6.2	0.64
8	1.524	3.14	5.6	0.94
9	2.417	1.34	5.1	0.90
10	1.045	2.75	4.6	1.00
11	1.728	2.50	3.6	0.98
12	2.180	2.48	2.9	0.37

Uncertainty of the Modes

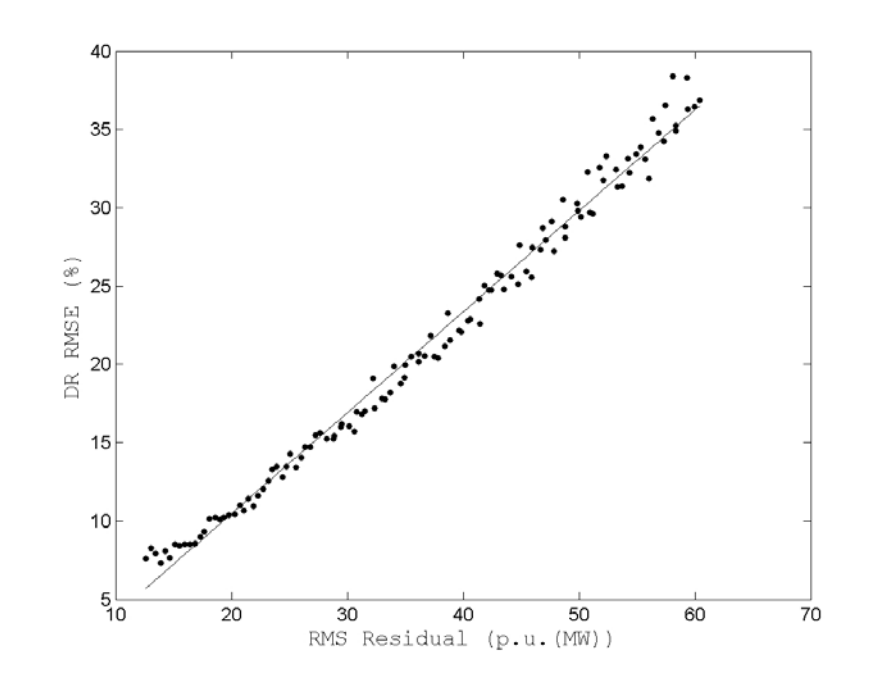
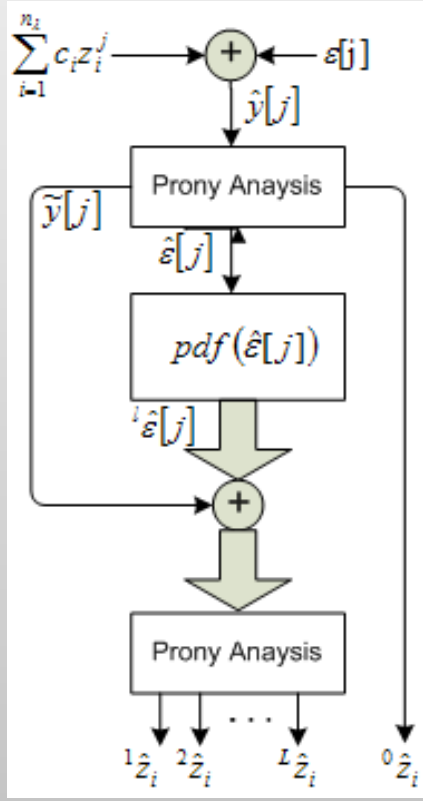


Fig. 3. Relationship between DR error and residuals for the 0.4220 Hz mode in the 17 machine model*.



*Jim Follum, Ning Zhou and John Pierre, "Evaluation of Mode Estimation Accuracy for Small-Signal Stability Analysis," North American Power Symposium, August 4-6, 2011, Boston, MA

Past Accomplishments

- Working with MT &UW, developed a prototype tool for detecting **ringdown responses** for modal analysis. The tool was installed in BPA laboratory to test its performance using field measurement PMU data;
- Working with MT &UW, developed a prototype tool for using **mode meter** algorithms. The tool was installed in BPA laboratory to test its performance using field measurement PMU data;
- Developed **a tool** for converting matlab data into dst format so that comparison can be made with different mode meter algorithms.
- Developed several **algorithms** for analyzing modes using PMU measurement;
- Published several journal and conference **papers** (the prize paper of the IEEE PES PSDP Committee in 2009);

Technical Accomplishments in FY12

- RD&D stage: Prototype/Field demonstration.

- Publications
  - N. Zhou, J.W. Pierre, D.J. Trudnowski, “A Stepwise Regression Method for Estimating Dominant Electromechanical Modes,” *IEEE Transaction on Power Systems*, vol. 27, no. 2, pp. 1051-1059, May 2012.
  - J.W. Pierre, D. Trudnowski, M. Donnelly, N. Zhou, F.K. Tuffner, and L. Dosiek, “Overview of System Identification for Power Systems from Measured Responses,” Proceedings of the International Federation of Automatic Controls (IFAC) Symposium on System Identification (SYSID), July 2012. (Invited Paper)
- Reviewed the running logs of the ringdown detection prototype tool running in BPA Lab and identified the needs to improve the robustness
- Revised and repacked the code for reading *.dst files
- Participated the ‘WISP modemeter’ project discussions and provided technical consultation and support

Planned Studies in FY 12

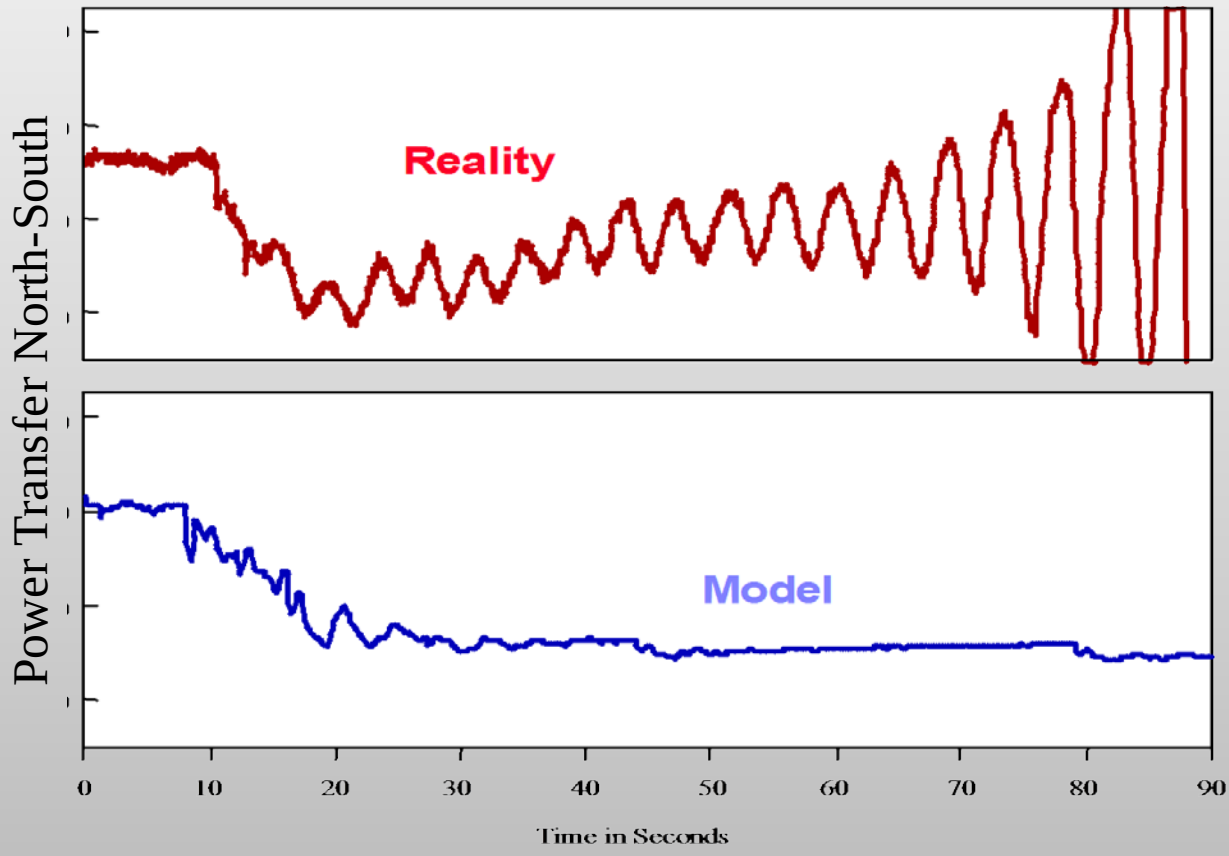
- Improve the robustness of modal analysis algorithms through enhancing noise models;
- Develop algorithms to balance between the mode tracking capability and mode estimation accuracy so that more informative modal estimation results can be generated;
- Improve ringdown analysis algorithm based on the running logs of the ringdown analysis prototype tool running in BPA lab;
- Support the WISP mode meter project by providing technical consultations;
- Support WECC probing tests;
- Explore opportunities to work with grid operators in the eastern interconnection on their oscillation problems.

Technical Transfer

- Work with industrial experts from BPA to get advise and align the studies to the needs.
- Bi-week conference call to get inputs.
- Support “WISP modemeter” project to develop production-grade modal analysis code;

Questions?

Measurements vs. Model Simulation



Initial Results from the Comprehensive Simulation Model using Component-based Modeling Method

[1] Kosterev, D. N., C. W. Taylor, and W. A. Mittelstadt, "Model Validation for the August 10, 1996 WSCC System Outage," IEEE Transactions on Power Systems, vol. 14, no. 3, pp. 967-979, August 1999.

Early Warnings based on PMU data