DOE/OE Transmission Reliability Program

Mode Meter Development

Presenter: Ning Zhou

Pacific Northwest National Laboratory

ning.zhou@pnnl.gov

27/28 June 2013

Washington, DC

CERTS

CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Work Team

- PNNL Team
  - Ning Zhou
  - Frank Tuffner
- 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:

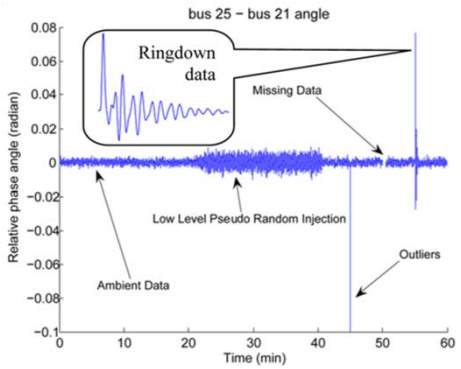
Mode Identification

- Problem formulation:
  - Lightly damped mode => growing oscillations => system breakup => large scale outage
  - Low confidence in oscillatory modes => conservative operation => lower asset utilization

- Objective:
  - Enhance the power system reliability by estimating oscillatory modes using PMU data.

Technical Approaches

- Modal Analysis from ringdown data:
  - Applicable after significant transient
  - Quickly detect lightly damped modes

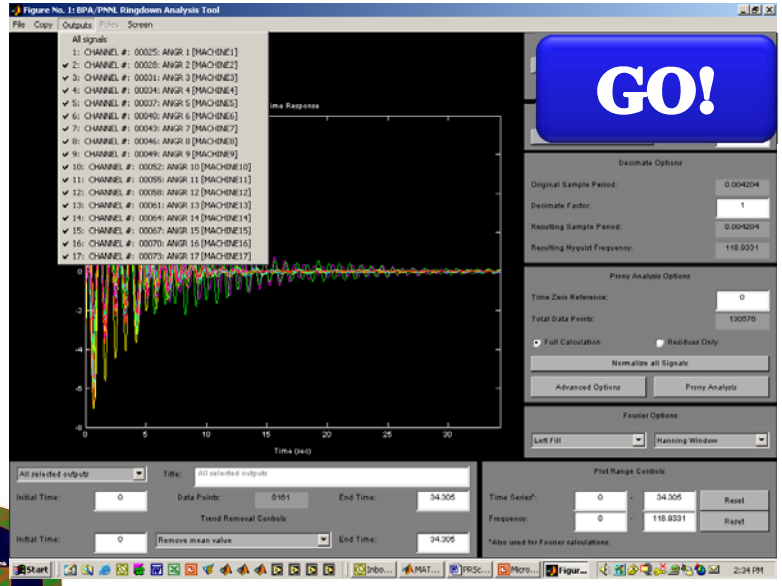


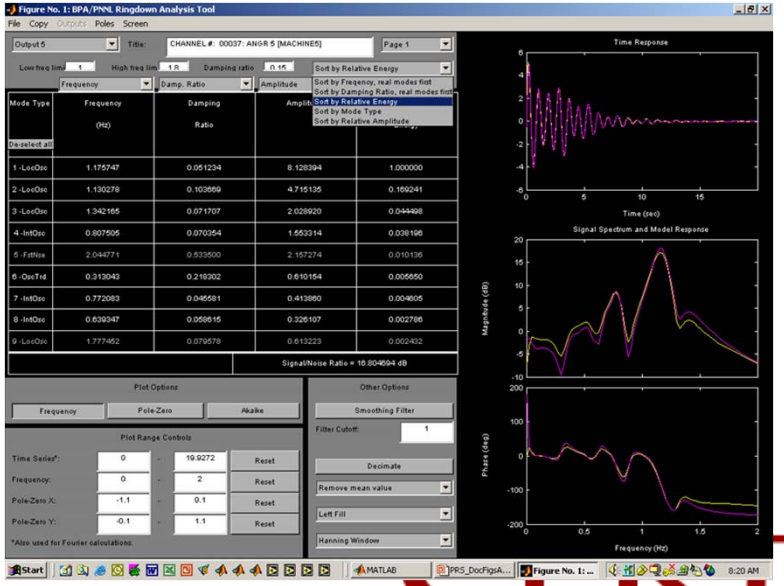
1. Detect Ringdown
2. Select Channels
3. Modal Analysis
4. Select Dominant Modes
5. Quantify the Uncertainty

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

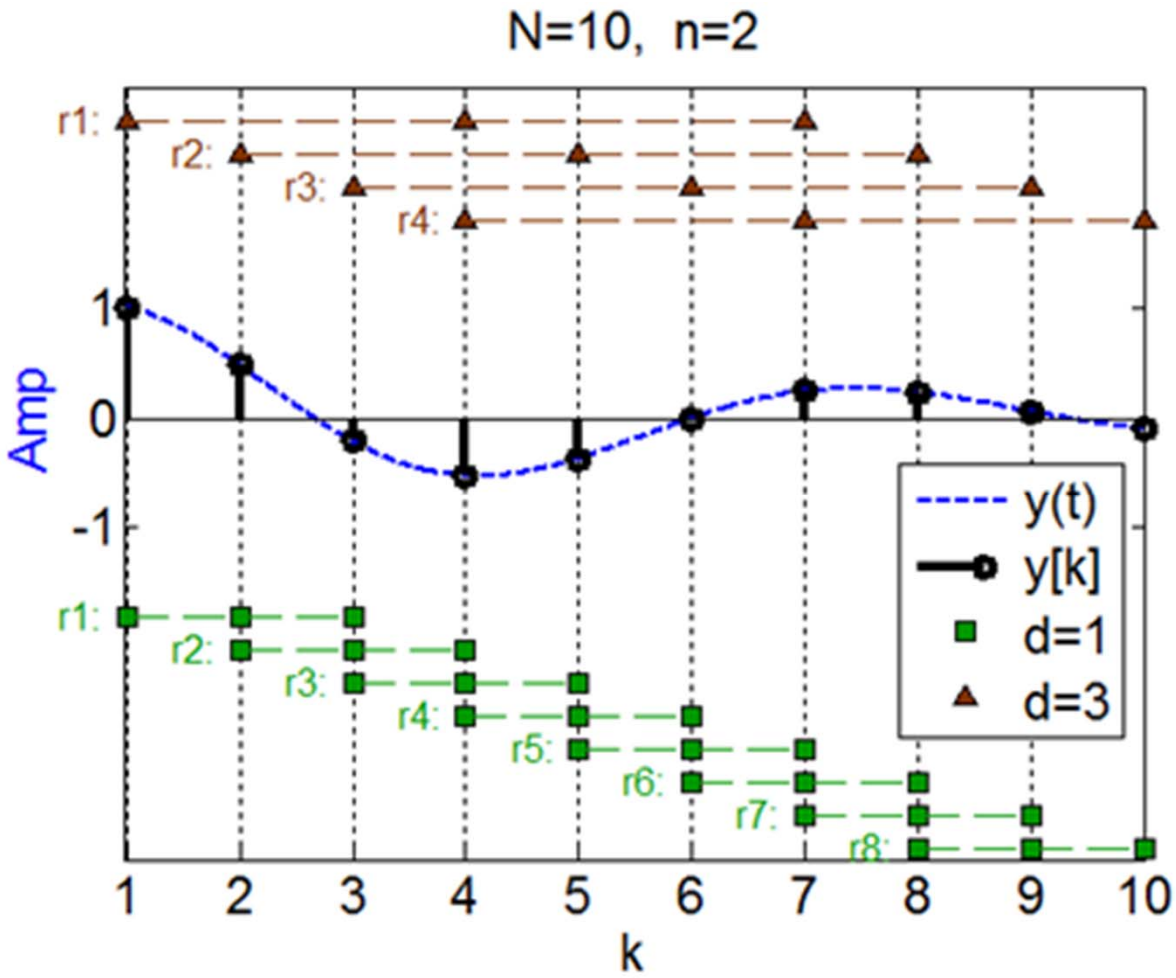
Challenges

- Many user choices
  - Data (***N, ch***)
  - Decimation factors (***d***)
  - Model orders (***n***)
  - Solvers of prediction equations (***LS***, ***TLS***, ***PE***)
  - Dominant modes and trivial modes





The Decimation Method

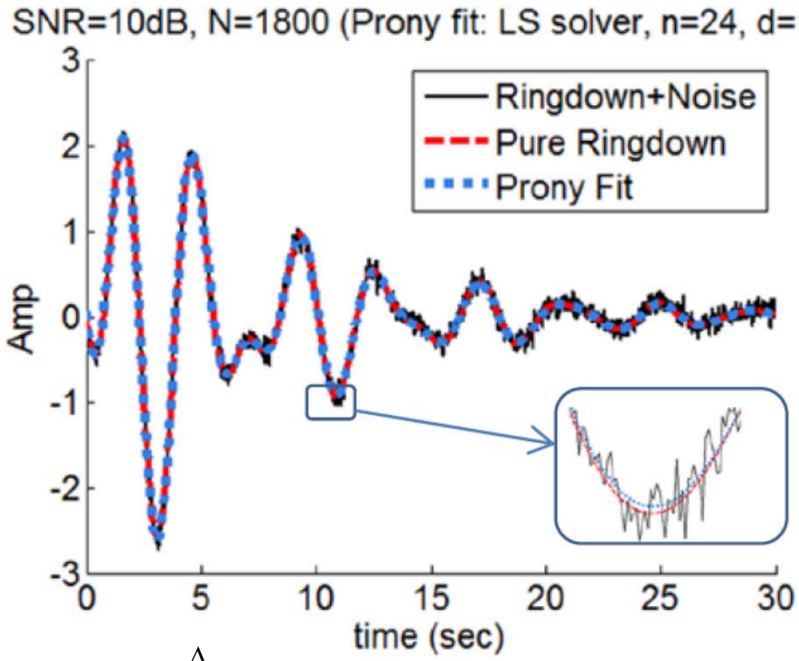


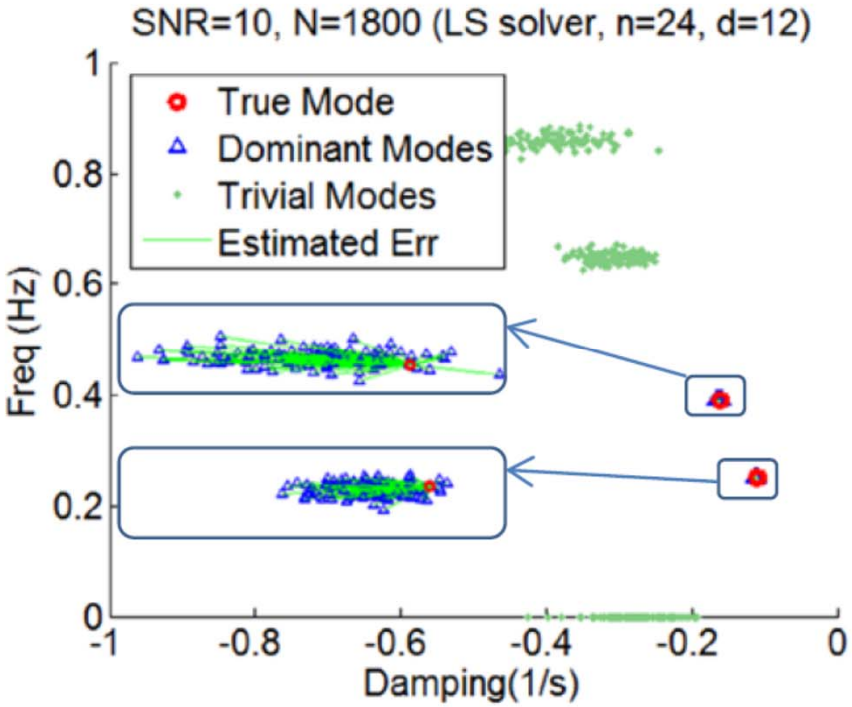
CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Metrics for Evaluating Performance

$$\hat{y}(t) = 2e^{-0.1102t}\cos(1.5708t + 1.5\pi) + 2e^{-0.1596t}\cos(2.4504\,t + 0.5\pi) + \varepsilon(t)$$

60 samples/s



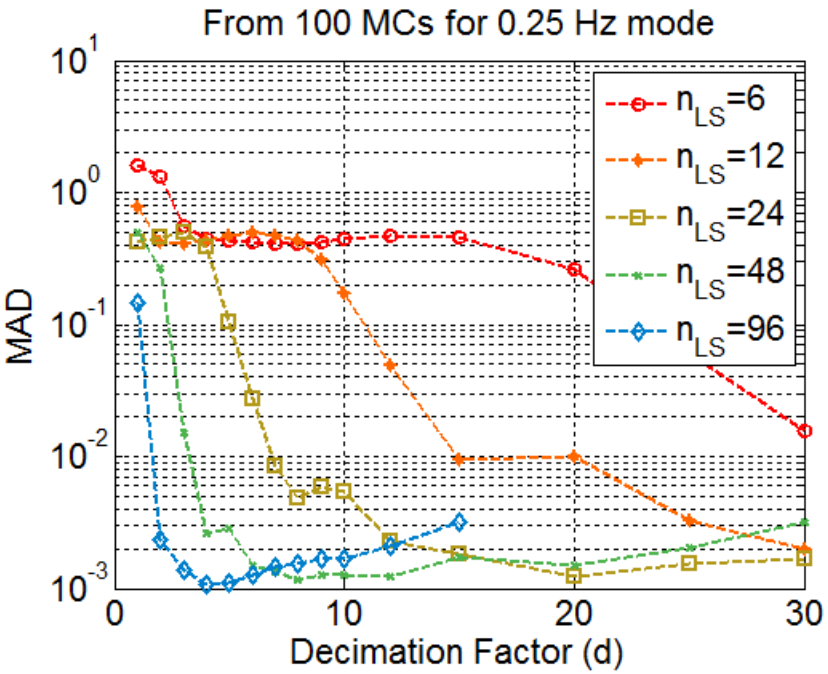


$$\hat{\varepsilon}[k] \stackrel{\Delta}{=} \hat{y}[k] - \tilde{y}[k]$$

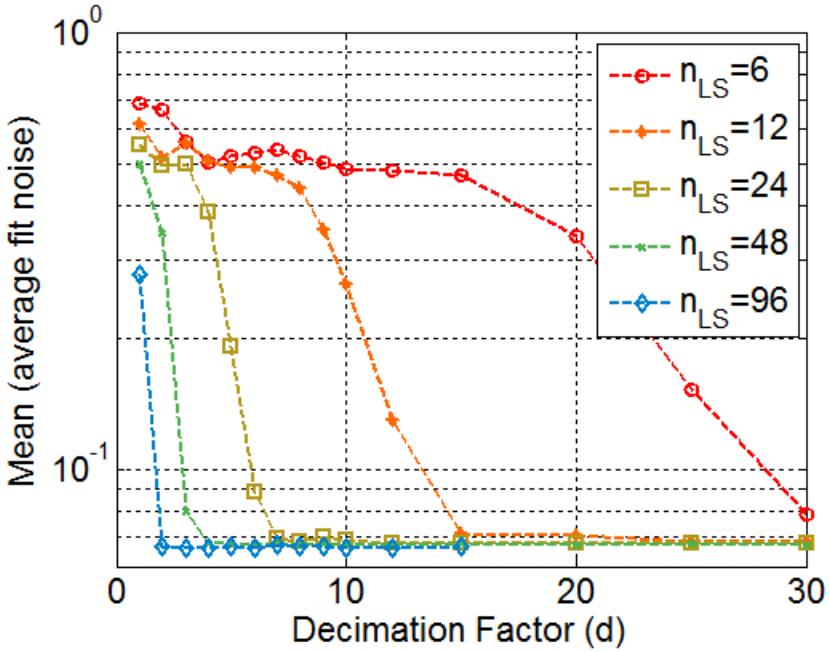
$$average\ \ fit\ noise \stackrel{\Delta}{=} \sqrt{\frac{1}{N}\sum_{k=1}^{N}(\hat{\varepsilon}[k])^2}$$

$$MAD(\hat{\lambda}_i) \stackrel{\Delta}{=} \underset{mc\in\{1,2,\cdots,100\}}{median}\left(\left|\hat{\lambda}_i(mc) - \lambda_{i,true}\right|\right)$$

Decimation (d) and Model Order (n)

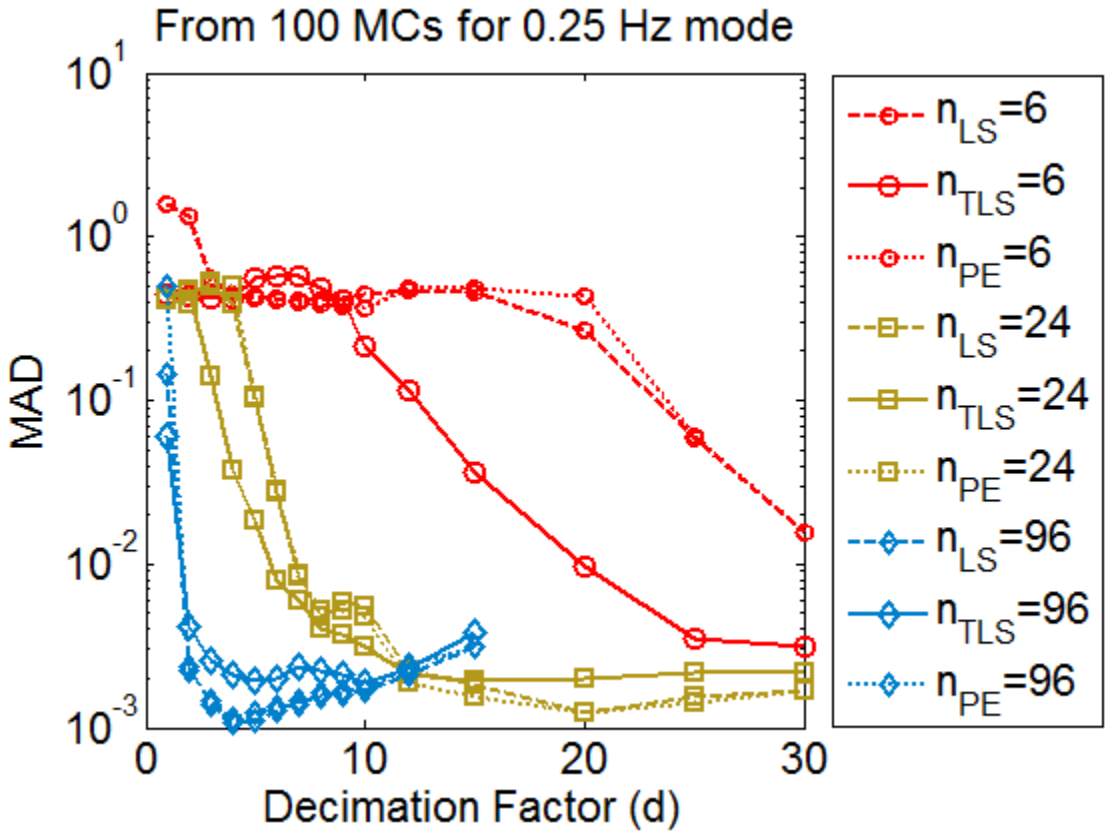


The MADs of 0.25 Hz mode estimates for different decimation factors (d) using the LS solver



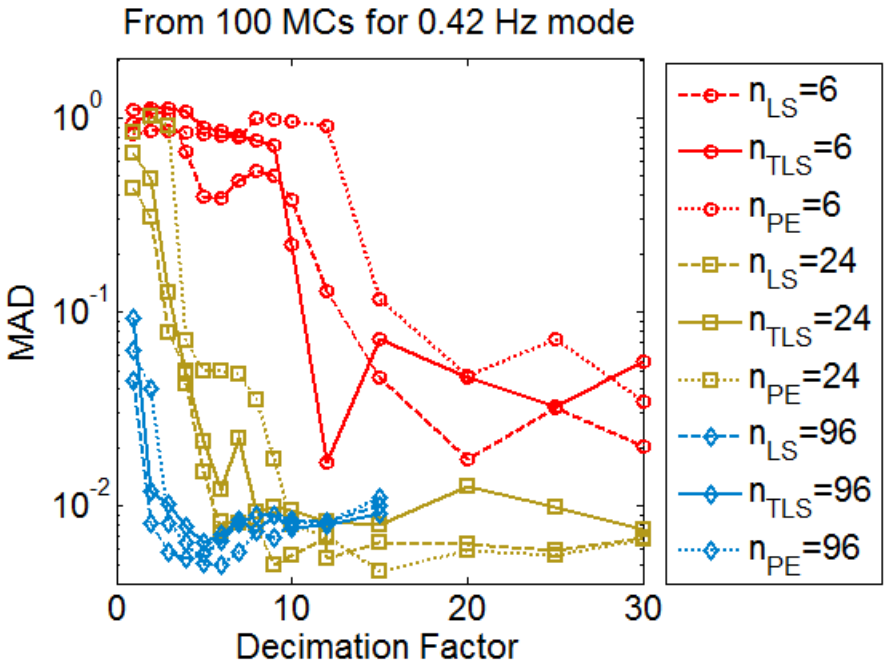
The mean value of average fit noise for different decimation factors (d) using the LS solver.

Solvers (LS, TLS, PE)

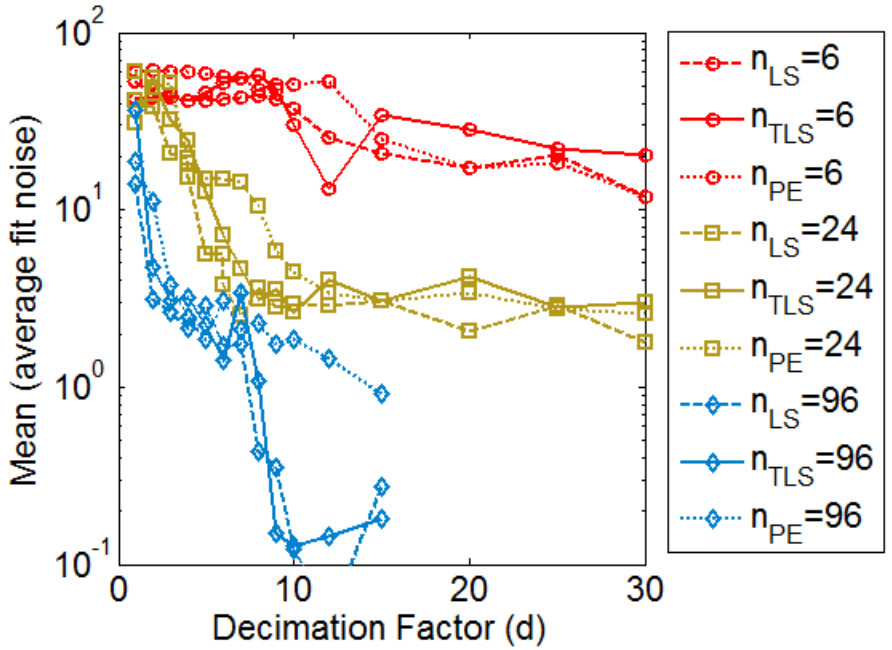


The MADs of 0.25 Hz mode estimates from **LS** (dashed lines), **TLS** (solid lines), and **PE** (dotted lines) solvers for the simple model.

Results from a 17-machine Model



The MADs of 0.42 Hz mode from LS (dashed lines), TLS (solid lines), and PE (dotted line) solvers for the 17-machine model



The mean value of average fit noise using LS, TLS, and PE solvers.

Summary

- *d* and *n* shall be increased until the fit noise cannot be significantly reduced;
- The lower bound of *d* shall be determined by the bandwidth of ringdown responses;
- For high SNR, the difference between the LS, TLS and PE solvers is insignificant.

Major Technical Accomplishment

- Supported the *Montana Tech* and *University of Wyoming* in deploying MM at WECC as part of the WISP II grant
- 1 paper accepted by IEEE PES GM 2013 as one of the ***Best Papers*** on Network Analysis and Dynamic Performance
  - **Ning Zhou**, John Pierre, and Daniel Trudnowski, "Some Considerations in Using Prony Analysis to Estimate Electromechanical Modes,"
- 1 paper accepted by the Electric Power Components and Systems
  - Peng Zhang, **Ning Zhou**, Ali Abdollahi "A General Sub-space Least Mean Square Method for High-Resolution Power System Oscillation Mode Estimation,"

RD&D CYCLE:
4. Field demonstration
5. Pre-commercial

RD&D CYCLE:
3. Prototype
4. Field demonstration

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Deliverables and Schedules Under FY 13 Funding

- Obtain and collect some representative forced oscillation data (06/30/2013, 90%)
- In a proof-of-concept, develop and implement algorithms to detect forced oscillations and analyze system oscillation modes (09/30/2013, 10%)
- Evaluate the performance of the algorithms. (12/30/2013, 0%)
- Report the study results, and plan for future study. (03/31/2014, 20%)
  - WECC JSIS meeting, in WECC, Salt Lake City, 06/11-06/13/2013
  - 2 accepted papers

Risk Factors & Mitigation Approaches

- Major risks: Algorithm assumptions may NOT always hold well.
  - Design algorithms that are more robust
  - Make reasonable assumptions
  - Verify assumptions through residual analysis

Follow on work for FY14

- A hybrid approaches for modal analysis (Combine the information from models and data)
  - Improve estimation accuracy
  - Enable control strategies
  - Enable event diagnosis

Questions or Comments?

ning.zhou@pnnl.gov

509-372-6438

CERTS

CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS