OE Visualization and Controls Peer Review

Load Control for System Reliability
and
Measurement-Based Stability Assessment

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Presentation Outline

- Introduction
  - Goals, Enabling technologies, Overview
- Load Control
  - Activities, Status
- Stability Assessment
  - Activities, Status
- Wrap up
  - Related activities, Staff

Goals

- Research and develop technologies to improve T&D reliability
- Technologies
  - Real-time load control methodologies
  - Measurement-based stability-assessment

Enabling Technologies

- Load control enabled by GridWise technology (e.g. PNNL's GridFriendly appliance)
- Real-time stability assessment enabled by Phasor Measurement (PMU) technology

Project Overview

- Time line: April 18, 2006 thru April 17, 2008
- Funding:
  - DOE (FY06): $1,900k
  - Matching (Universities, Private): $475k
  - Total: $2,375k
- Research participants:
  - Academia: Montana Tech, Montana State University, University of Wyoming
  - Labs/private: Pacific Northwest National Laboratory (PNNL), NorthWestern Energy, Electric Power Group, MSE-TA.
- Other Collaborators: Bonneville Power Administration, PNNL
- Advisory board: BPA, WAPA, PNNL, NorthWestern Energy, NETL, DOE

Tasks

- **Task 1**: Load control strategies
- **Task 2**: Measurement-based stability assessment
- **Task 3**: Laboratory development

Task 1 – Load control

- **Goal**: Develop and demonstrate control strategies for extracting the optimal benefits from intelligent loads for improving T&D reliability
- Issues to be considered are
  - **Subtask 1.1**: Angle stability and frequency regulation
  - **Subtask 1.2**: Voltage regulation and stability
  - **Subtask 1.3**: Power quality
  - **Subtask 1.4**: Frequency measurement feasibility
- **Major Milestones**
  - Develop load control strategies
  - Demonstrate strategies via computer simulation or bench-scale testing
  - Determine feasibility and methods of distribution level frequency measurement

Task 1 – Load control goals

- **Subtask 1.1**: Improve system angle stability and frequency regulation
  - Develop modeling and simulation tools
  - Develop load control strategies and concepts
  - Actual-system computer simulation case study
- **Subtask 1.2**: Improve system voltage regulation and stability
  - Develop modeling and simulation tools
  - Develop load control strategies and concepts
  - Actual-system computer simulation case study
- **Subtask 1.3**: Design a Reactive and Harmonic Current Compensator.
  - The compensator circuit will reduce the harmonic content of a load and provide reactive power support
  - The goal is to build and demonstrate a working prototype
- **Subtask 1.4**: Conduct a wide-based frequency measurement study
  - Results of the study will provide information on load control feasibility and new signal measurement technology

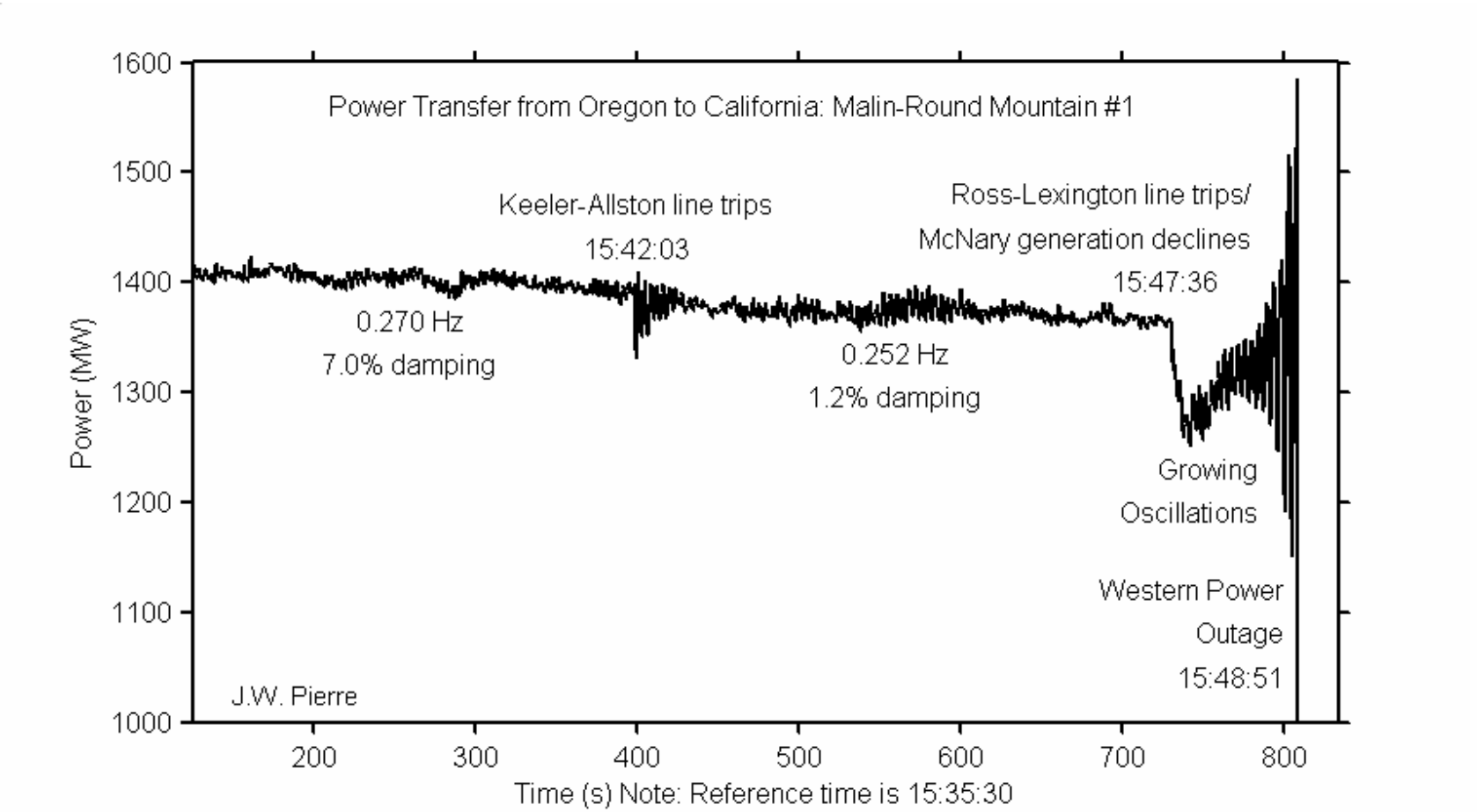
Task 1 – Current status

- **Subtask 1.1**:
  - Work is being coordinated with similar research at PNNL
  - Simulation tool has been developed
  - Control strategies have been hypothesized and are currently being tested on reduced-order systems
- **Subtask 1.2**:
  - For voltage control, the load model is critical
  - A dynamic model that will predict the power demand of aggregate water heaters is currently being developed
- **Subtask 1.3**:
  - Limitations of modern compensators have been reviewed
  - New circuit topology has been developed
    - Simulations currently being conducted
- **Subtask 1.4**:
  - A synchronized frequency sensor circuit has been develop
  - Circuit and measurement systems are currently being designed and tested

Task 2 - Measurement-based stability assessment

- **Goal**: Develop and demonstrate measurement-based real-time stability assessment tools that may be used by grid operators to improve system reliability and asset utilization
- **Subtask 2.1**: Electromechanical algorithms (i.e., “mode-meter”)
- **Subtask 2.2**: System control and monitoring tools
- **Subtask 2.3**: Voltage stability assessment
- **Research Group**: Mr. Bill Mittelstadt (BPA), Dr. John Hauer (PNNL), Dr. Henry Huang (PNNL), Dr. Manu Parashar (EPG), Dr. John Pierre (UW), Dr. Ning Zhou (PNNL), Trudnowski (Tech)
- **Builds upon 20+ years of research**
- **Major milestones**
  - development and demonstration of algorithms for accurate and fast mode estimation
  - testing mode-meter concept systems in operation and control centers

August 10, 1996 Outage



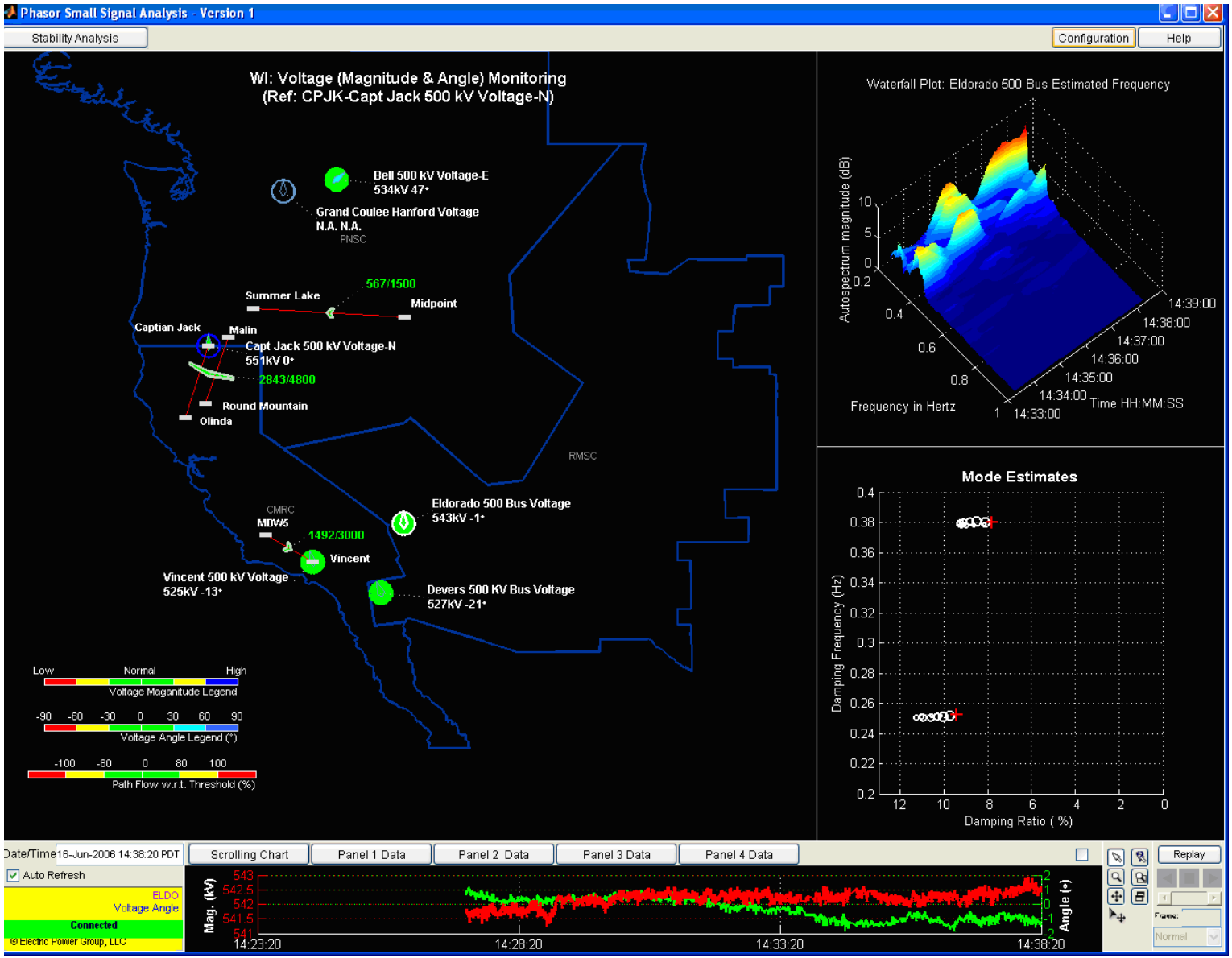
Task 2 - Goals

- **Subtask 2.1:** Refine, develop, and evaluate methods for estimating mode frequencies, damping, and shape, including error bounds, from measured data.
  - Both ambient and probing conditions shall be considered
  - Advanced signal processing
  - Issues: Accuracy, Window size, Data Type
- **Subtask 2.2:**
  - Transfer useful results from subtask 2.1 to industry
  - Develop and test prototype mode-meter tools
    - Certified code
    - Performance evaluation (Monte-Carlo testing, Real system testing)
- **Subtask 2.3**: Scope approaches for assessing system voltage stability properties using measured data

Task 2 – Current status

- **Subtask 2.1**:
  - Have developed 5 mode estimation algorithms for ambient data
  - Have developed 1 mode estimation algorithm for probing data
  - Currently developed error bounding algorithms
  - Currently developing mode shape estimation algorithms
- **Subtask 2.2**:
  - Developed, tested, and certified code for Yule Walker (YW), Yule Walker with spectral analysis (YWS), and Sub-space ID (N4SID) algorithms
  - Developing web page for posting certified code and related publications
  - Formed partnership with EPG for development of mode-meter in the RTDMS
  - First version of mode-meter has been implemented in RTDMS and presented at the Sep. 2006 EIPP meeting

RTDMS


Phasor Small Signal Analysis - Version 1
Stability Analysis
Configuration
Help
WI: Voltage (Magnitude & Angle) Monitoring
(Ref: CPJK-Capt Jack 500 kV Voltage-N)
Bell 500 kV Voltage-E
534kV 47•
Grand Coulee Hanford Voltage
N.A. N.A.
PNSC
Summer Lake
567/1500
Midpoint
Captian Jack
Malin
Capt Jack 500 kV Voltage-N
551kV 0•
2843/4800
Round Mountain
Olinda
RMSC
CMRC
MDW5
1492/3000
Vincent
Vincent 500 kV Voltage
525kV -13•
Eldorado 500 Bus Voltage
543kV -1•
Devers 500 KV Bus Voltage
527kV -21•
Low
Normal
High
Voltage Maganitude Legend
-90 -60 -30 0 30 60 90
Voltage Angle Legend (°)
-100 -80 0 80 100
Path Flow w.r.t. Threshold (%)
Waterfall Plot: Eldorado 500 Bus Estimated Frequency
Autospectrum magnitude (dB)
Frequency in Hertz
Time HH:MM:SS
14:33:00
14:34:00
14:35:00
14:36:00
14:37:00
14:38:00
14:39:00
Mode Estimates
Damping Frequency (Hz)
Damping Ratio (%)
Date/Time 16-Jun-2006 14:38:20 PDT
Auto Refresh
ELDO
Voltage Angle
Connected
© Electric Power Group, LLC
Scrolling Chart
Panel 1 Data
Panel 2 Data
Panel 3 Data
Panel 4 Data
Replay
Mag. (kV)
Angle (°)
14:23:20
14:28:20
14:33:20
14:38:20

Task 3 – Laboratory Development

- Scope and design a laboratory to teach and conduct research on intelligent power-system control issues
- **Major milestones**:
  - Development of a laboratory proposal

Key Staff

TASK	LEADER	SUPPORT	Collaboration	TOPIC
1				**Load Control**
1.1	New Faculty (Tech)	R. Shah (NorthWestern); Trudnowski (Tech)		Stability and frequency regulation
1.2	Nehrir (MSU)	D. Pierre (MSU); Trudnowski (Tech)		Voltage regulation
1.3	Gao (MSU)			Power quality
1.4	Morrison (Tech)	TBD (MSE); Trudnowski (Tech)		Frequency measurement feasibility
2				**Measurement-based stability assessment**
2.1	J. Pierre (UW)	Zhou (PNNL), Trudnowski (Tech)		Mode-meter algorithm development
2.2	Trudnowski (Tech)	Zhou (PNNL)	EPG, BPA	Mode-meter operation and control tools
2.3	Trudnowski (Tech)			Voltage stability assessment
3	Wahl (Tech)	TBD (MSE); Trudnowski (Tech)		**Energy lab design**

Publications

Task 1:

- D. Trudnowski, M. Donnelly, and E. Lightner, “Power-System Frequency and Stability Control using Decentralized Intelligent Loads,” *2005/2006 IEEE PES T&D Conference and Exposition*, Dallas, TX, May 2006.

Task 2:

- N. Zhou, J.W. Pierre, and D.J. Trudnowski, “A Bootstrap Method for Statistical Power System Mode Estimation and Probing Signal Selection,” *Proceedings of the IEEE Power Engineering Society General Meeting*, June 2006. (Invited Panel Paper).
- N. Zhou, J. W. Pierre, D. Trudnowski,R. Guttromson, “Robust RLS Methods for On-line Estimation of Power System Electromechanical Modes,” *IEEE Trans. on Power Systems*, (in review).
- D. J. Trudnowski, J. W. Pierre, N. Zhou, M. Parashar, J. F. Hauer, “Performance of Three Mode-Meter Block-Processing Algorithms for Automated Dynamic Stability Assessment,” *IEEE Trans. on Power Systems*, (to be submitted).

Comments and Questions?