# Wide-Area Small-Signal Stability Controller

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# Background

- PSERC S19 project
- Detection, Prevention and Mitigation of cascading events
- Detection: Mladen Kezunovic at Texas A&M
- Prevention: (this seminar)
- Mitigation: Vijay Vittal at Iowa State/ASU

# Project team at WSU

- Jaime Quintero, PhD thesis, 2005
- Jaime - now a professor at Universitad Autonama De Occidente, Cali, Columbia
- Guoping Liu, PhD student at WSU
- Guoping – a summer intern at Schweitzer Engg. Labs, Pullman, WA, summer 2005.

# Industry collaboration

- Carson Taylor, BPA
- Armando Guzman, SEL
- Floyd Galvan, Entergy (new project)
- Lisa Beard, TVA (new project)

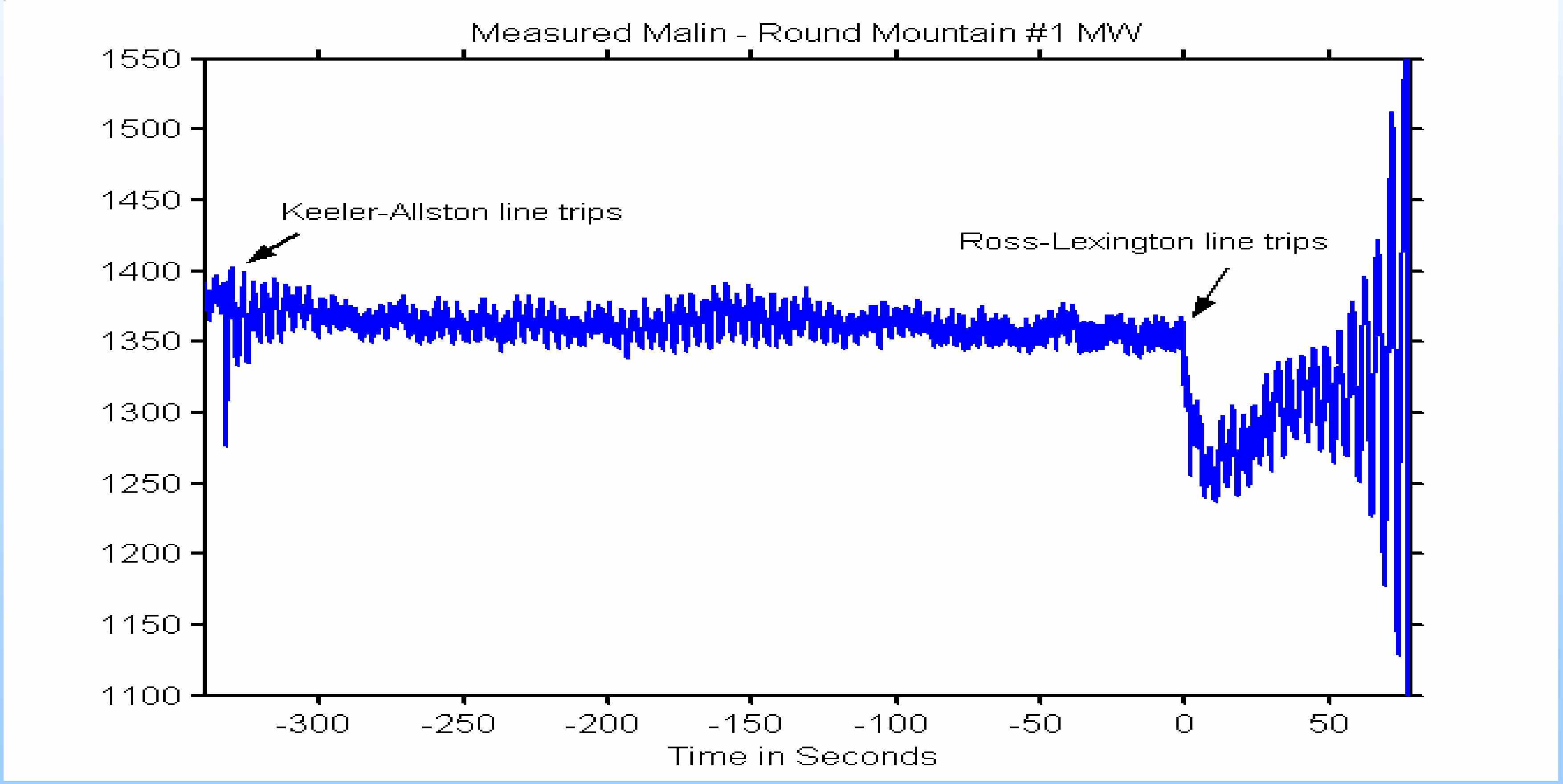
# Wide-area Real-time Controllers

- Slow voltage controller (AVC)
  - viability, voltage security
  - testing by NSR at BPA
- Small-signal stabilizing controller
  - small-signal stability, this seminar.
  - new project on prototype for Entergy/TVA
- Fast transient stability controller
  - first swing stability (WACS)
  - prototype at BPA

# Small-signal Stabilizing Controller

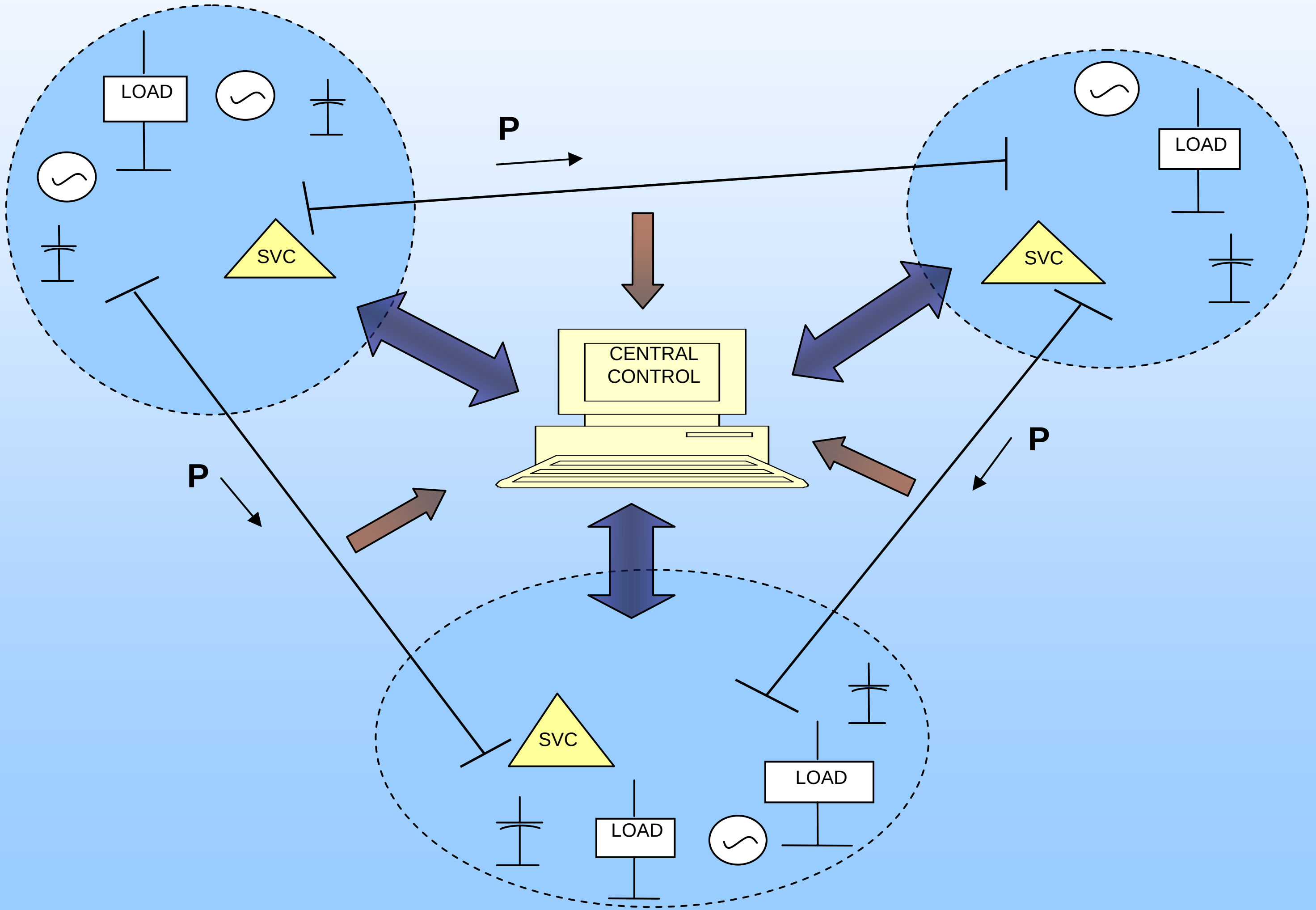
- One or more eigenvalues are poorly damped or negatively damped.
- Oscillations develop slowly over several swings.
- Sufficient time to detect oscillatory instability and to take corrective actions.
- Make sure there is a problem.
- Aggressive counteractions.
- Meant to buy some time for operator actions.
- Project funded by PSerc, BPA and CERTS
- PSerc project S19 from 2002 to 2005.
- S19 Extension on prototype implementations to start soon.

# Small-Signal Instability Example




**August 10, 1996 western electric black-out**

# Controller Framework



# Central Controller Algorithm

**Task 1) Oscillation Detection**

- Multi-Prony Analysis
- Matrix pencil algorithm
- Crosschecking crucial

**Task 2) SVC Selection**

- Off-line recommendations
- Real-time Coordination
- Sending or Receiving End

# SVC design for Inter-area Mode

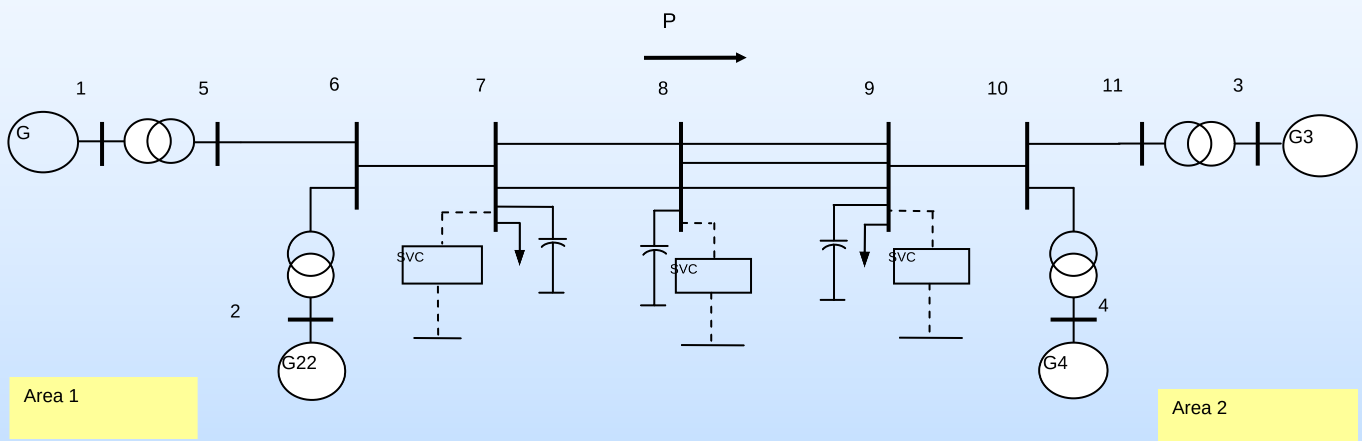
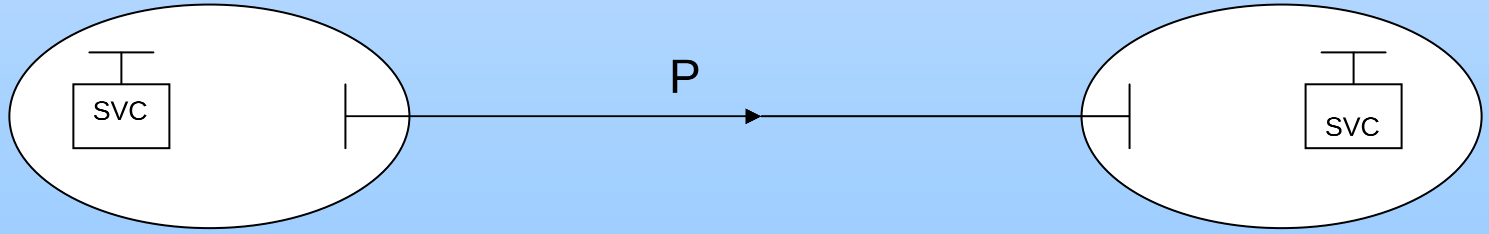



Fig. 3. Two-area Power System

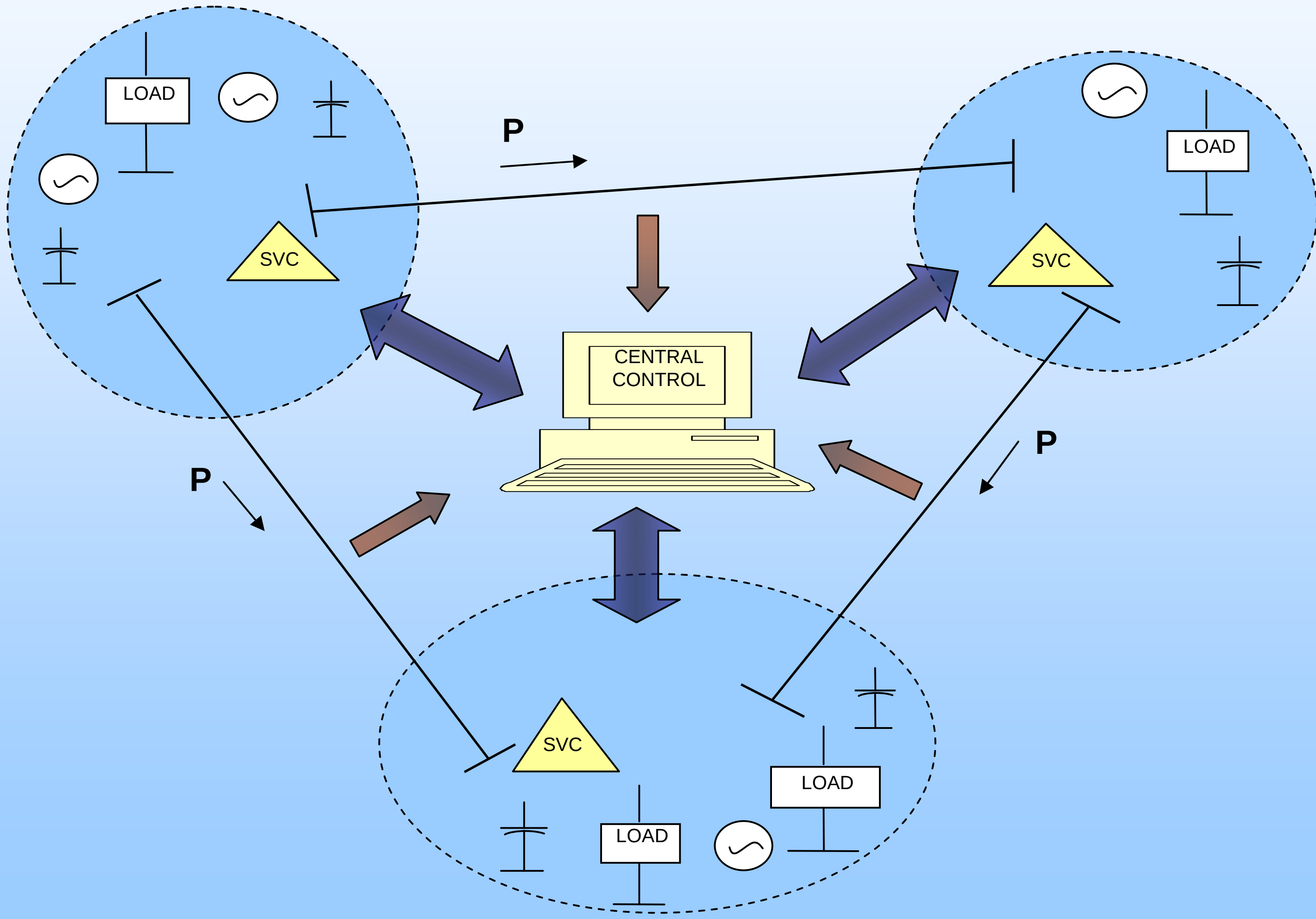
$$
\mathbf{J} = \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 \\
J_{21} & -\dfrac{K_{D1}}{2H_1} & J_{23} & 0 & 0 & a \\
0 & 0 & 0 & 1 & 0 & 0 \\
J_{41} & 0 & J_{43} & -\dfrac{K_{D2}}{2H_2} & 0 & b \\
J_{51} & 0 & J_{53} & 0 & -\dfrac{1}{T_{2LP}} & c \\
J_{61} & 0 & J_{63} & 0 & d & e
\end{bmatrix}
$$

# SVC Control Design

- Stressed Operating Condition
- Near-by tie line active power-flow used as control input
- Sending end => Phase Lag Compensator
- Receiving end => Phase Lead Compensator



# Controller Framework



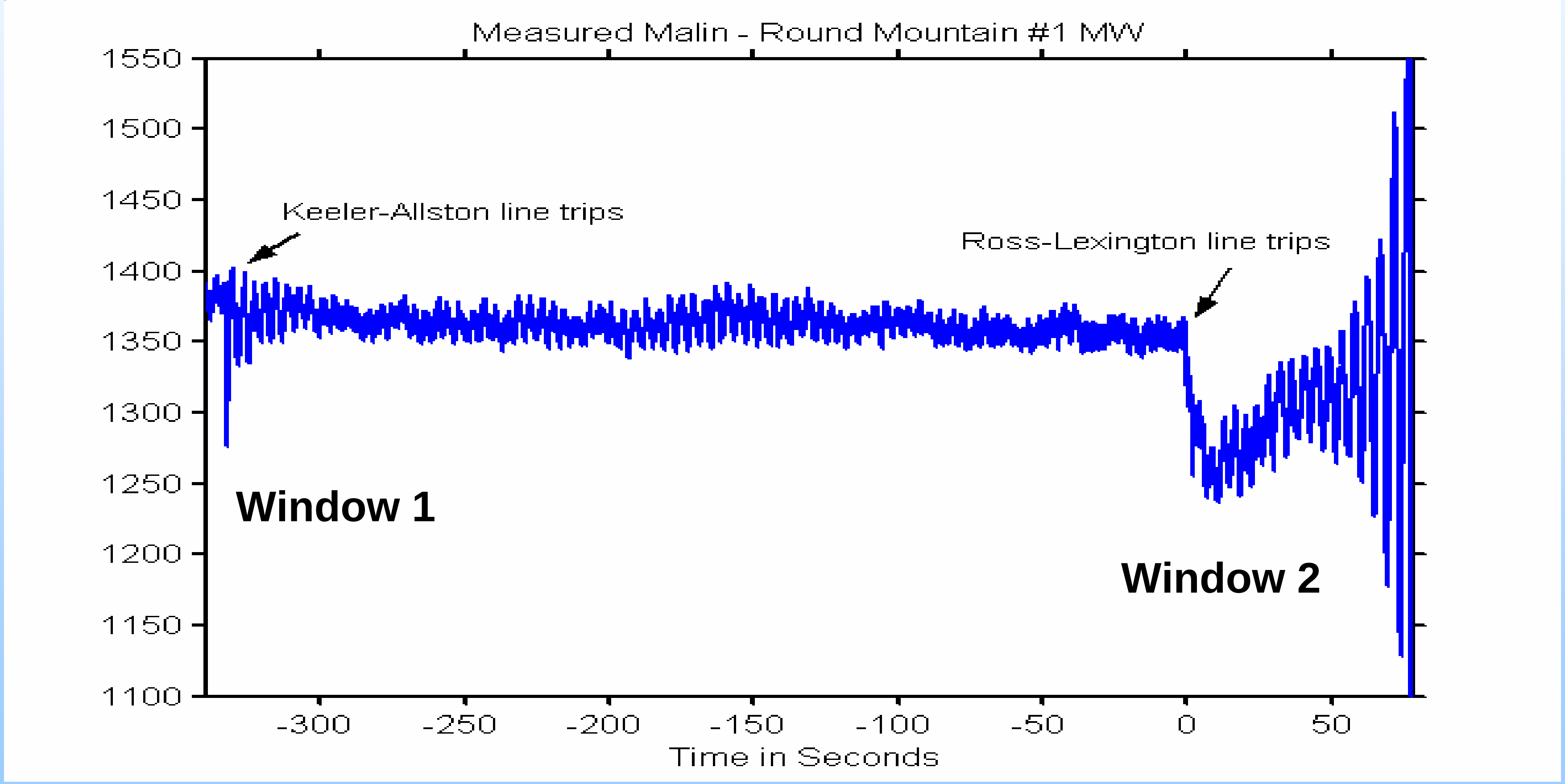
# Oscillation Detection

- Multi-Prony and Matrix pencil methods
- Designed for real-time monitoring
- Looks for linear modal responses
- Different groups of measurements
- Different moving time-windows
- Crosschecking crucial
- Helps rule out nonlinear responses
- Matlab toolbox available - Guoping.

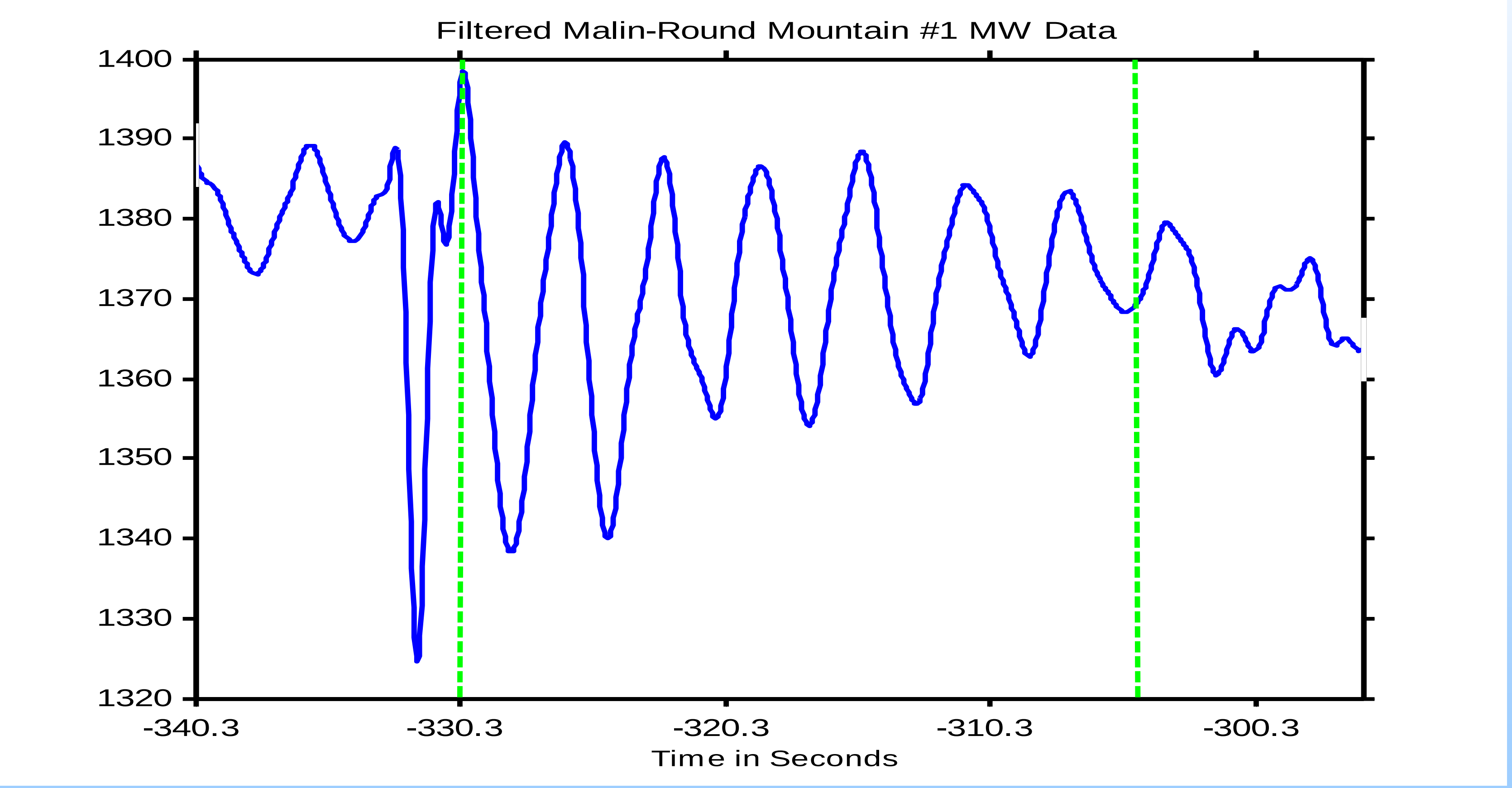
# Linear versus Nonlinear

- Linear dynamical system
- Any output – a linear combination of the basic modal responses, $e^{\lambda_i t}$
- Power system nonlinear
- Prony valid for small perturbations
- Too small – noisy?
- Too large – nonlinear?
- Discrete switching effects?
- Reliable rules needed for real-time applications.

# August 10, 1996 test data



# Window 1 Analysis



# Window 1 Prony results

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TABLE XI
MULTI-PRONY COI MODE DAMPING
ESTIMATION IN PERCENT
CASE 1 [a]

| Time Window in Seconds [b] | $P_{mr1}$, $P_{bound}$ and $f_{tacoma}$ | $P_{custer}$, $V_{malin}$ and $P_{coulee}$ | Average | < 2 % Difference |
|---|---|---|---|---|
| -330.3 to -318.3 | 5.0 | 5.6 | 5.3 | Yes |
| -328.3 to -316.3 | 4.5 | 5.4 | 4.9 | Yes |
| -326.3 to -314.3 | 0.4 | 2.3 | 1.3 | Yes |
| -324.3 to -312.3 | -0.4 | 0.0 | -0.2 | Yes |
| -322.3 to -310.3 | No Good Estimations | | Neglected | No |
| -320.3 to -308.3 | 1.6 | 1.0 | 1.3 | Yes |
| -318.3 to -306.3 | 3.0 | 2.3 | 2.6 | Yes |

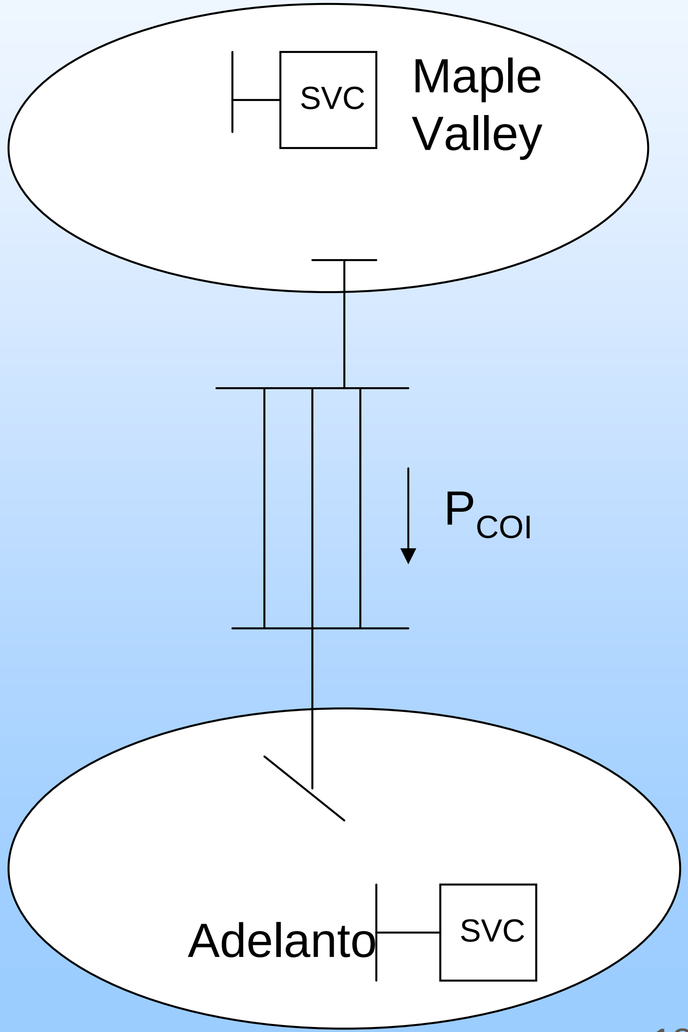
[a] Measured data taken just after Keeler-Allston line trips at -332.3 seconds.
[b] Time with respect to Ross-Lexington line trip.

Sampling frequency is 20 samples/sec. Prony estimation was calculated using the Ringdown GUI program from BPA/PNNL Dynamic System Identification (DSI) Toolbox. Signal mean values were removed. A smoothing filter with 1 Hz cutoff frequency was used.

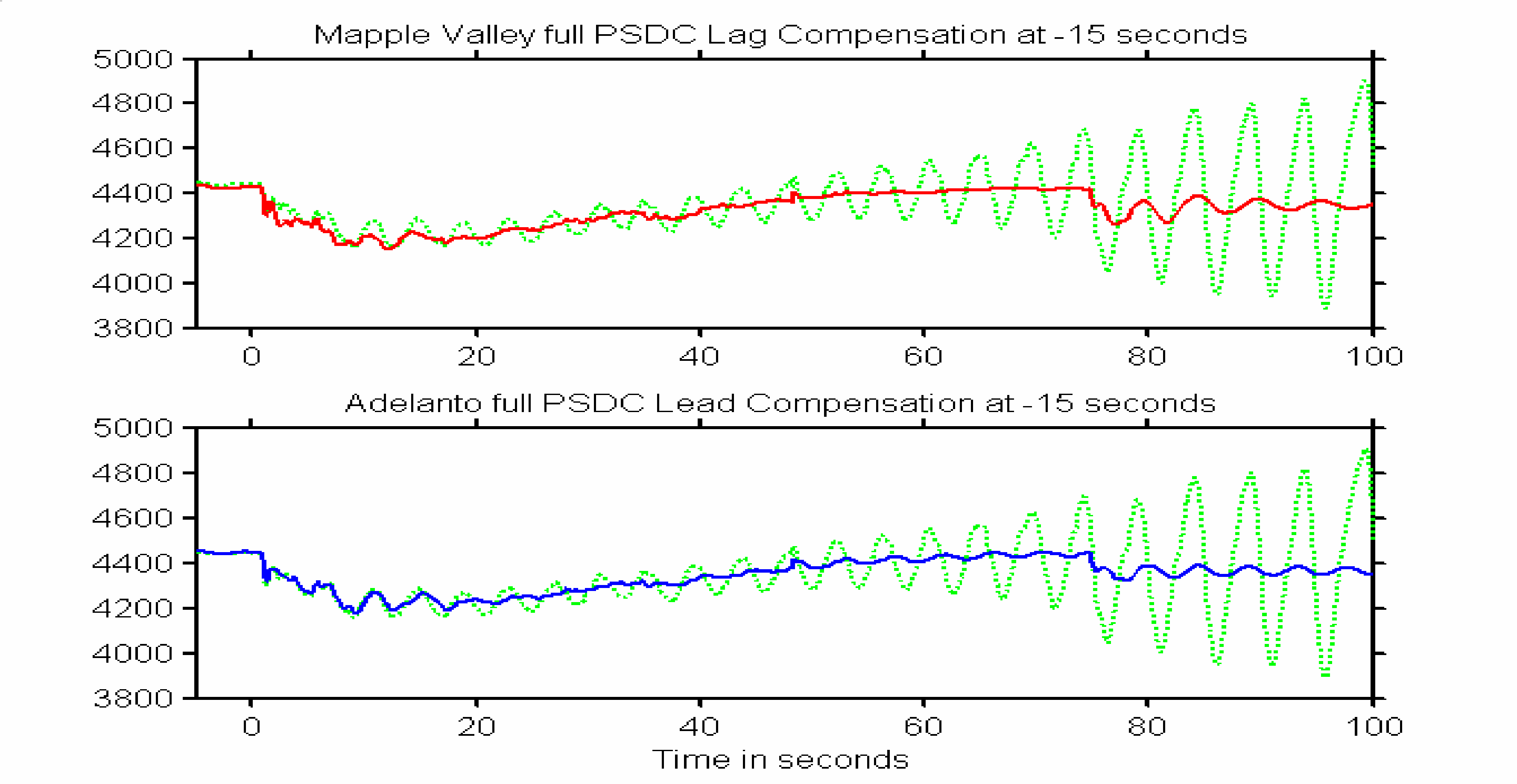
**Damping Trigger Set-Point at say +3% => Trigger @ -306.3**

# SVC PSDC Operations

- California-Oregon 500 kV active power-flow $P_{COI}$ used as control input
- Maple Valley (Seattle) – Sending End – Phase Lag Design
- Adelanto (Los Angeles) – Receiving End – Phase Lead Design
- Either SVC effective.

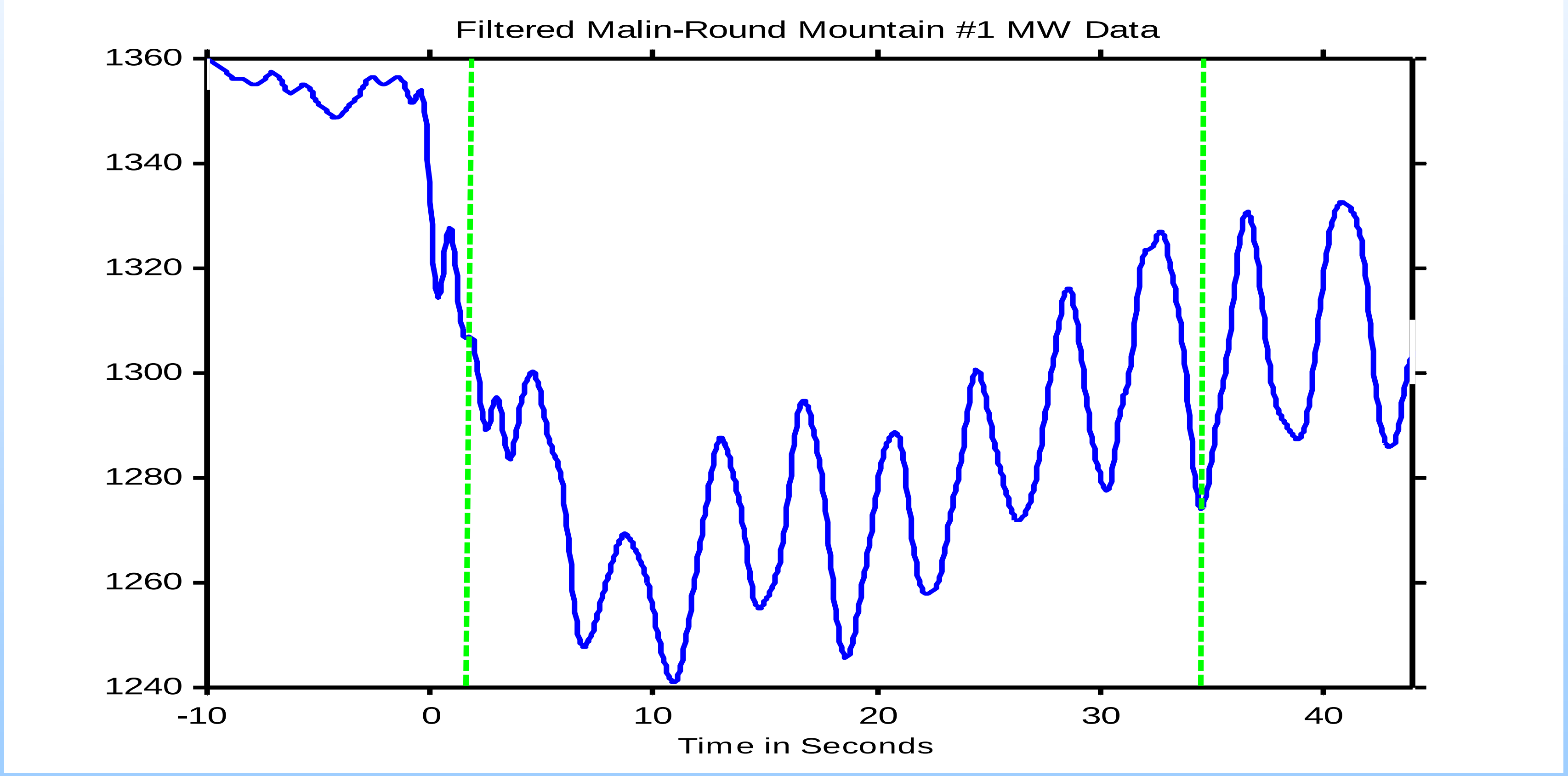


# SVC PSDC @ -300 secs.




**Instability prevented with either of the two SVC's in PSDC mode**

# Window 2 Analysis



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# Multi-Prony Analysis

TABLE XII
MULTI-PRONY COI MODE DAMPING
ESTIMATION IN PERCENT
CASE 2 [a]

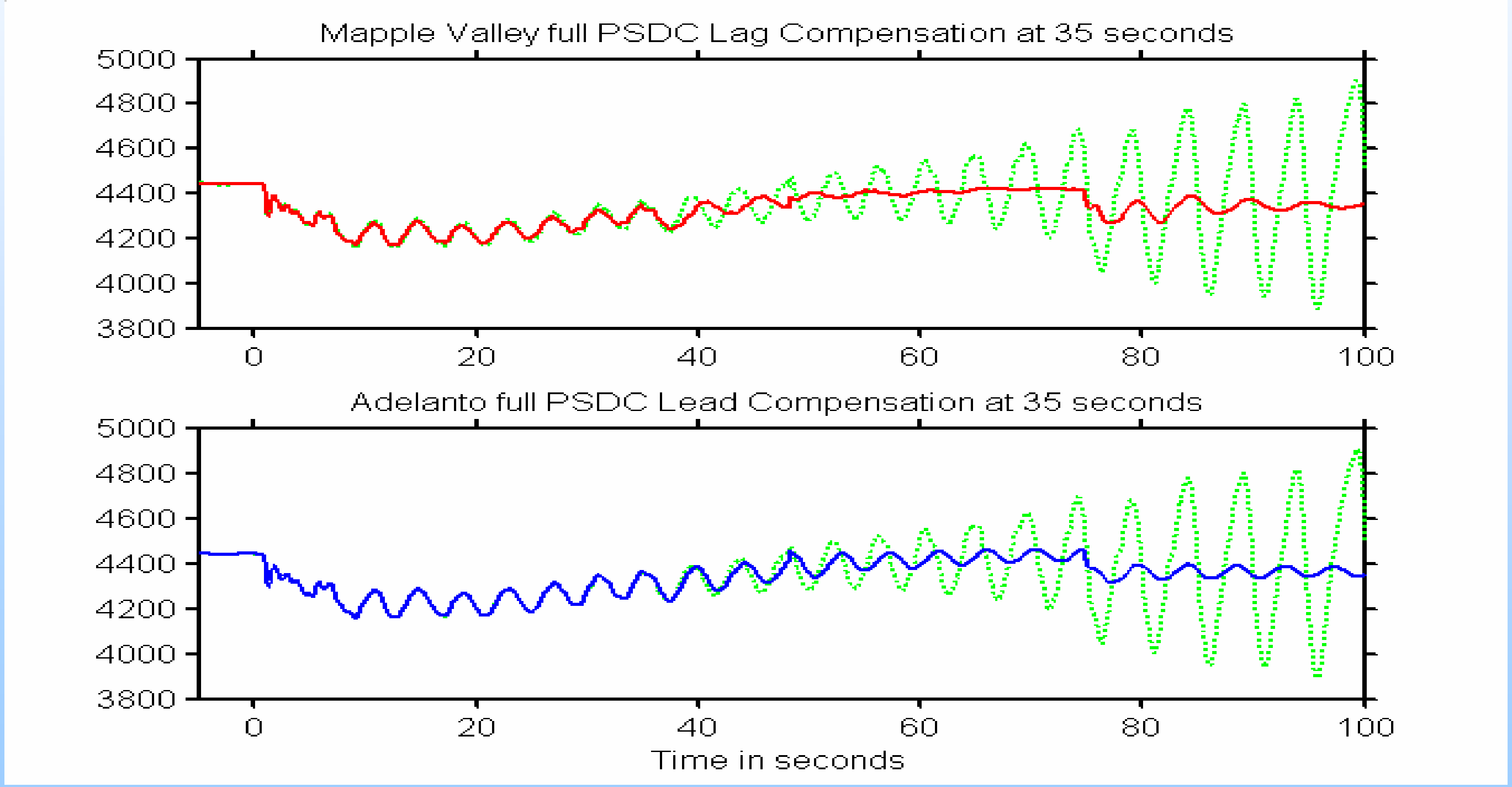
| Time Window in Seconds [b] | $P_{mr1}$, $P_{bound}$ and $f_{tacoma}$ | $P_{custer}$, $V_{malin}$ and $P_{coulee}$ | Average | < 2 % Difference |
|---|---|---|---|---|
| 2.0 to 14.0 | No Good Estimations | | Neglected | No |
| 4.0 to 16.0 | No Good Estimations | | Neglected | No |
| 6.0 to 18.0 | 1.0 | 1.1 | 1.0 | Yes |
| 8.0 to 20.0 | -0.9 | 0.2 | -0.3 | Yes |
| 10.0 to 22.0 | 0.0 | 0.8 | 0.4 | Yes |
| ... | ... | ... | ... | ... |
| 18.0 to 30.0 | No Good Estimations | | Neglected | No |
| 20.0 to 32.0 | -2.1 | -3.4 | -2.7 | Yes |
| 22.0 to 34.0 | -3.4 | -3.1 | -3.2 | Yes |

[a] Measured data taken just after Ross-Lexington line trips at 0.0 seconds.
[b] Time with respect to Ross-Lexington line trip.
Sampling frequency is 20 samples/sec. Prony estimation was calculated using the Ringdown GUI program from BPA/PNNL Dynamic System Identification (DSI) Toolbox. Signal mean values were removed. A smoothing filter with 1 Hz cutoff frequency was used.

**Damping Trigger Set-Point at +1% => Trigger @ 22 secs.**

**Set-point at -2% => Trigger @ 34 secs.**

# SVC PSDC Control @ 35 secs.




**Either of the two SVC's effective for stabilization**

# Features of GUI Matlab toolbox

- Prony or Matrix Pencil Method
- Continuous implementation of moving time windows
- Results can be plotted or tabulated
- Results can be saved into designated files
- Supports both .mat and .txt files
- Future support of BPA stream data
- Rules for real-time alarms and triggers
- Part of thesis work of Guoping Liu

# Controller Summary

- Prony and Matrix pencil algorithm rules for reliable real-time oscillation detection.
- SVC PSDC design rules for real-time implementation.
- Sending or Receiving => Lag or Lead.
- New rules for HVDC modulation - Guoping.
- Closed loop supervision for coordination.
- Safety net type wide-area control.
- Effective in large scale simulations.
- Matlab toolbox under development.
- Controller testing on Entergy and TVA systems in the new PSERC project.