

Wide-Area Small-Signal Stability Controller

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A thick, horizontal yellow brushstroke is positioned across the middle of the slide, below the author's name and affiliation.

PSERC Tele-Seminar

April 4, 2006

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 Universidad Autonoma 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)**

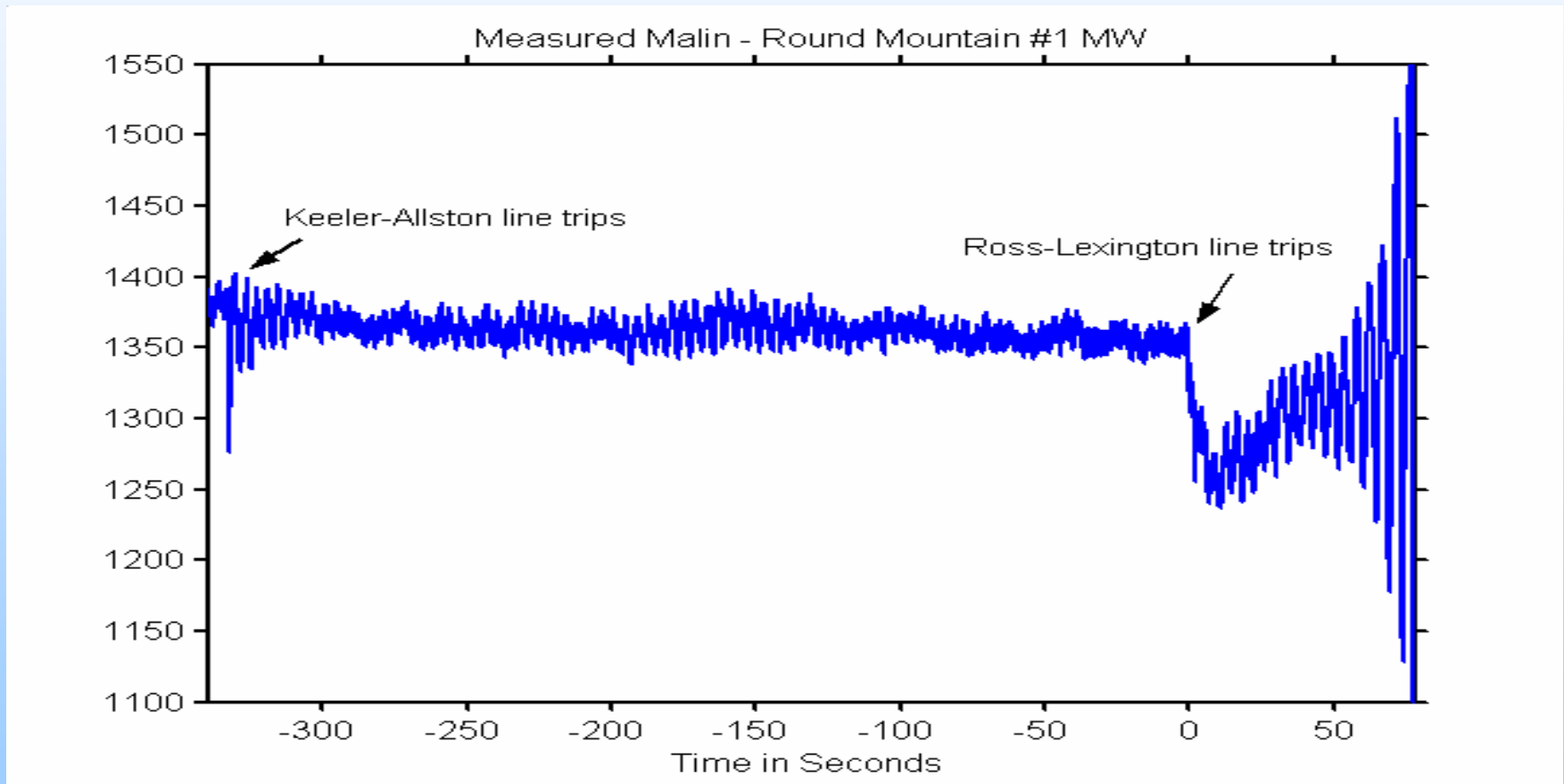
Wide-area Real-time Controllers

- **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

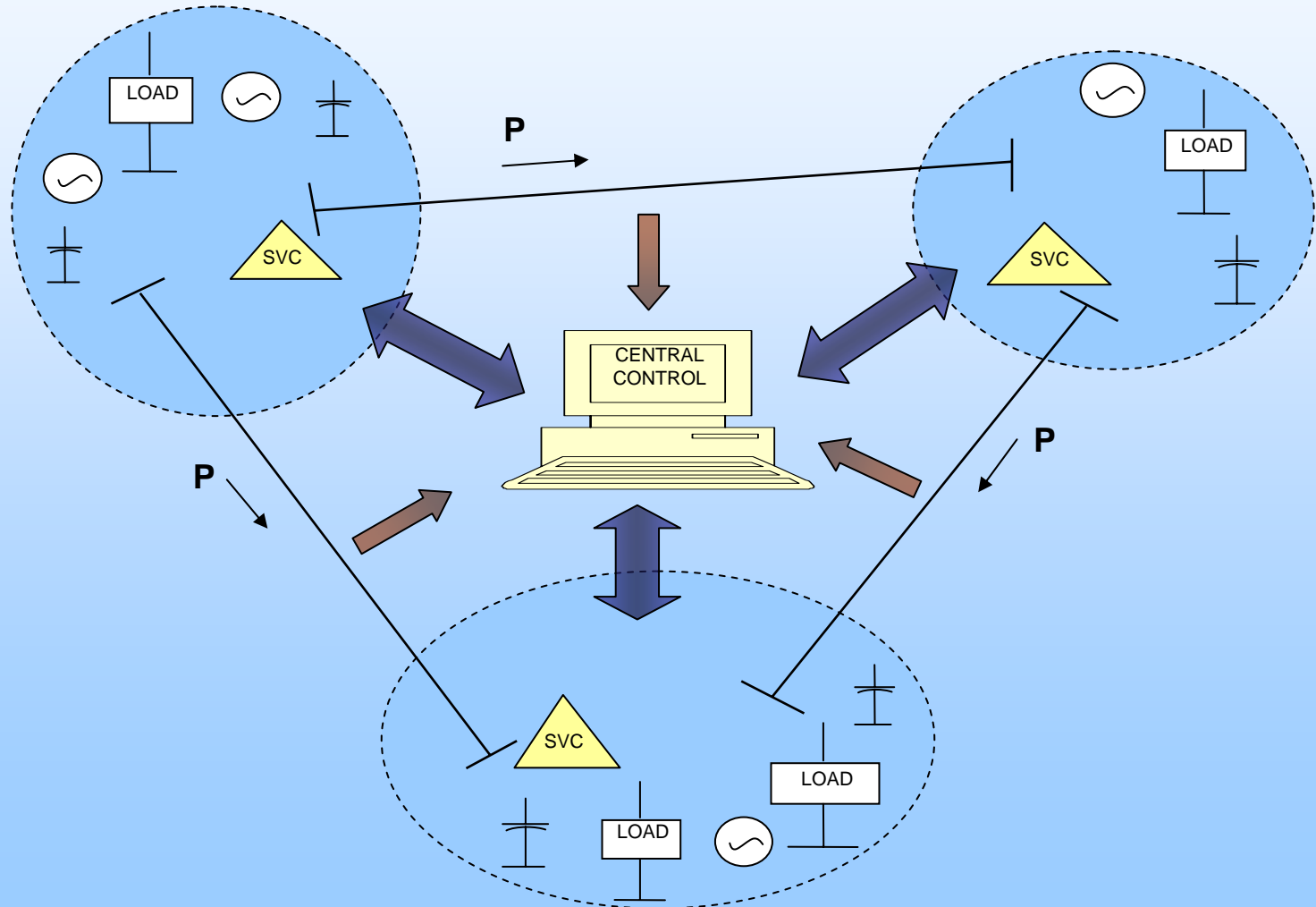
- One or more eigenvalues are poorly damped or negatively damped.
- Oscillations develop slowly over several swings.
- Sufficient time to detect oscillatory instability and to take corrective actions.
- Make sure there is a problem.
- Aggressive counteractions.
- Meant to buy some time for operator actions.
- 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

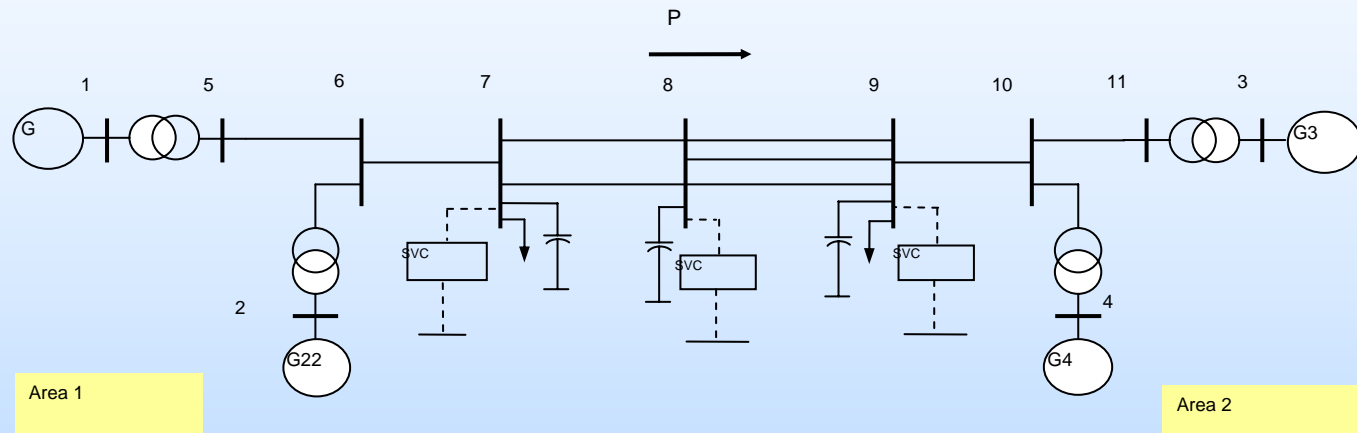
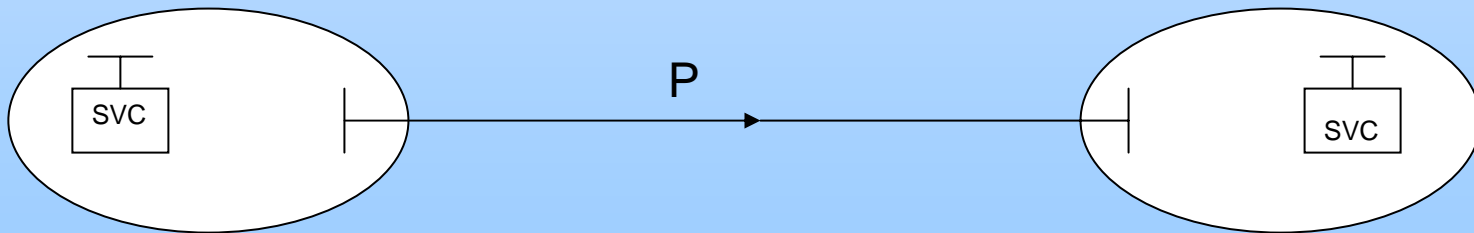


Fig. 3. Two-area Power System

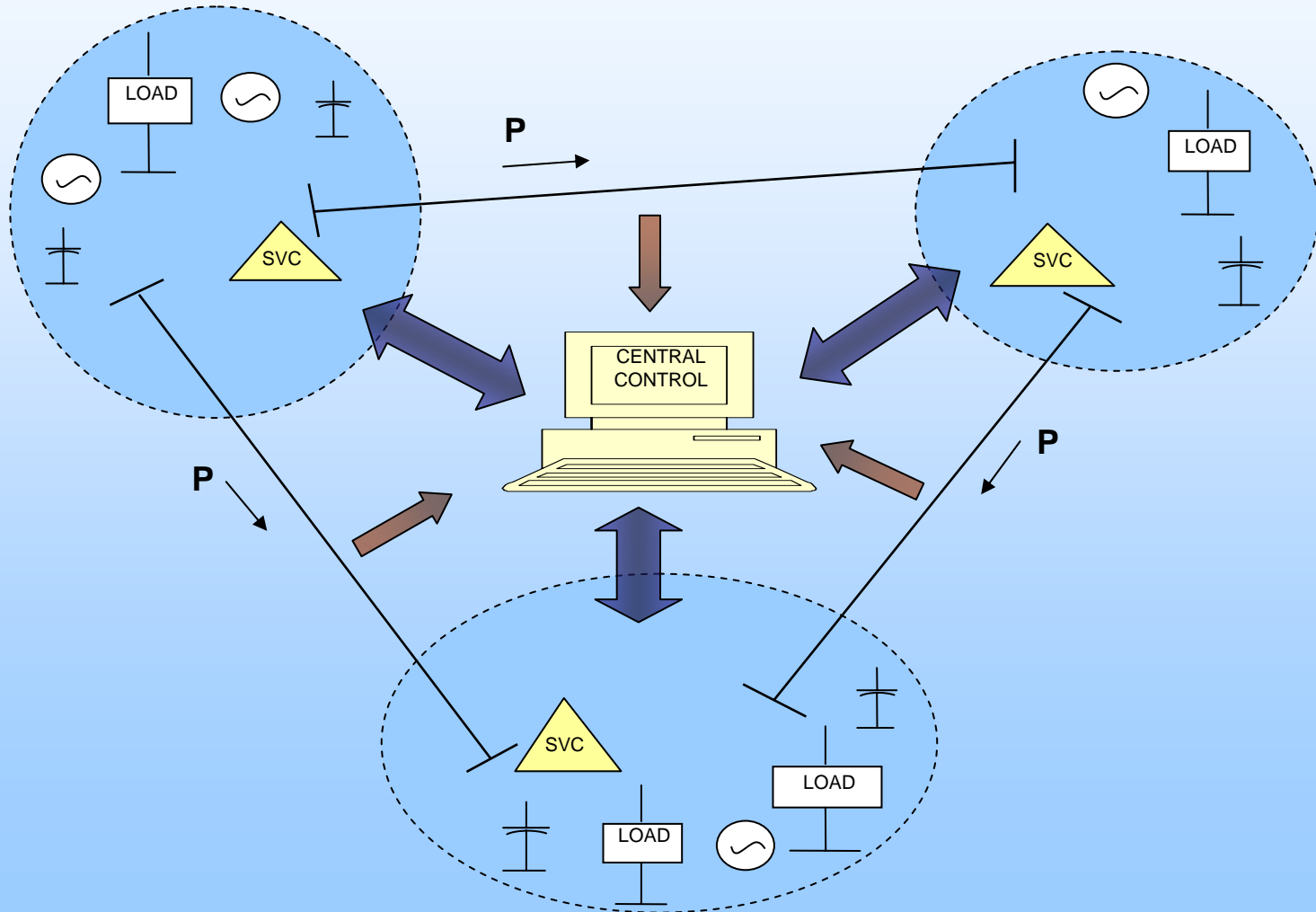
$$\mathbf{J} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ J_{21} & -\frac{K_{D1}}{2H_1} & J_{23} & 0 & 0 & a \\ 0 & 0 & 0 & 1 & 0 & 0 \\ J_{41} & 0 & J_{43} & -\frac{K_{D2}}{2H_2} & 0 & b \\ J_{51} & 0 & J_{53} & 0 & -\frac{1}{T_{2LP}} & c \\ J_{61} & 0 & J_{63} & 0 & d & e \end{bmatrix}$$

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



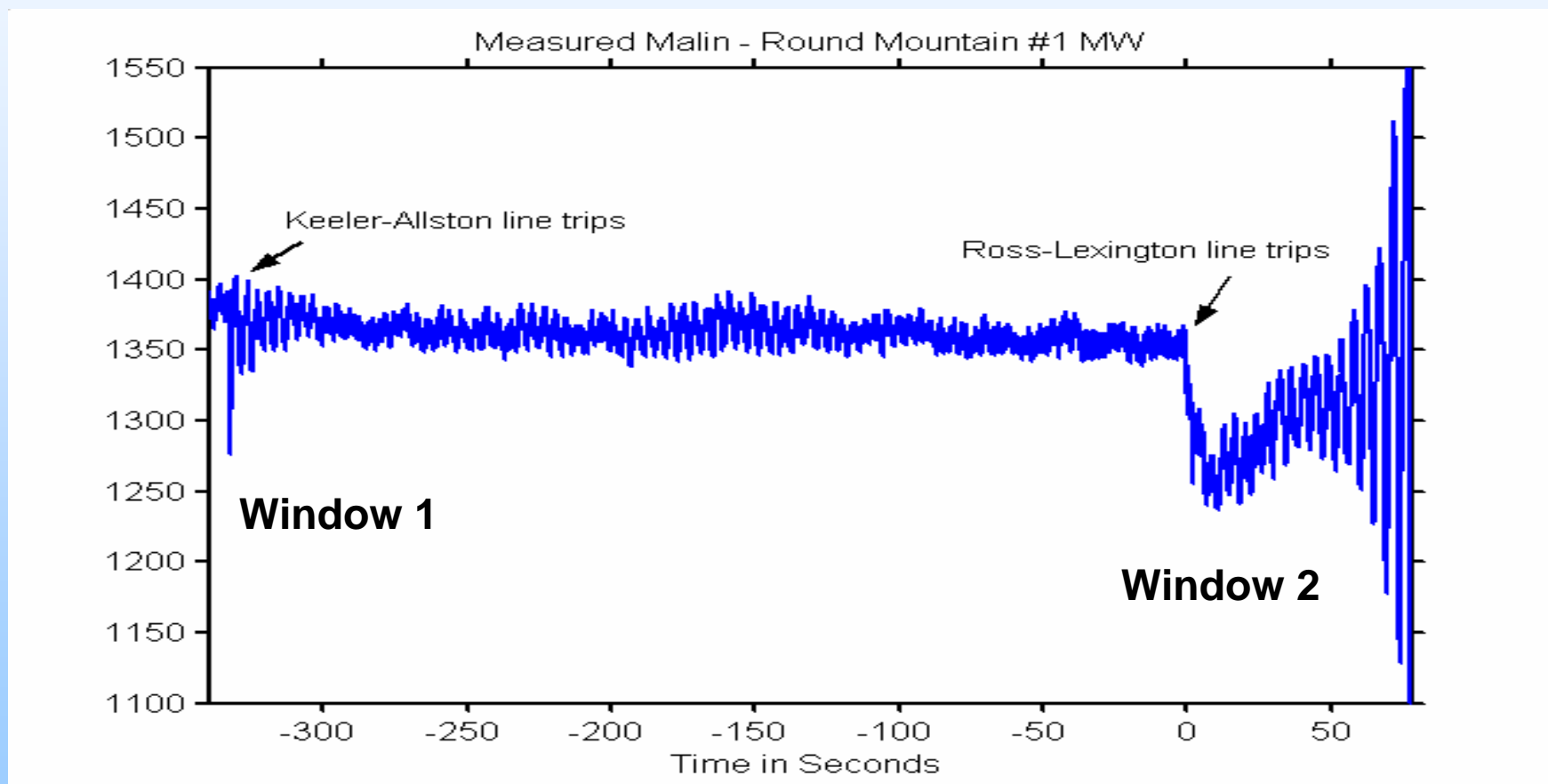
Oscillation Detection

- **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.**

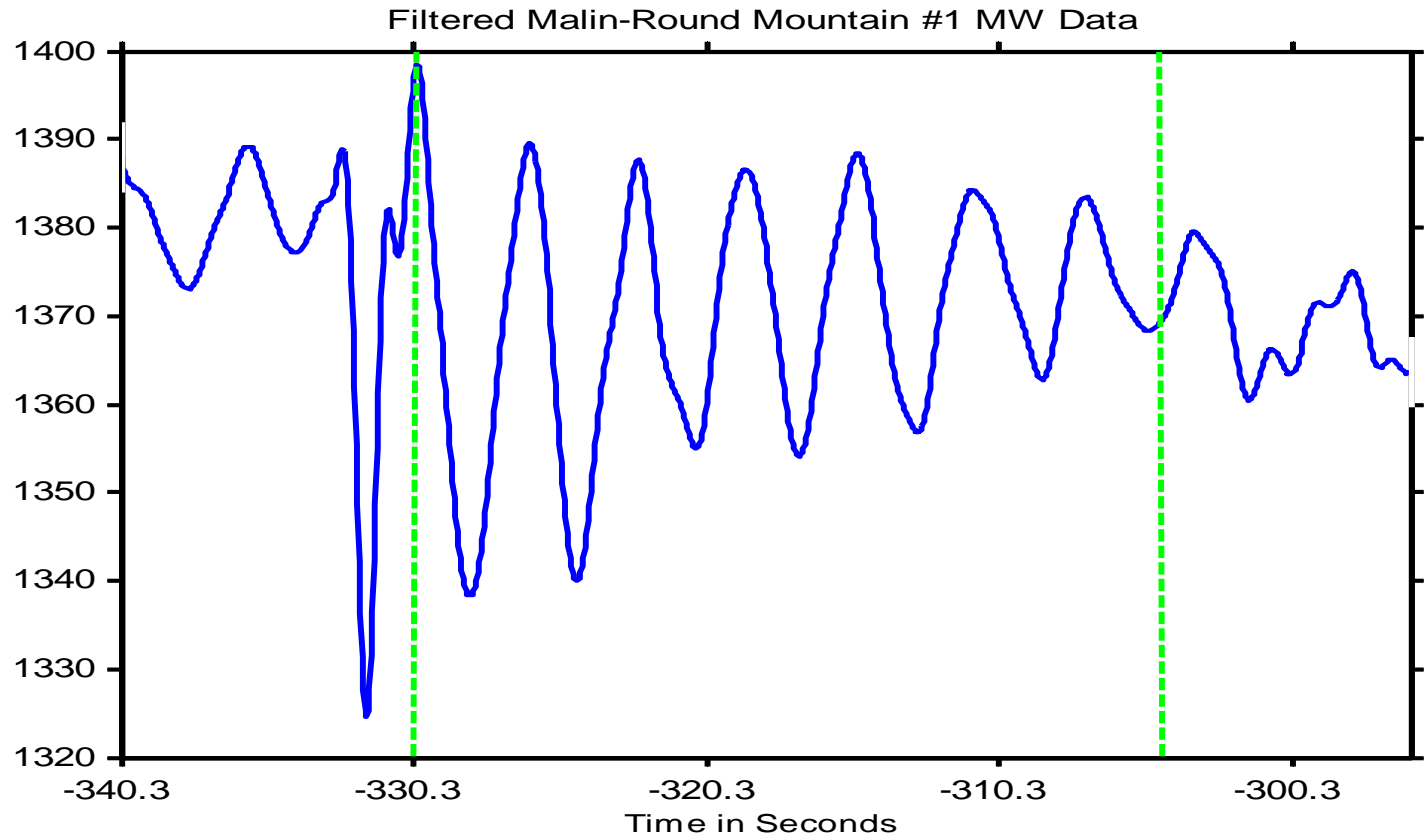
Linear versus Nonlinear

- **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

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.

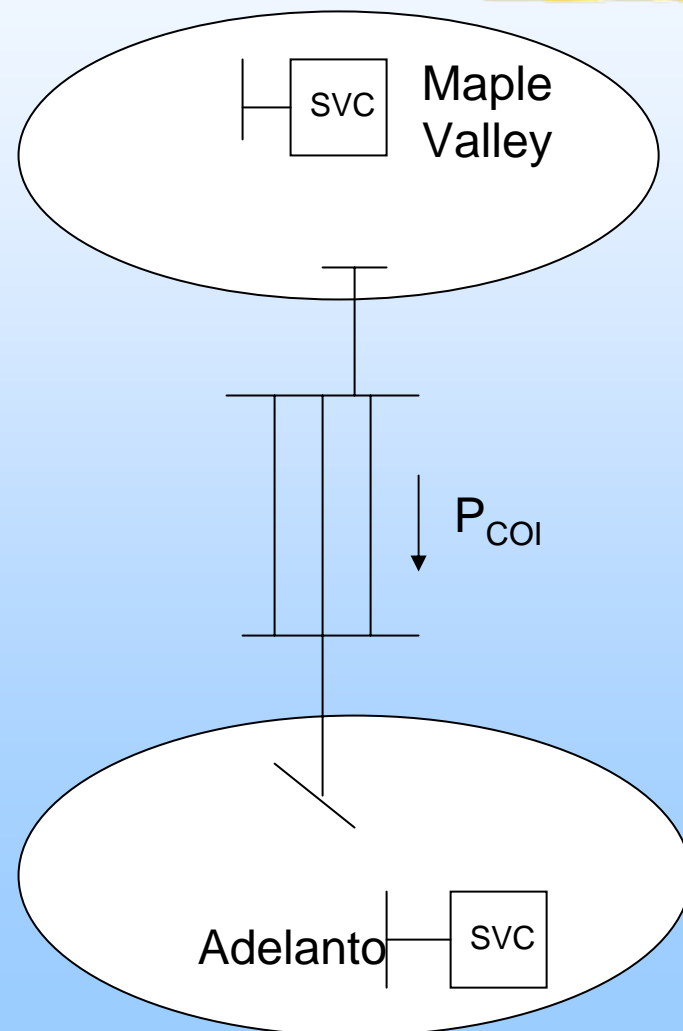
^b Time with respect to Ross-Lexington line trip.

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.

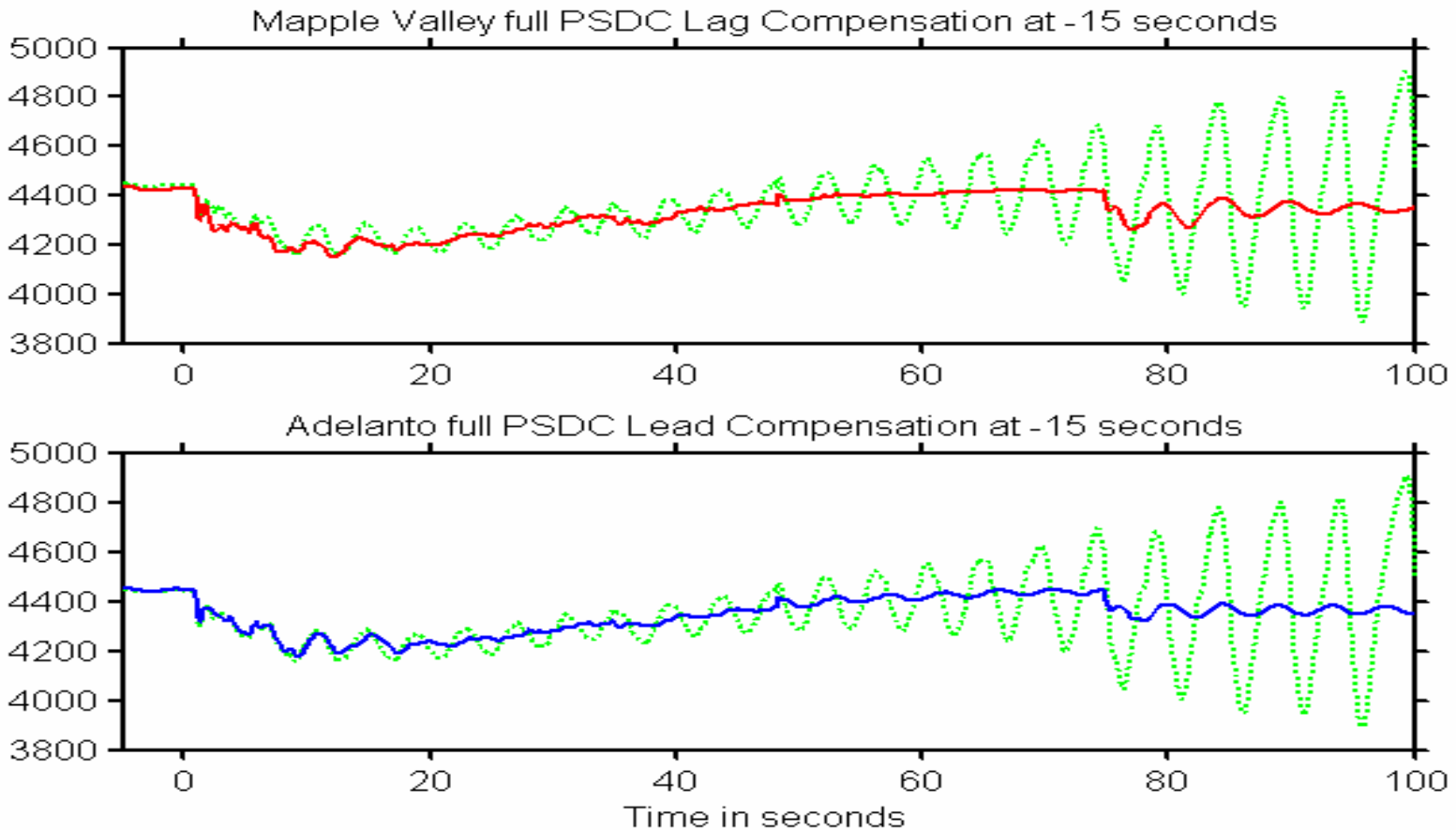
Damping Trigger Set-Point at say +3% => Trigger @ -306.3

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.**

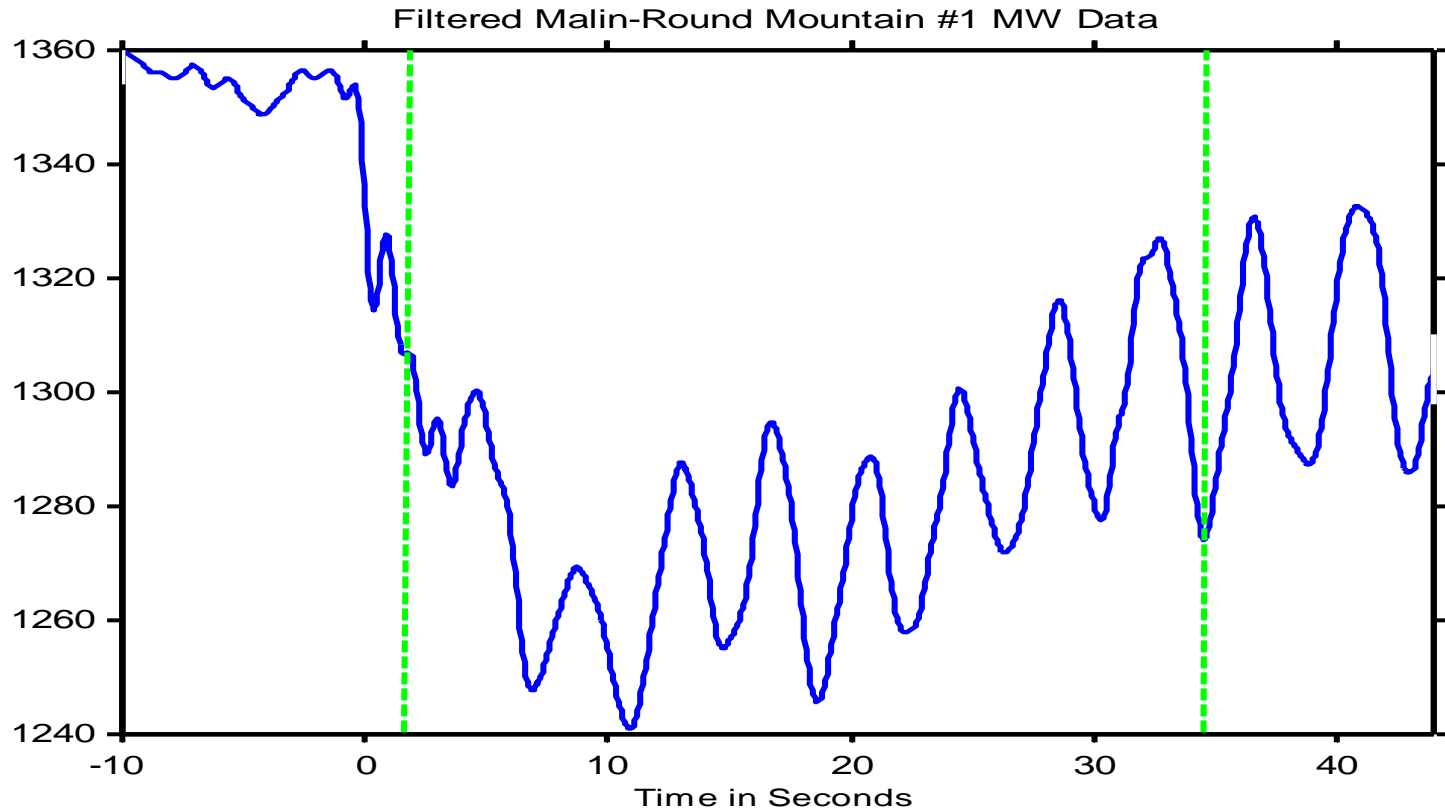


SVC PSDC @ -300 secs.



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

Window 2 Analysis



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.

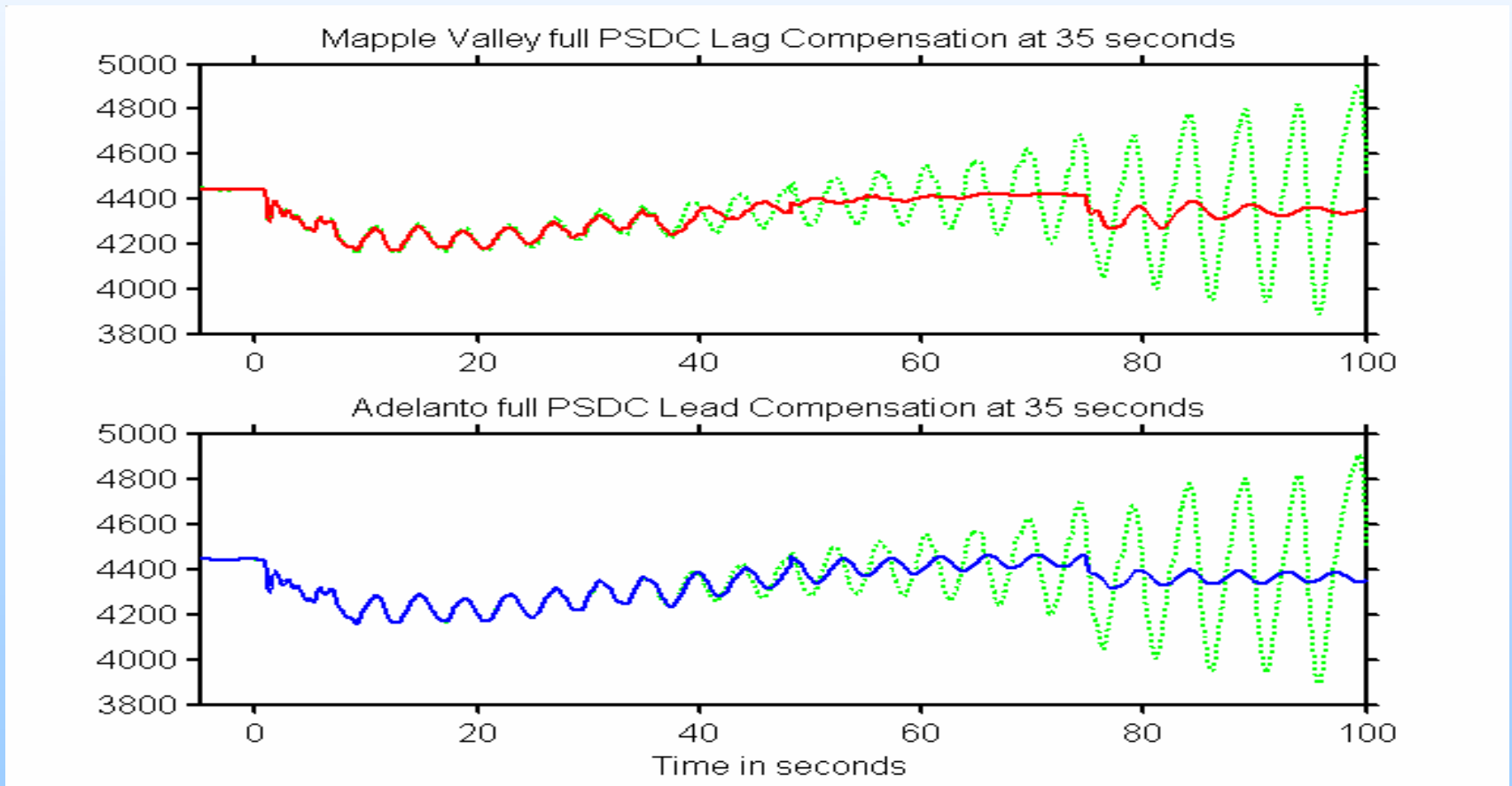
^b Time with respect to Ross-Lexington line trip.

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.**