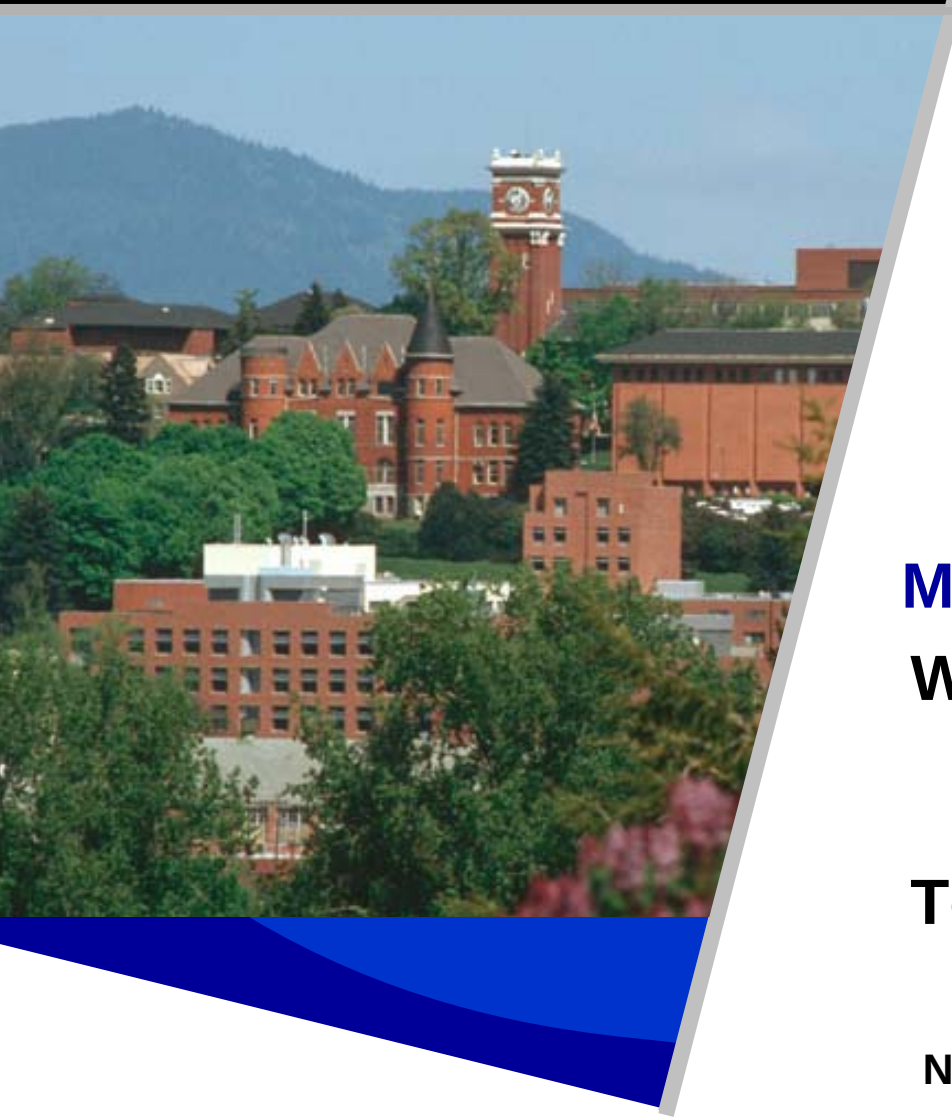

Oscillation Monitoring System at TVA

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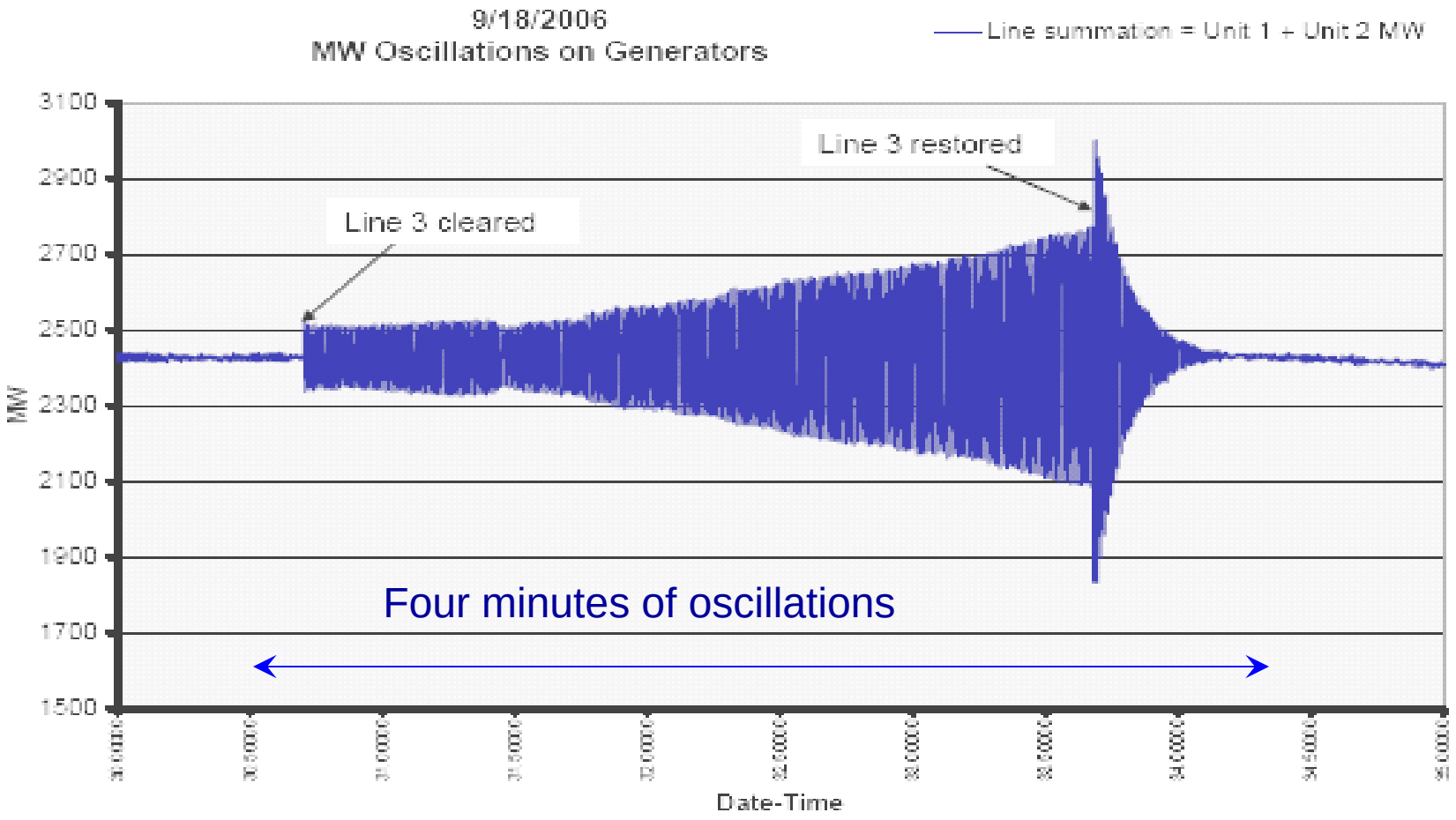
NASPI Meeting, New Orleans, March 2008

Project Team

- **WSU:**
  - **Guoping Liu**
  - **Mani V. Venkatasubramanian**

- **TVA:**
  - **Ritchie Carroll**
  - **Gary Kobet**
  - **Lisa Beard**

TVA Cumberland event

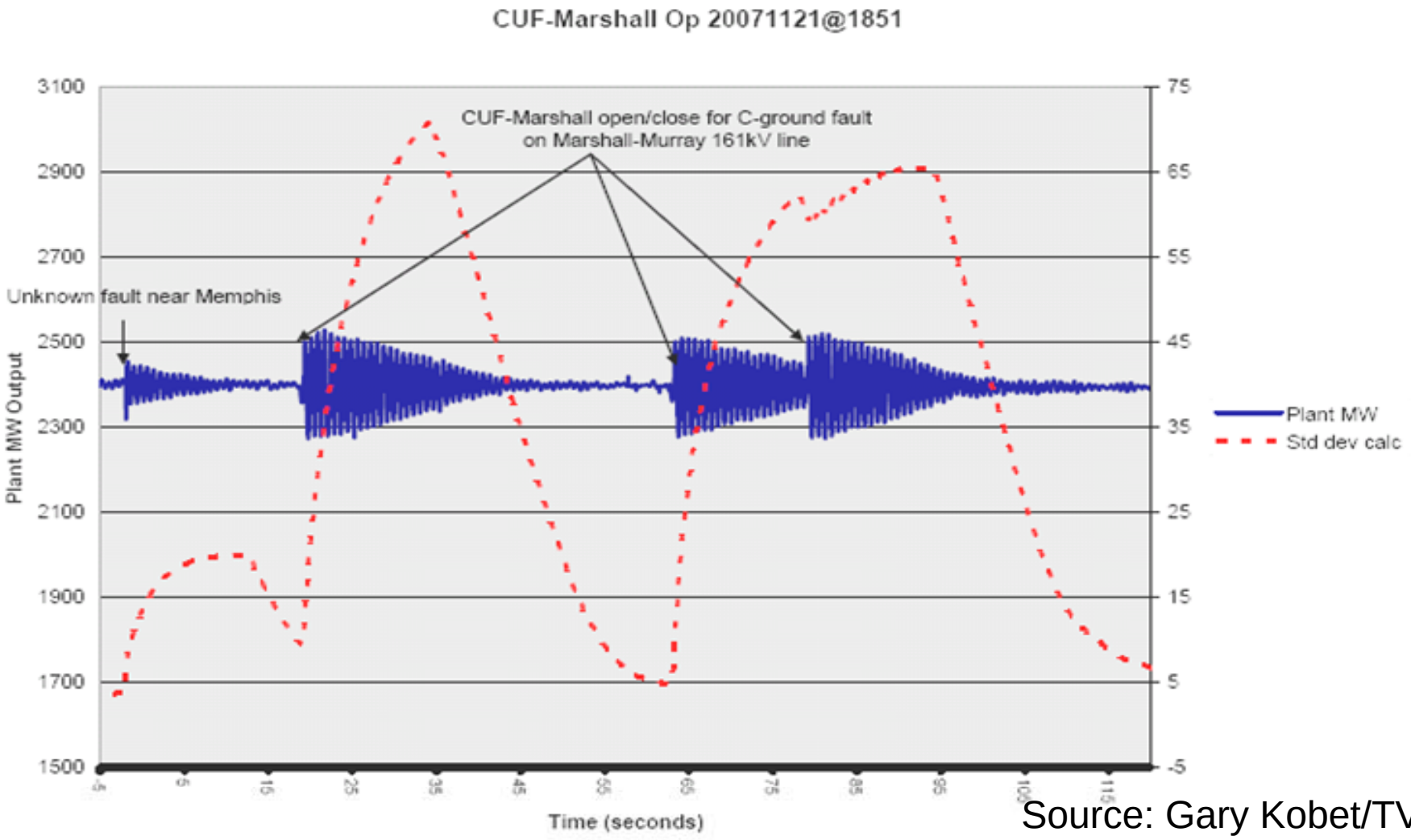


Source: Gary Kobet/TVA

Motivation

- **Recent oscillatory event at TVA:**
  - **Oscillations at Cumberland plant 9/18/2006**
  - **PMU recordings enabled the analysis**
  - **Local 1.2 Hz mode changed from +1.5% damping to –0.2% damping and back to +1.5% damping during the event**
  - **PSS installed at the plant subsequently**
  - **PMU based real-time alarm coded into TVA PDC as back-up measure – uses standard deviation thresholds – plant operators to reduce MW output when alarm received.**

Standard Deviation Trigger



Source: Gary Kobet/TVA

Update on Cumberland Alarm

- **Standard Deviation calculated in real-time from moving windows of Cumberland PMU MW data**
- **Alarm threshold has never been exceeded since implementation in 2007. Operator Alarm never issued.**
- **Concern about potential oscillations at other TVA plants or from outside TVA.**
- **Collaboration with WSU on the current project of implementing Oscillation Monitoring System since 2006.**

Oscillation Monitoring System

- PSerc project on real-time oscillation monitoring has been on-going since 2003
- Current phase on prototype implementations at TVA and Entergy started in 2006
- Real-time code tested – speed and memory
- Initial plan to present the results on a protected website
- Plan to extend to Entergy PMU's next

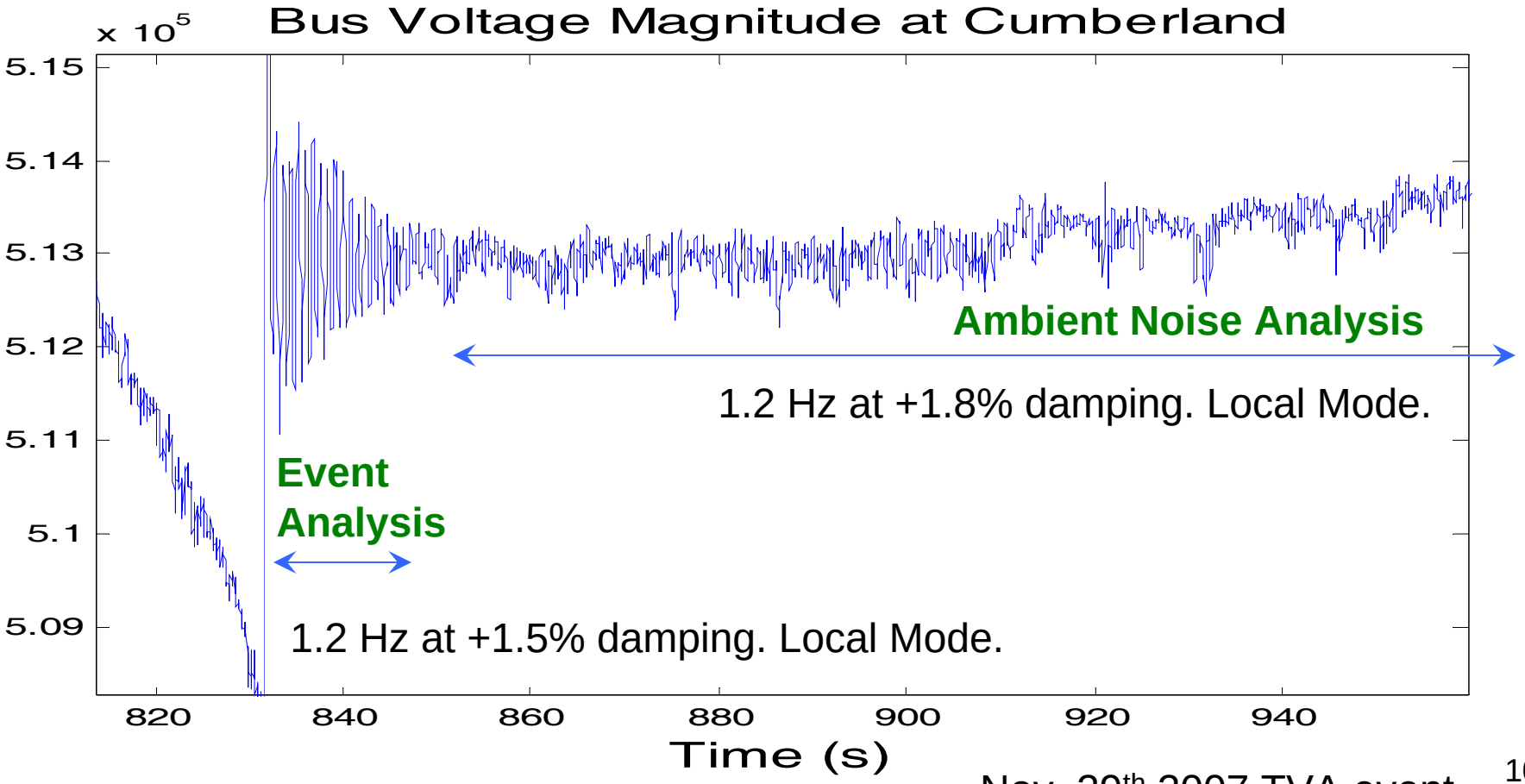
Oscillation Monitoring System

- Software Engines built into TVA PDC
- Real-time streaming data input to the engines
- Fast detection of poorly damped oscillatory modes: mode frequency, damping and mode shape
- Multiple algorithms integrated by expert system like rules
- Focus on Redundancy and Reliability

OMS Engines

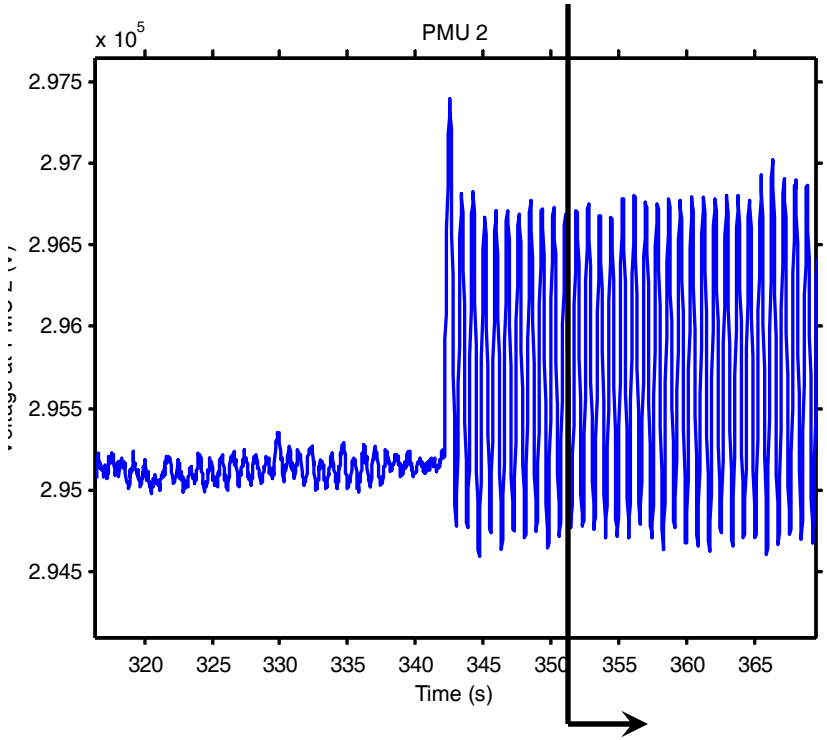
- **Event Monitor Engine**
  - **Automated Prony type analysis of oscillatory ringdown responses**
  - ***Five seconds* of PMU data analyzed every *one second***
- **Damping Monitor Engine**
  - **Automated analysis of ambient noise data**
  - ***Three minutes* of PMU data analyzed every *ten seconds***

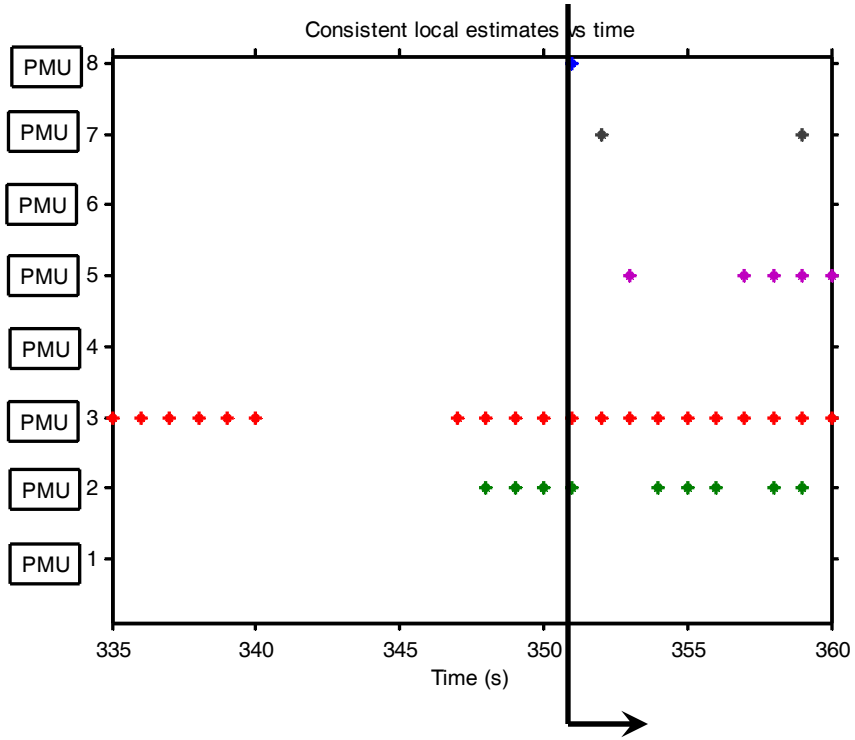
Results from Two Engines



Nov. 29th 2007 TVA event

Example of Event Analysis





- Consistent estimate at +9 sec
- Frequency = 1.1785 Hz. Damping at 0.04%

Complementary Engines

- **Event Analysis Engine**
  - **Three algorithms: Prony, Matrix Pencil and Hankel Total Least Square.**
  - **Aimed at events resulting in sudden changes in damping**
- **Damping Monitor Engine**
  - **Ambient noise based. Continuous.**
  - **Frequency Domain Decomposition Algorithm**
  - **Provides early warning on poorly damped modes**

Example of results for TVA

Damping history of 1.2 Hz mode	Event Analysis	Damping Monitor	PSS Status
Sept. 18, 2006	+1.7%	+1.7%	No PSS
Dec. 16, 2006	+7.2%	No data	PSS installed
Nov. 29, 2007	+1.5%	+1.8%	PSS offline
Feb. 5, 2008	+4.0%	+3.0%	PSS offline

Tool provides continuous monitoring of poorly damped modes if any present. PSS status and effectiveness from the damping level of the local mode.

Eastern System Interarea Mode

- Interarea mode frequency varies between 0.4 Hz to 0.5 Hz depending on season.
- Damping Monitor (ambient noise) showed the mode to be poorly damped around +3% to +5% seasonally.
- 0.47 Hz Interarea mode clearly visible in Event Analysis of Feb. 26th 2008 Florida blackout event.
- Mode involves many eastern control areas.
- Frequency ~ 0.47 Hz, damping ~ +7%, on Feb. 26th 2008.
- Likely not related to the blackout. Mode damping at +7% is comparable to the interarea modes in the western system.

OMS Summary

- Successful implementation of real-time code into TVA PDC
- Advanced signal processing algorithms for oscillation analysis of events and ambient noise
- Automatic detection of poorly damped electromechanical modes and their mode shape
- Operator alerts, Operator alarms, Control actions, …
- Provides early warning on emerging oscillatory problems
- Can validate effectiveness and status of PSS at generators when PMU near generator

Things I've learned from dealing with fast moving time-synchronized data

- It's amazing what you can get done in 1/30 of second
- There is a limit to what you can get done in 1/30 of second
- 1000 milliseconds per second does not provide enough resolution
- 10,000,000 ticks per second provides sufficient resolution
- GPS time-synchronized devices do not always report accurate time
- A timestamp with year 2057 in the future is not an accurate time
- Do not assume your most recent received time is real-time
- If you assume your most recent received time is real-time, and most recent time has a year of 2057, all other accurate times will appear to be very old
- Getting timestamps offset in local time zones is a pain
- UTC timestamps are your friend
- Any exceptions your application throws are time and CPU expensive
- You should write to code that doesn't throw exceptions :)
- Your brain has a tendency to think in second resolution, not sub-second resolution
- System instability will occur if you report errors at 30-times per second
- You should not report any event at 30-times per second

In any human endeavor, once you have exhausted all possibilities and failed, there will be one solution--simple, obvious, and highly visible to everyone else.

--Ritchie Carroll