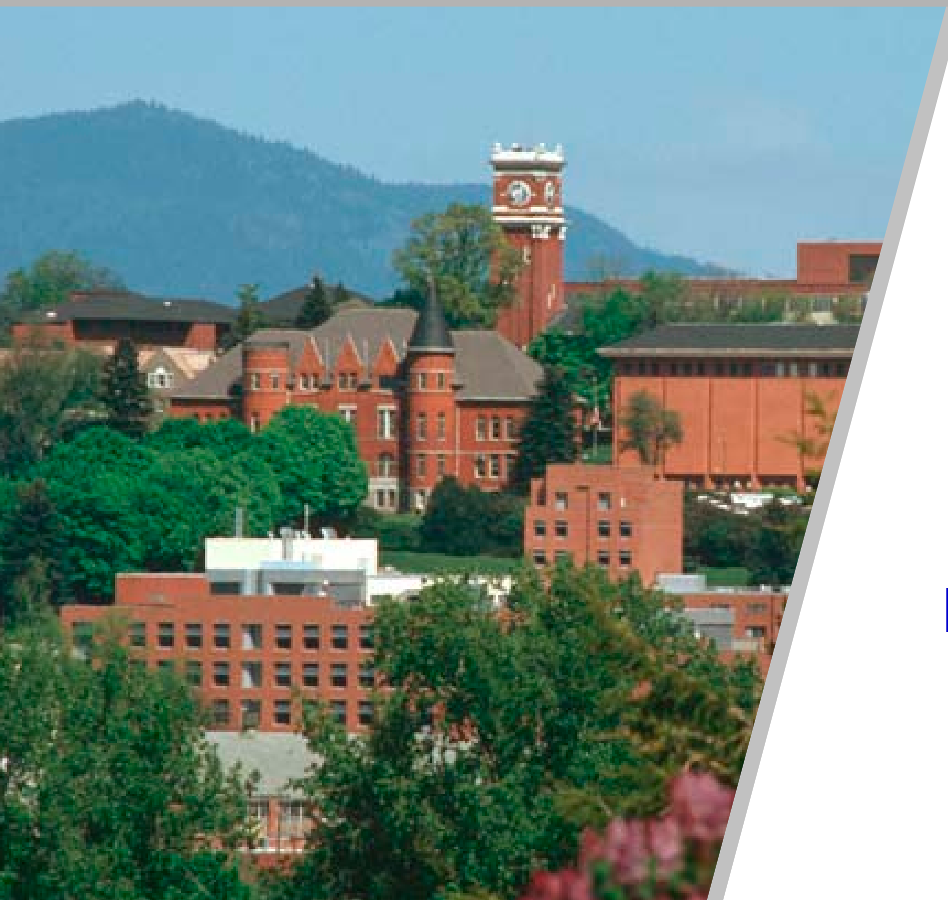
Washington State University

TVA



Oscillation Monitoring System

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NASPI Meeting, Charlotte, October 2008

Project Team

- WSU:
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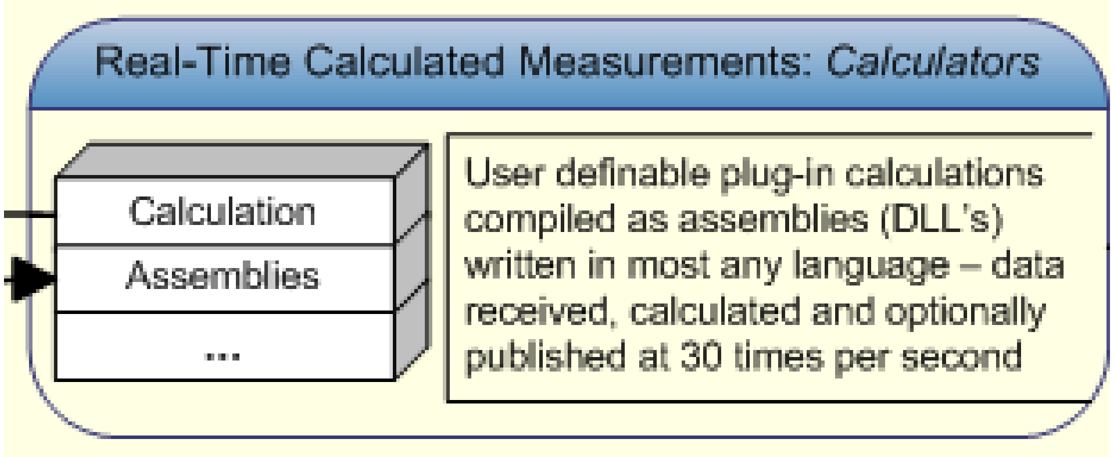
- TVA:
  - Ritchie Carroll, Gary Kobet, Lisa Beard, Ryan Zuo

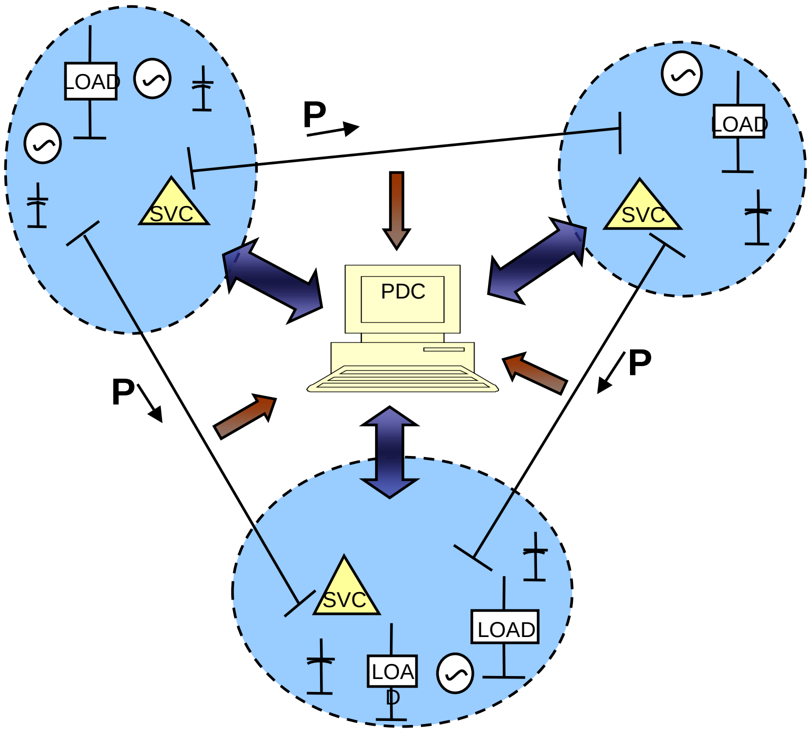
Extensibility Module

- Measurements in…
- Perform calculation (1/30 of a second)
- Measurements out…

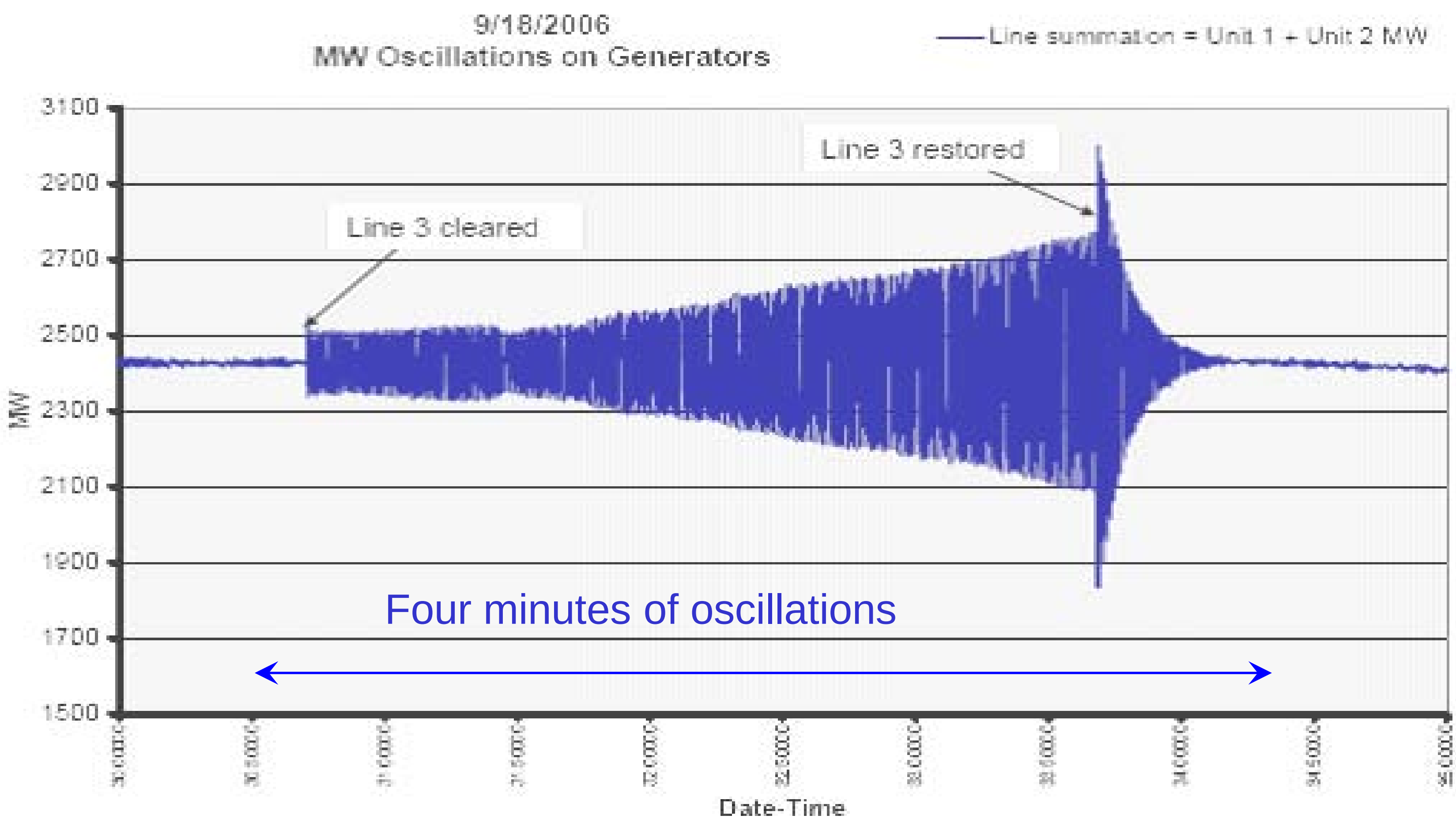


Oscillation Monitoring System (OMS)

- Goal of Oscillation Monitoring System (OMS)
  - Early detection of poorly damped oscillations as they appear
  - Trigger warning or control signals
- OMS is made possible by Wide Area PMU Measurements
  - Growing numbers of PMU's across the power grid
  - Fast algorithms available for online measurements
  - Rule based automatic analysis of PMU measurements
  - Prototype implementation at TVA



TVA Cumberland Event



Source: Gary Kobet/TVA

Motivation

- 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

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 2002**
- **Current phase on prototype implementations at TVA and Entergy started in 2006**
- **Real-time code tested at TVA – *speed and memory requirements critical***
- **Focus on scalability to hundreds of PMU's from across large-scale power system**

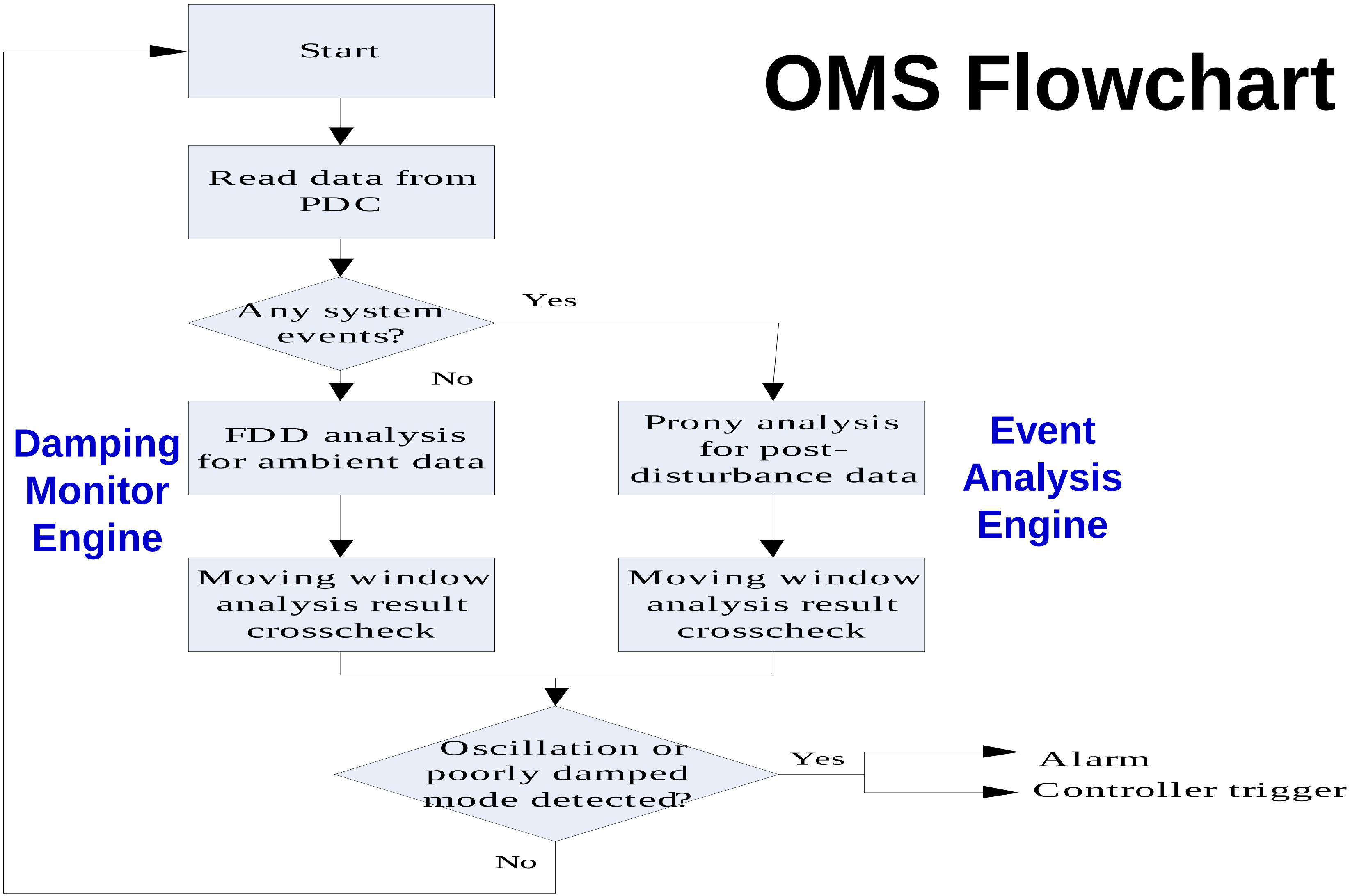
Oscillation Monitoring System

- 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

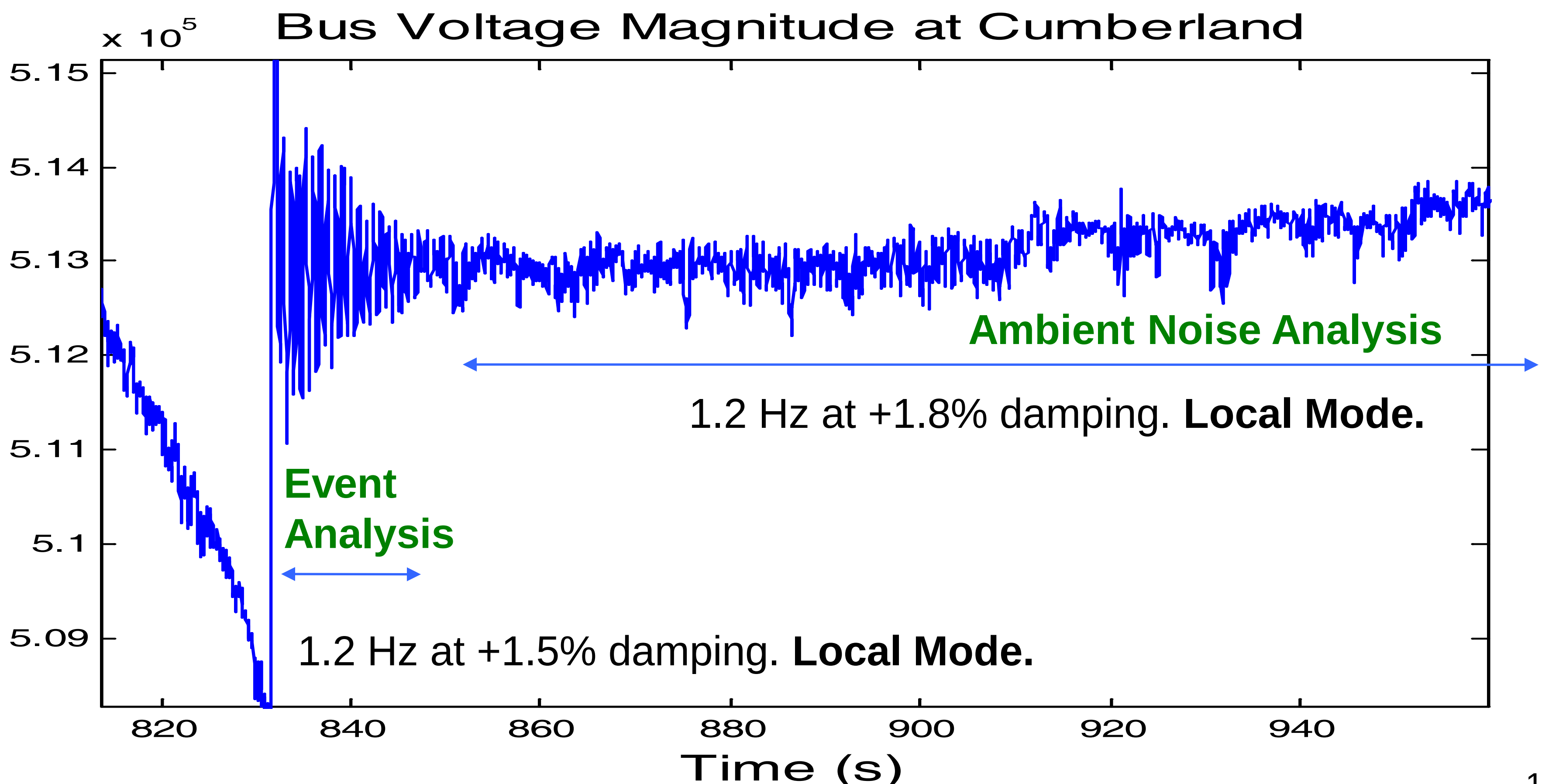
OMS Engines

- 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*

OMS Flowchart

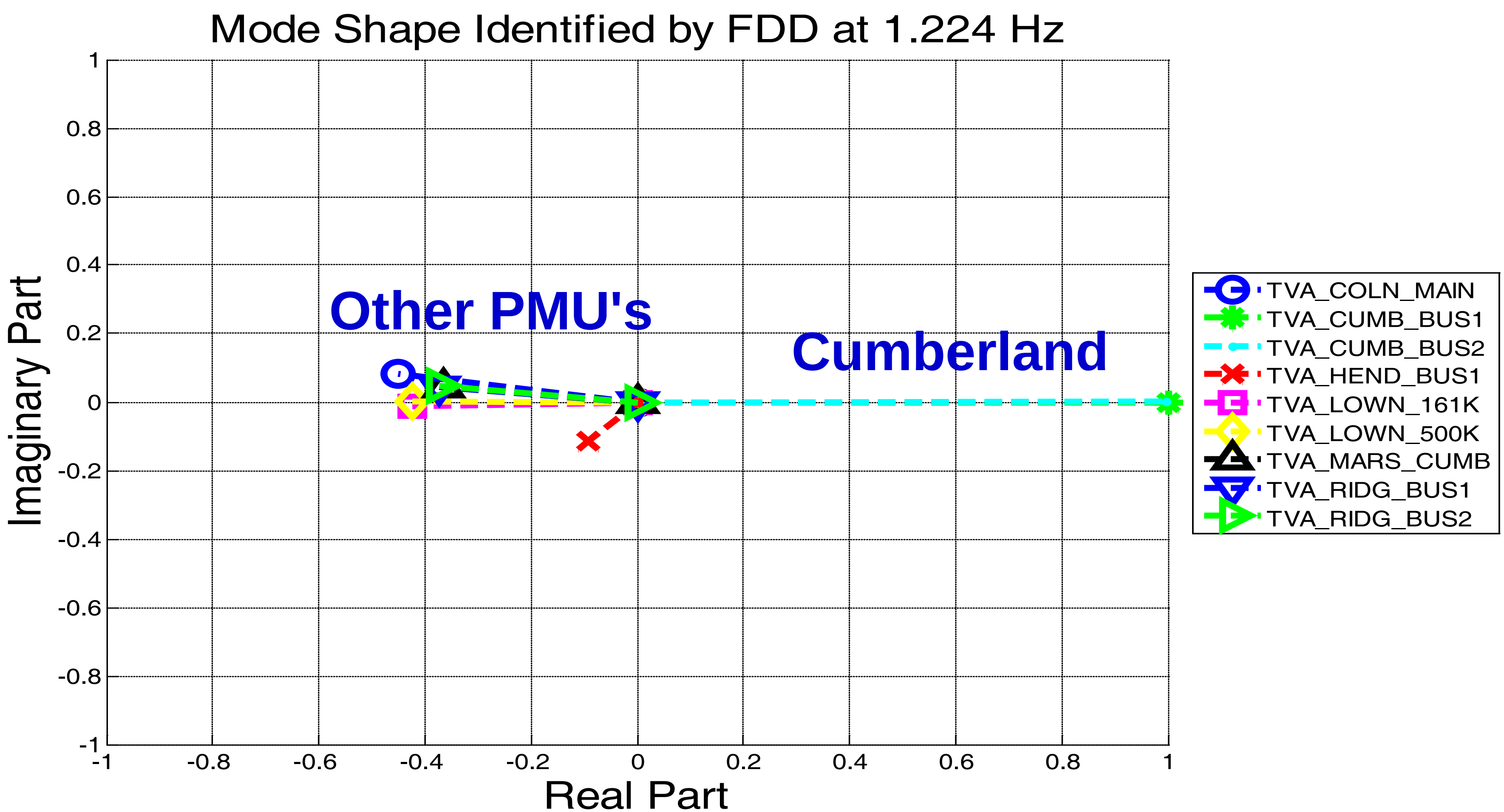


Results from Two Engines



Nov. 29th 2007 TVA event

Mode Shape – Local Mode



Cumberland oscillating against rest of system – local mode

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TVA

Rules for Real-time Analysis

- Crosscheck is crucial
  - Nonlinear phenomenon in the system
  - Switching events and noisy measurements
  - Bad estimate from a single algorithm
  - Unknown system dynamics
- Crosscheck the results
  - Different methods
  - Different signal groups
  - Moving window analysis results

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 **(2U)**
Dec. 16, 2006	+7.2%	No data	PSS installed **(1U)**
Nov. 29, 2007	+1.5%	+1.8%	PSS offline **(2U)**
Feb. 5, 2008	+4.0%	+3.0%	PSS offline **(1U)**

PSS status and effectiveness from the damping level of the local mode. *PSS not effective for two units in service*. **PSS hardware problem detected and fixed (June 2008).**

OMS Summary

- **Successful implementation of real-time code into TVA PDC**
- **Automatic detection of poorly damped electromechanical modes and their mode shape**
- **Immense data size – 30 samples a second, many minutes of data, many channels per PMU, many PMU's – *memory requirements grow quickly.***
- **We are already reaching the limitations of a 32-bit architecture. 32-bit operating system have a physical limit of 2^32 = 4,294,967,296 (over 4 billion bytes, i.e. 4 GB).**
- **Porting code to run on a 64-bit operating system which has a theoretical limit of 2^64 = 18,446,744,073,709,551,616 (over 18 quintillion bytes, i.e. ~18 *Exa*-bytes).**

Ongoing Work

- Implementation, testing and tuning at TVA
- Conversion of OMS code to 64-bit architecture
- New dedicated eight processor machine with 32-GB dynamic memory at TVA
- Parallel and efficient code using C# under development
- Expansion to other PMU’s for Eastern Grid
- Determining proper enunciation of events to operator as alerts and alarms – then best course of action for operator response.