

Oscillation Monitoring System

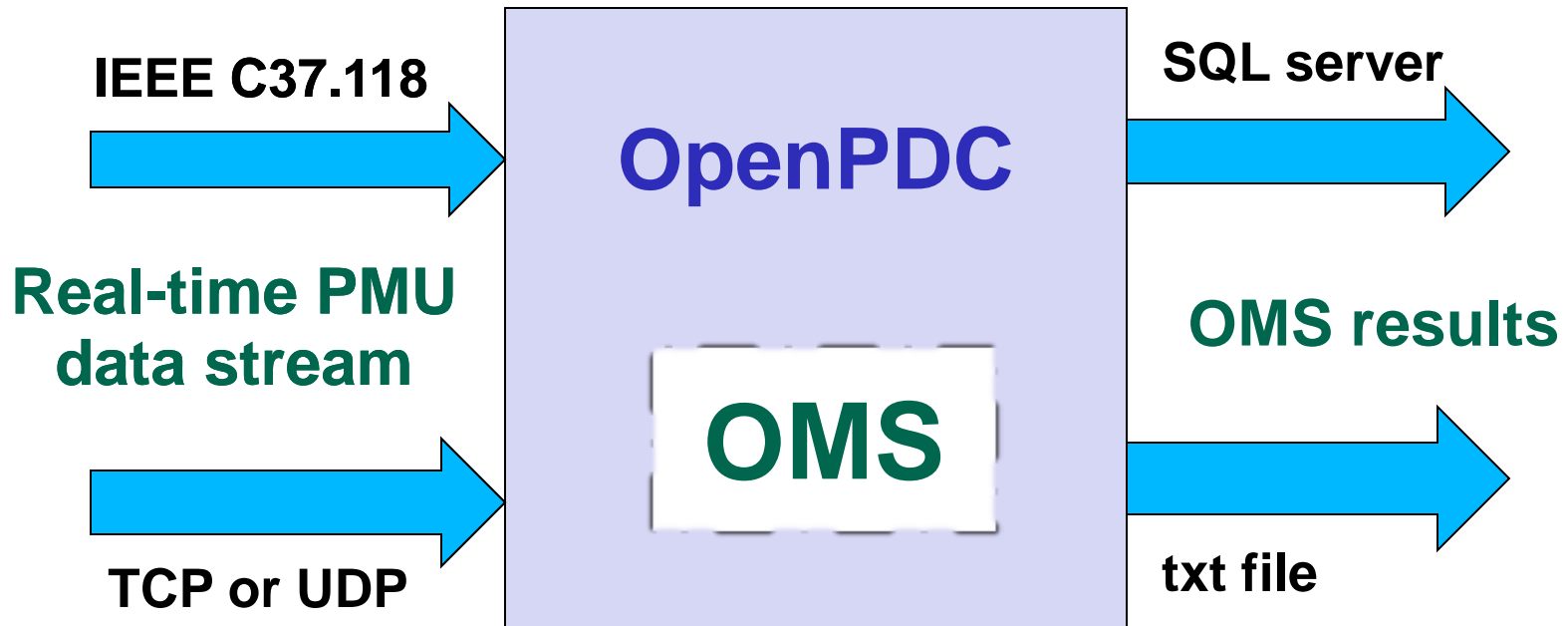
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Pullman WA**

Small-Signal Stability Analysis

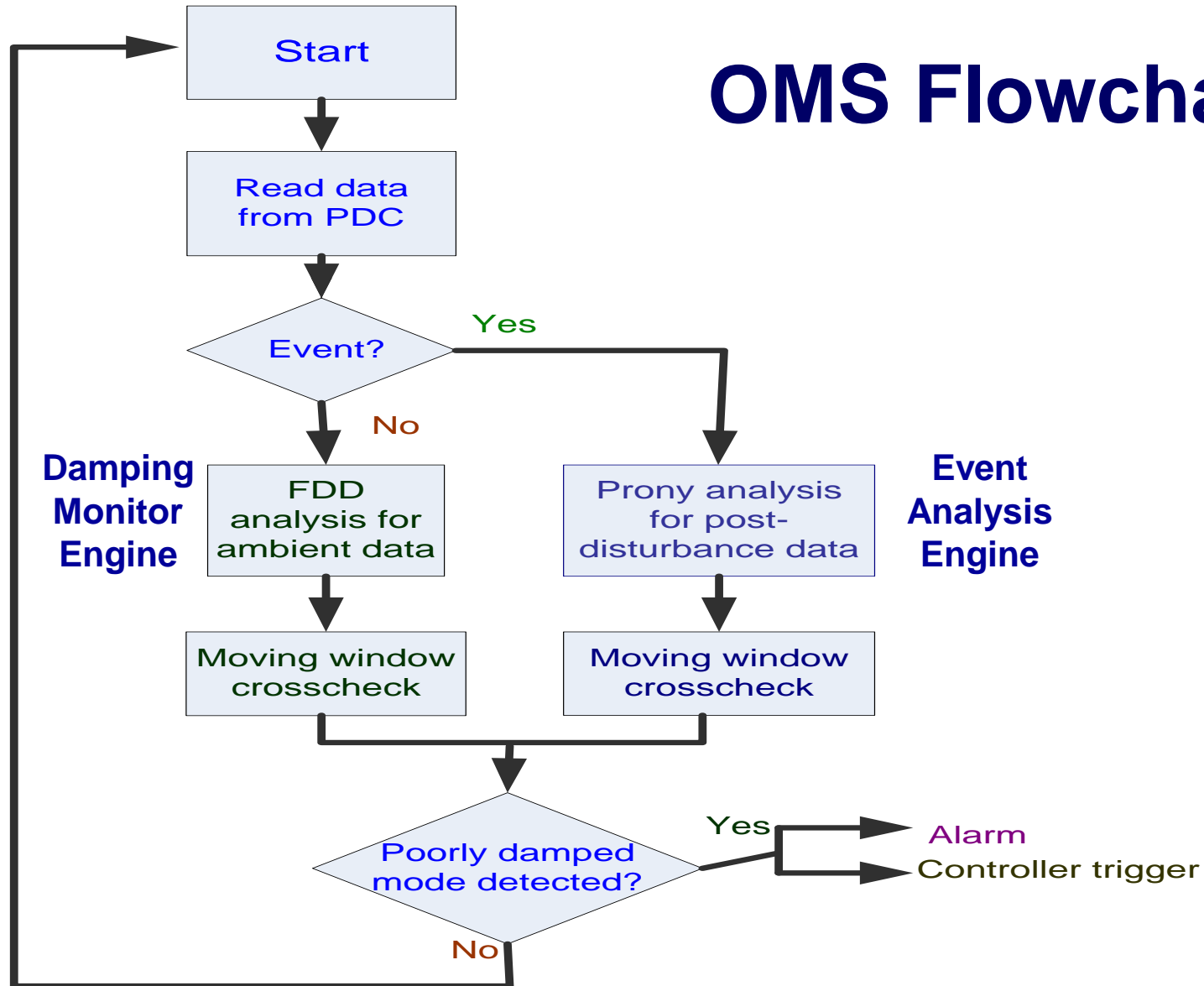
- **Model based analysis**
 - Mathematical models of dynamics
 - Solve for equilibrium from power-flow solution
 - Compute eigenvalues and damping
 - Used in planning studies
- **Measurement based analysis**
 - Wide-area measurements from PMU
 - Off-line and real-time analysis
 - **Ambient noise algorithms and Ring-down algorithms**

Oscillation Monitoring System



OMS action adapter built into OpenPDC 64 bit version 1.4 sp1. Available for beta testing.

OMS Flowchart



Complementary Engines

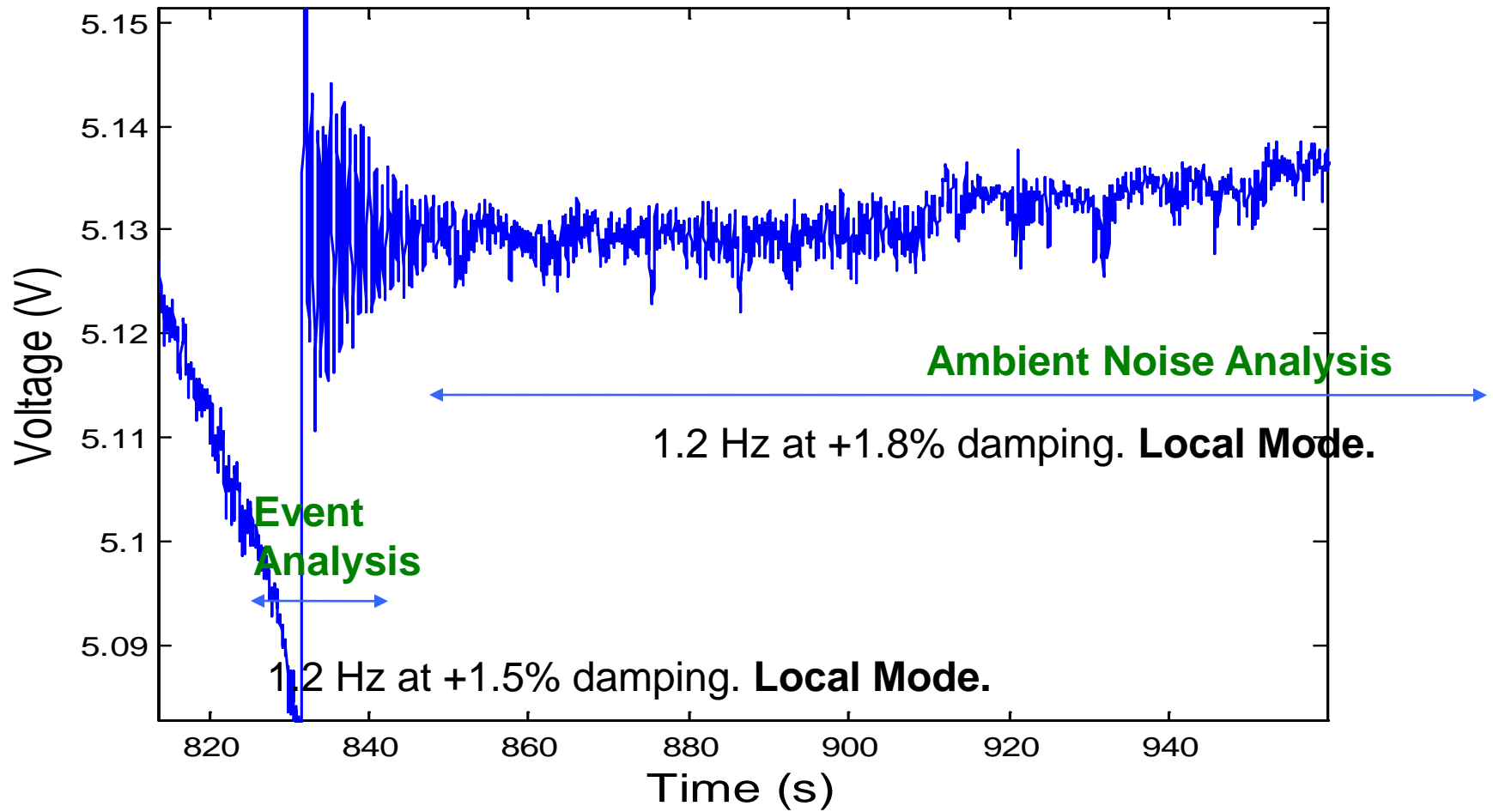
- **Event Analysis Engine**

- ◆ 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
- ◆ Provides **early warning** on poorly damped modes

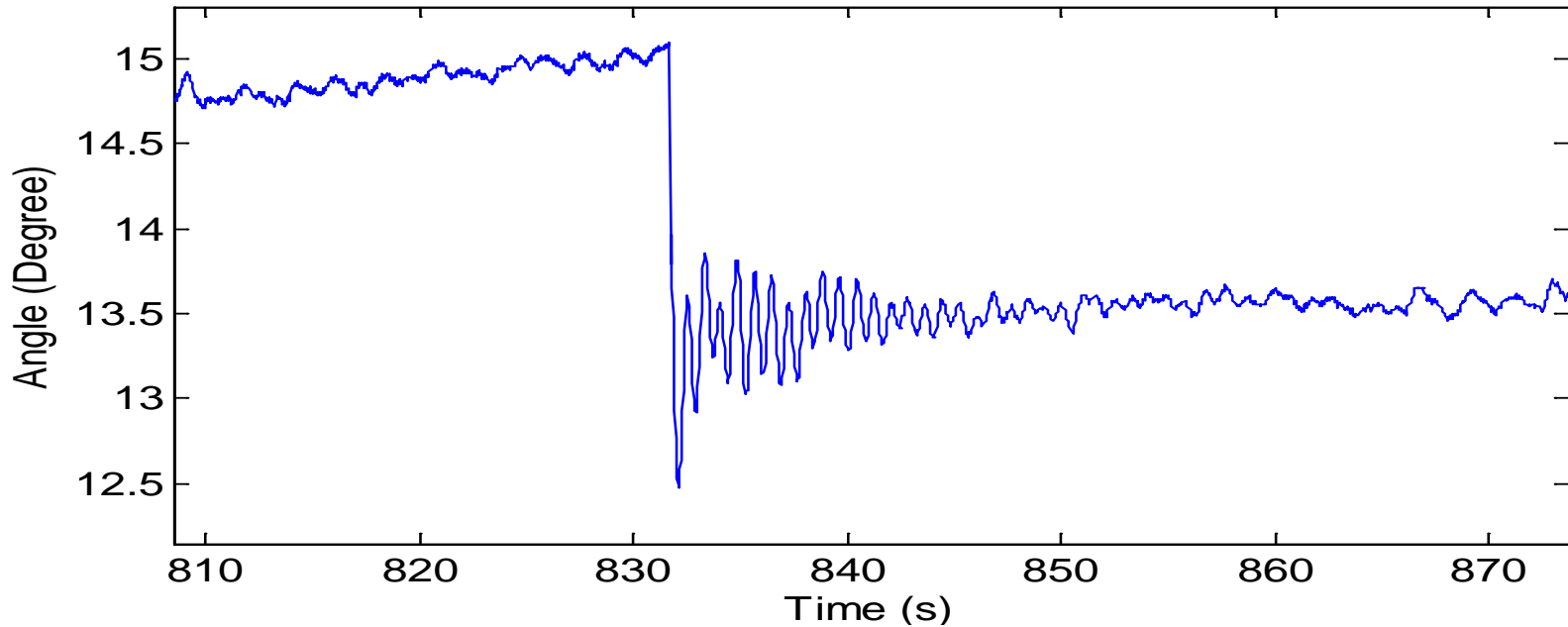
Results from Two Engines



OMS Engines

- Event Monitor Engine
 - ◆ Automated Prony type analysis of oscillatory ringdown responses
 - ◆ *Ten seconds* of PMU data analyzed every *one second*
- Damping Monitor Engine
 - ◆ Automated analysis of ambient noise data
 - ◆ *Five minutes* of PMU data analyzed every *ten seconds*
 - ◆ Multiple PMUs – Fast and Accurate

Nov 29 2007 TVA Event



Prony analysis:

1.25 Hz Mode

@ 1.5% damping ratio

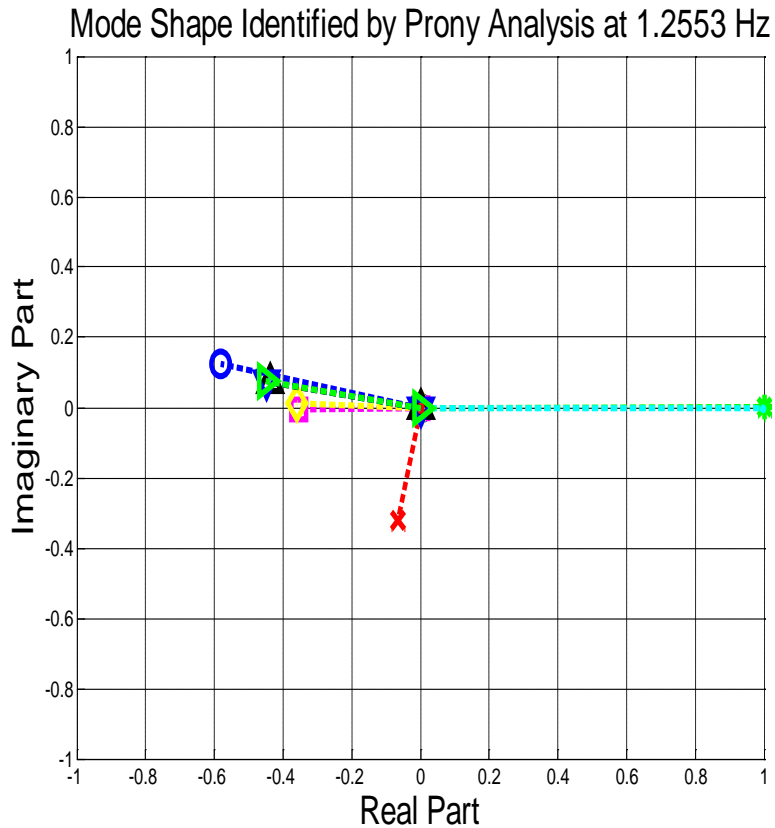
FDD Analysis:

1.224 Hz Mode

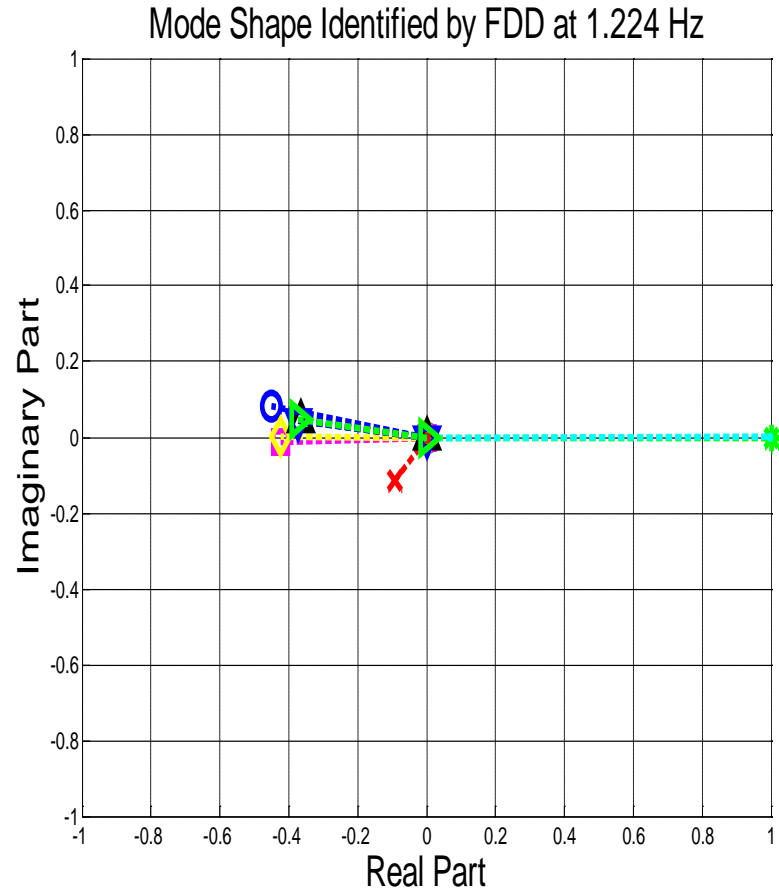
@ 1.17% damping ratio

Defective card found in Power System Stabilizer and fixed.

Mode Shape Estimation



Prony Mode Shape



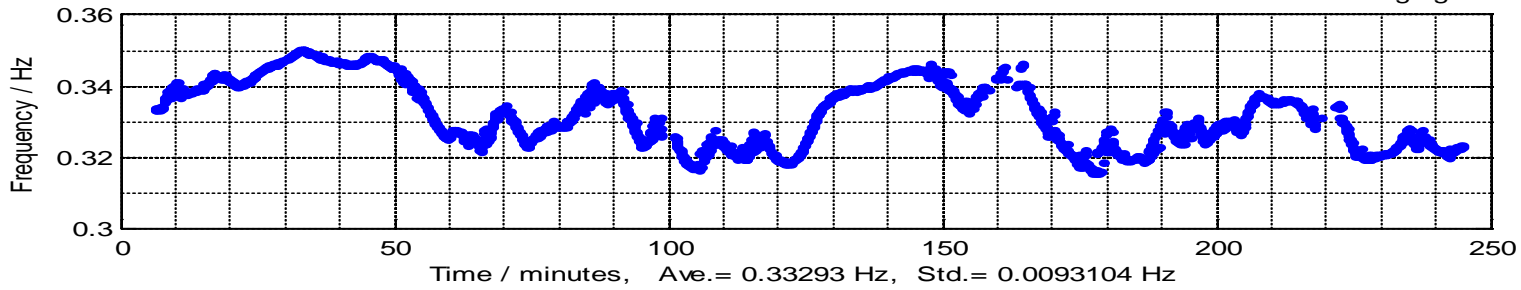
FDD Mode Shape

Mode shape helps pinpoint the root cause of oscillations.

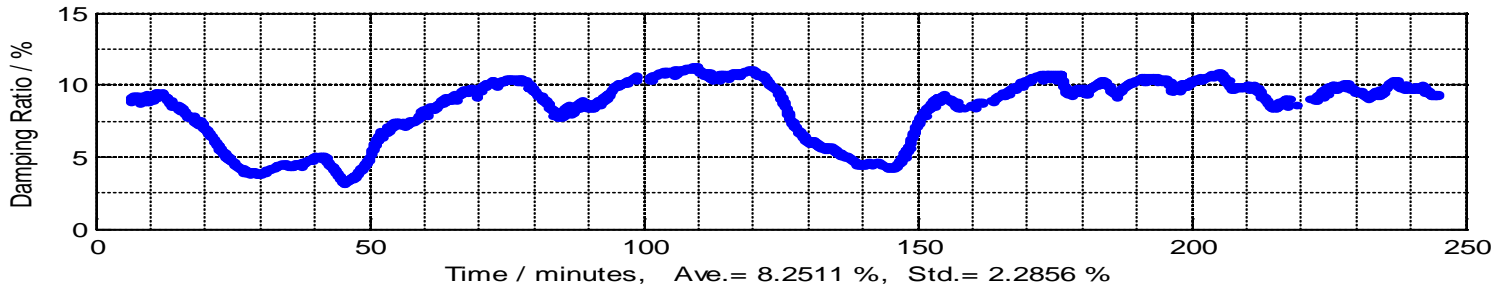
Damping Monitor Estimation Results

- Dominant modes are analyzed for each data set (every ten seconds)
- For each mode:
 - Mode frequency
 - Mode damping ratio
 - Mode energy
 - Mode shape
 - Estimation summary flag
 - Estimation confidence level

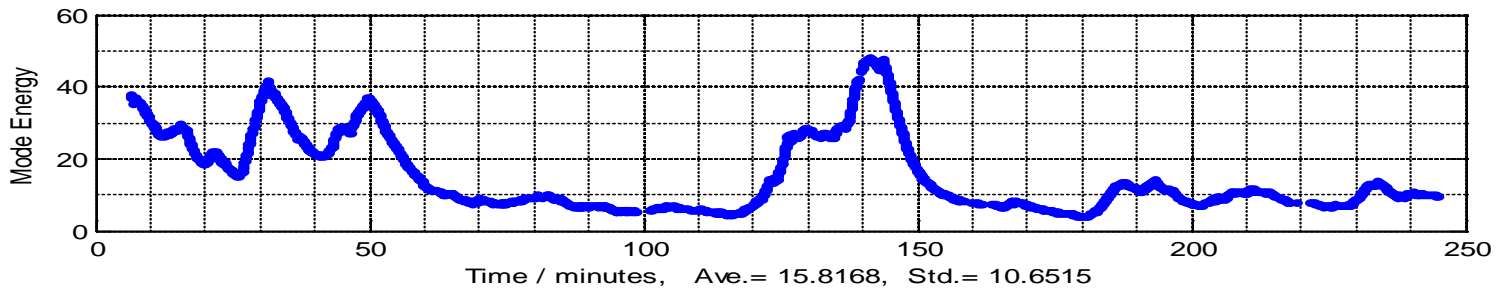
Western System Event



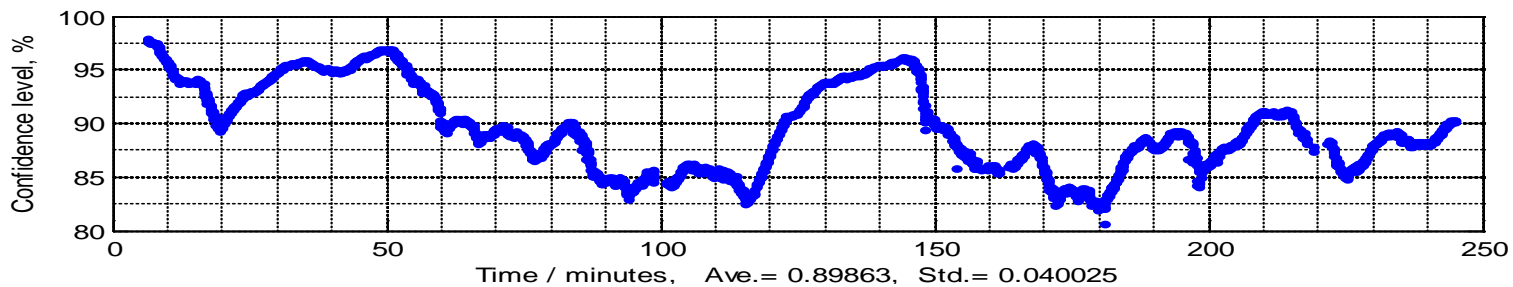
Mode Frequency



Damping Ratio



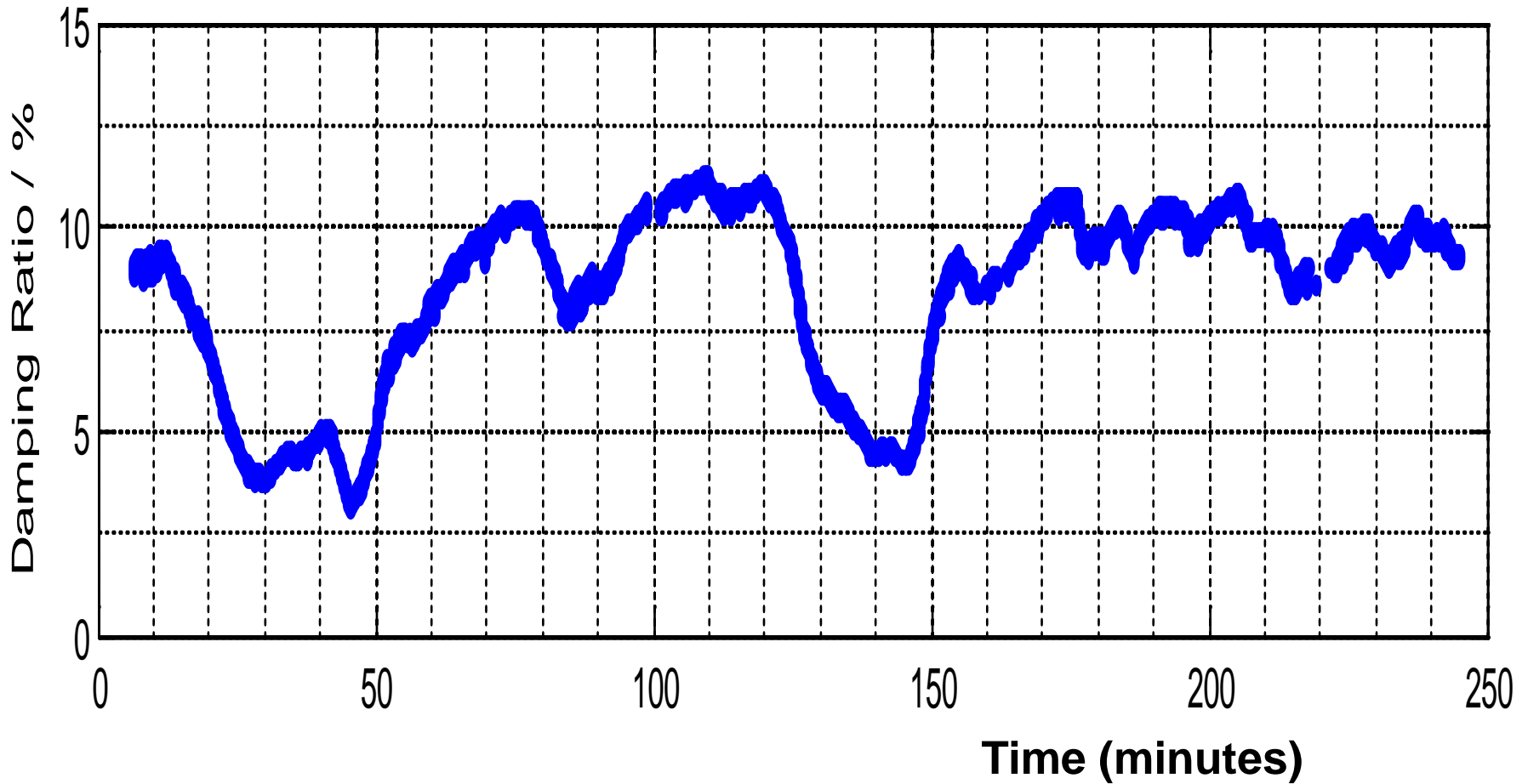
Energy Estimate



Estimate Confidence

Rapid Changes in System Damping

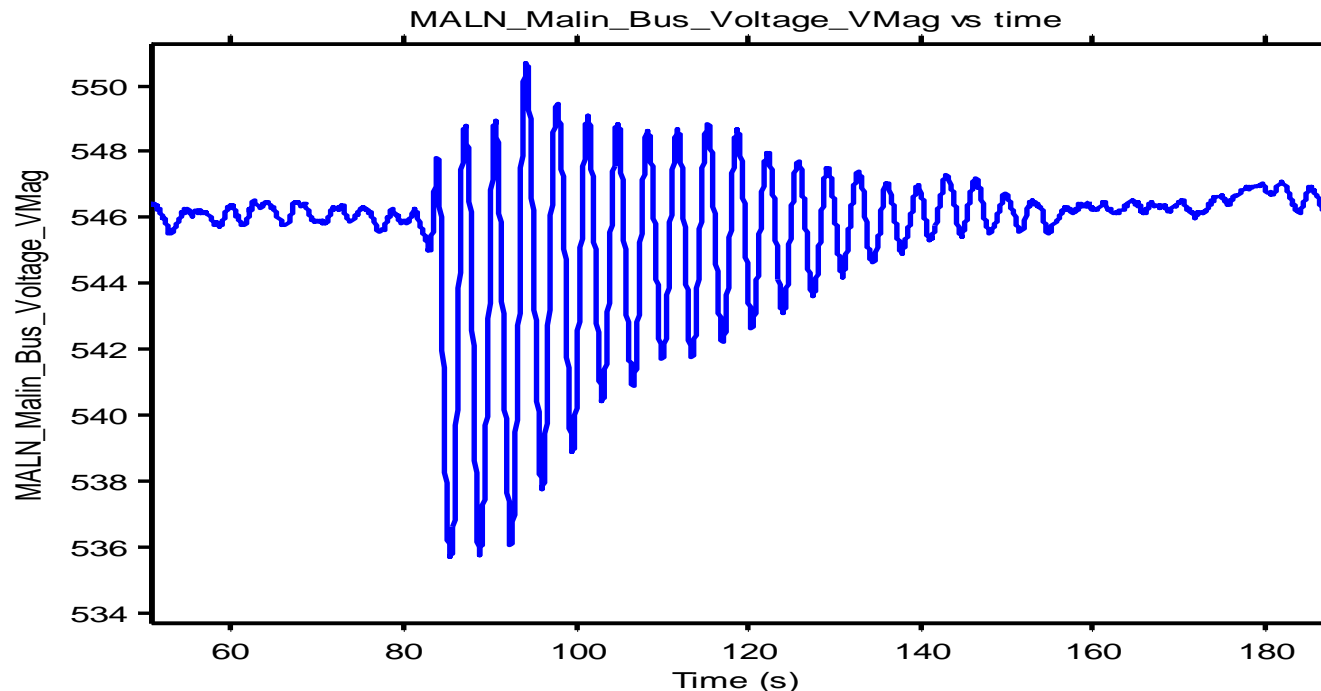
Western System Event



Power System Prony Analysis

- Nonlinear Large Scale System
- In theory, Prony Analysis works well for analyzing “small-disturbance responses”
- Nonlinearity dominant just after large disturbances
- Switching of lines and cap banks in the middle of analysis windows
- Noise effect on results if disturbance “fades away”
- How to get reliable estimation automatically?

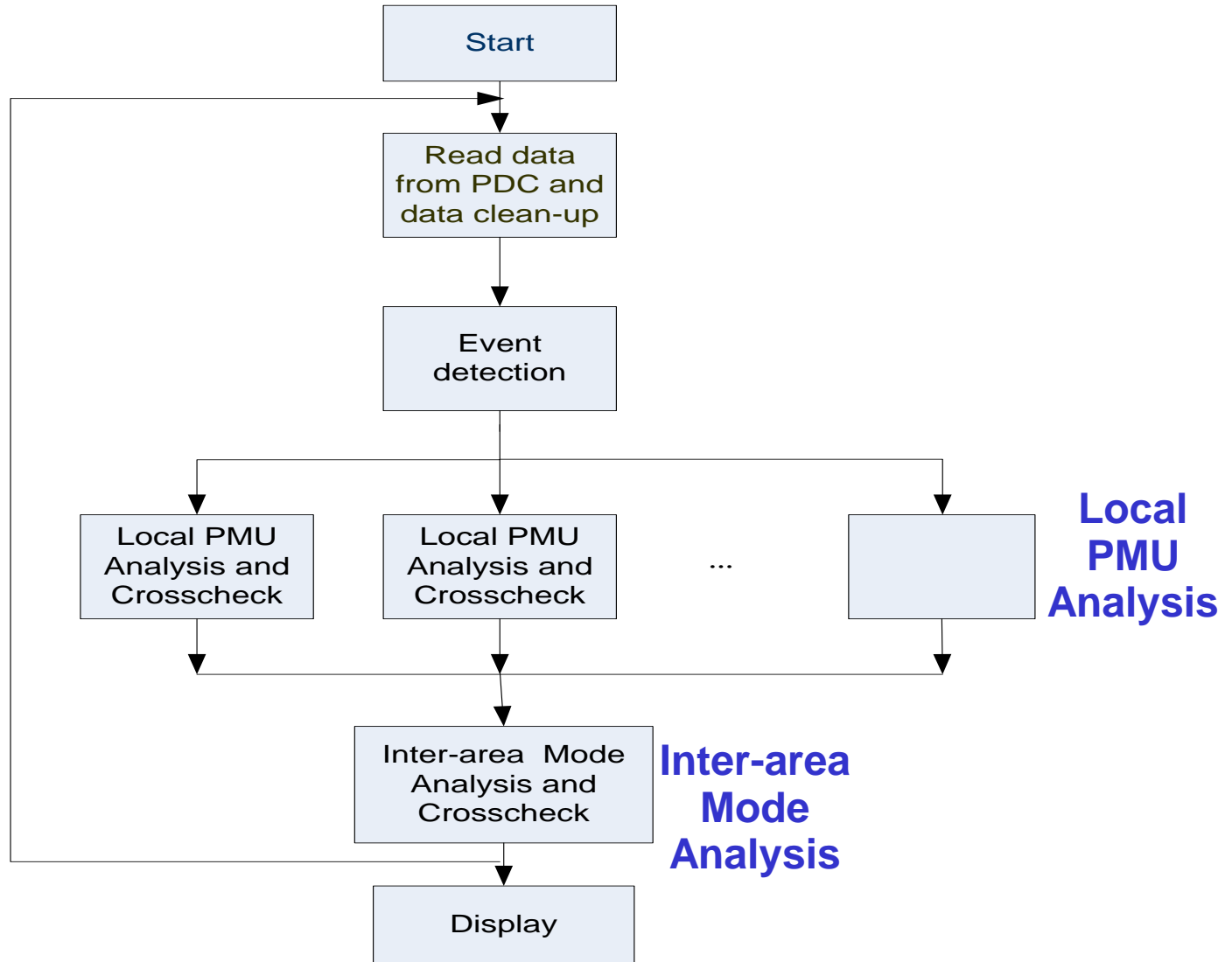
Rules for Real-time Prony Analysis



Three types of Consistency Crosscheck rules

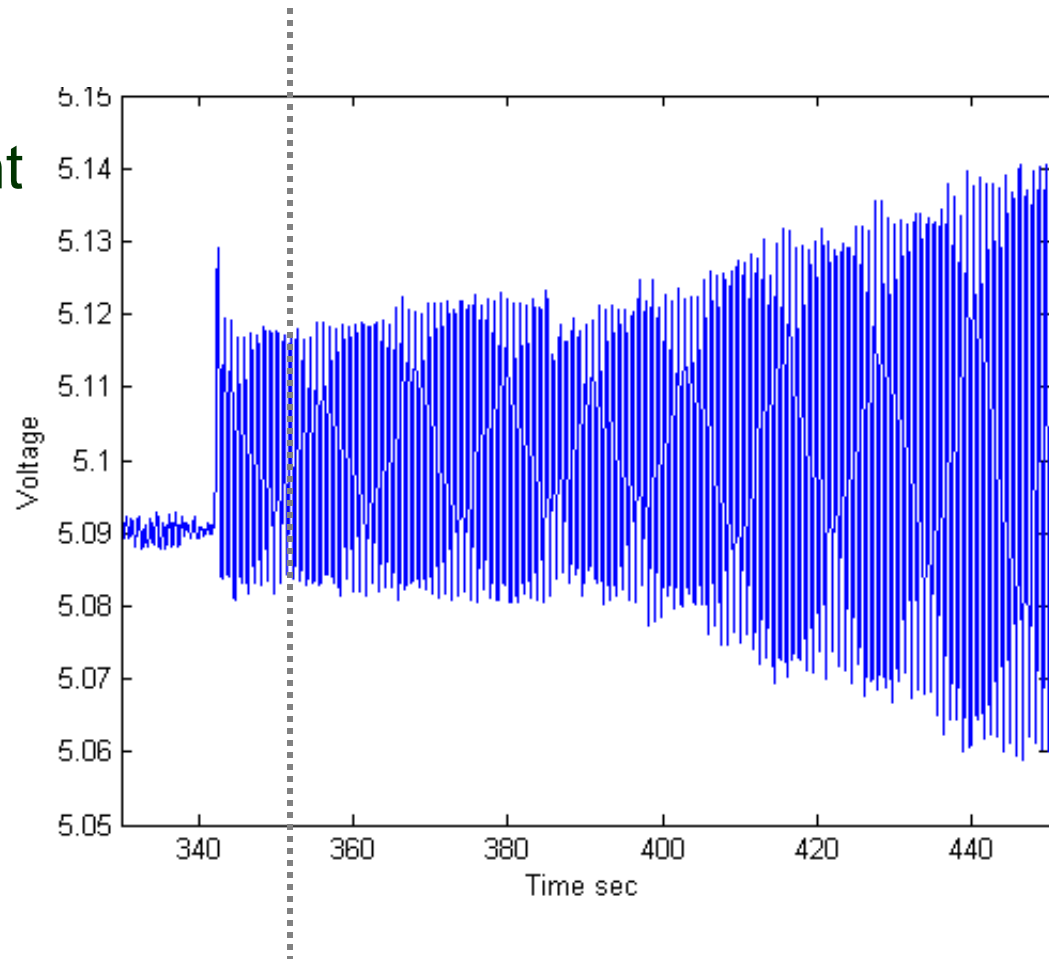
- Different Curve-fitting Methods (Redundancy)
- Different Signal Groups (Superposition)
- Moving Window Analysis (Linearity of Responses)

Event Analysis Engine

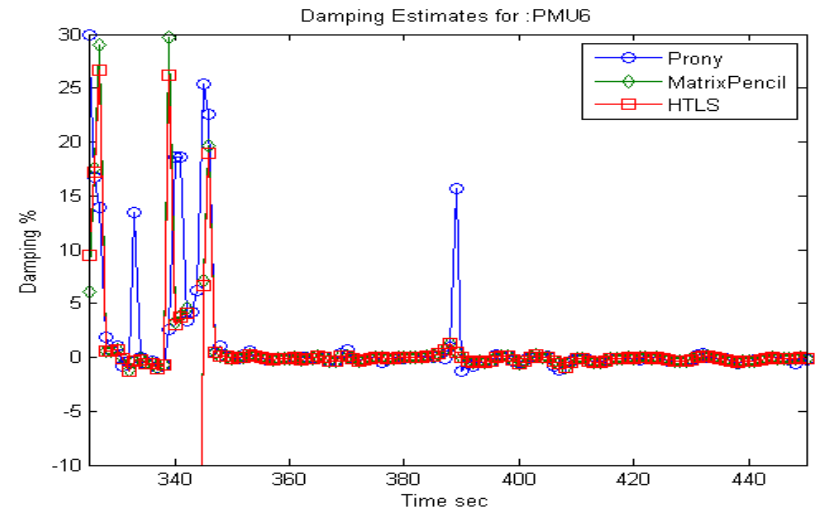
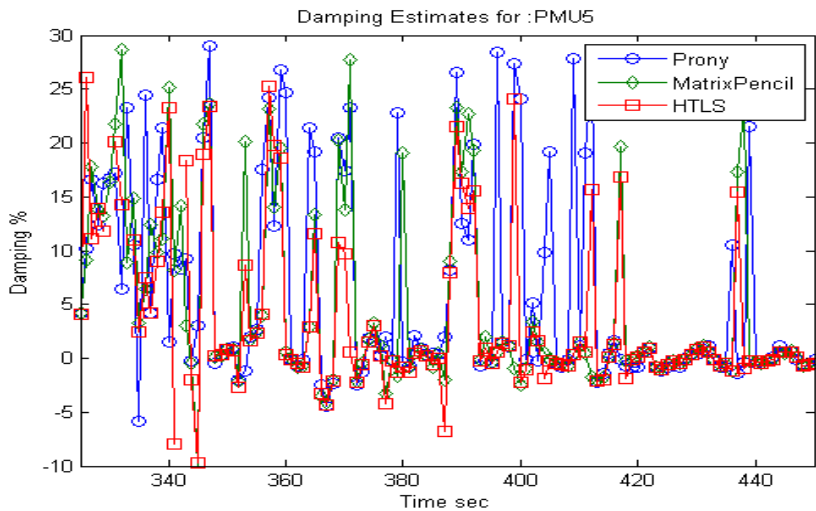
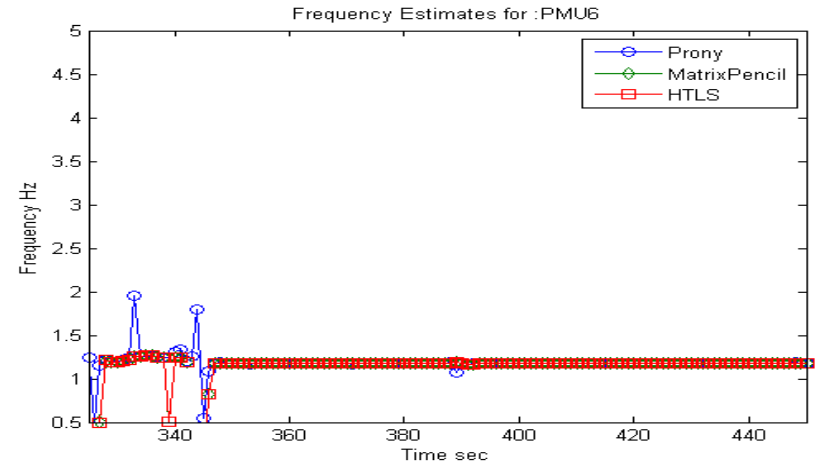
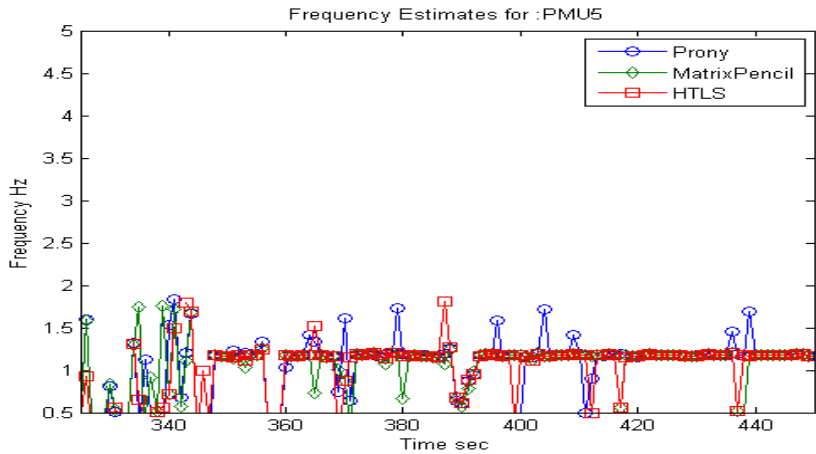


Event Analysis Example

- Eastern System Event
- Local oscillations at a generating plant
- 1.18 Hz oscillations



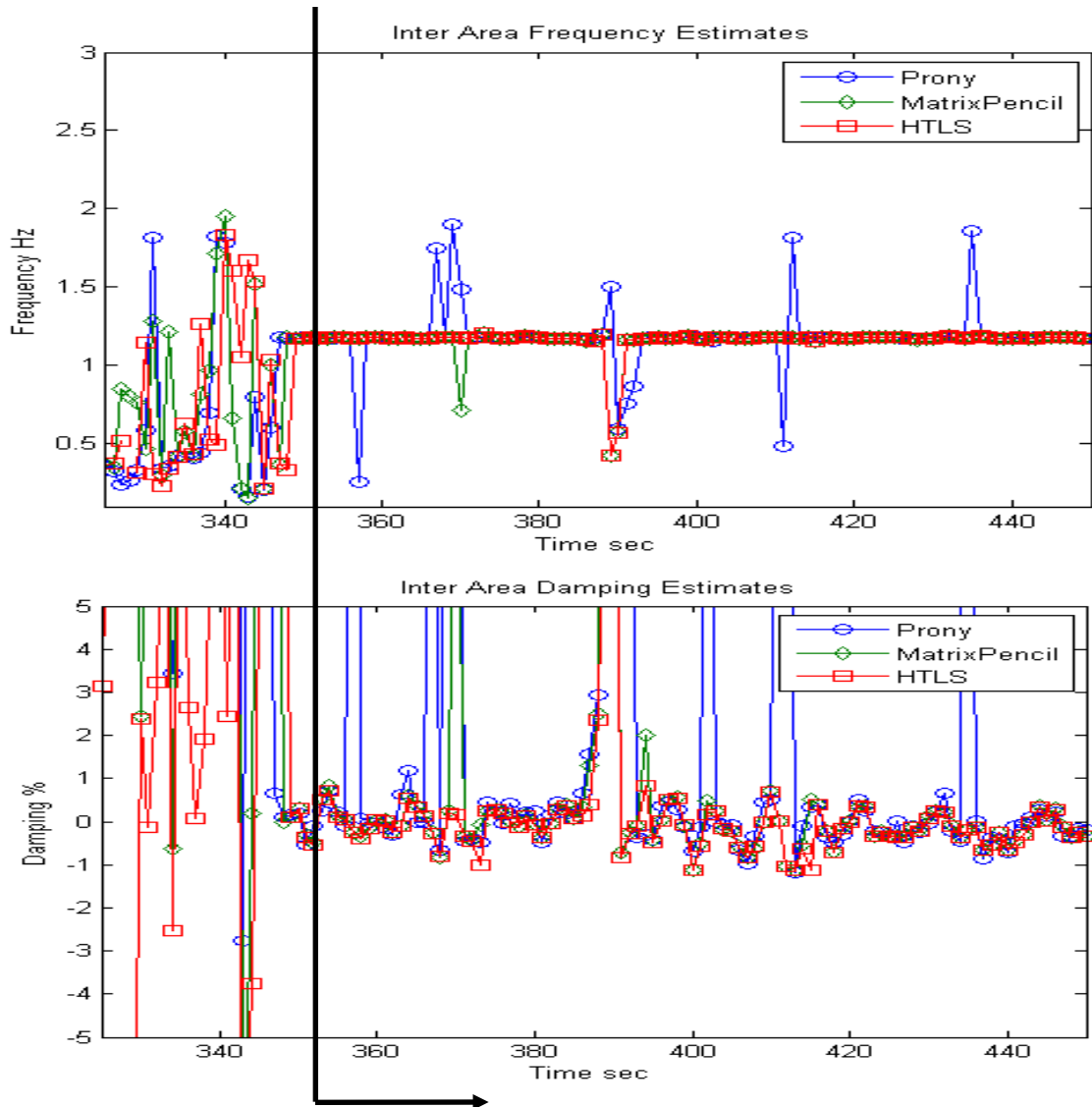
Case Study 1 – Local PMU Analysis



PMU5

PMU6

Case Study 1 – Multiple PMU Analysis

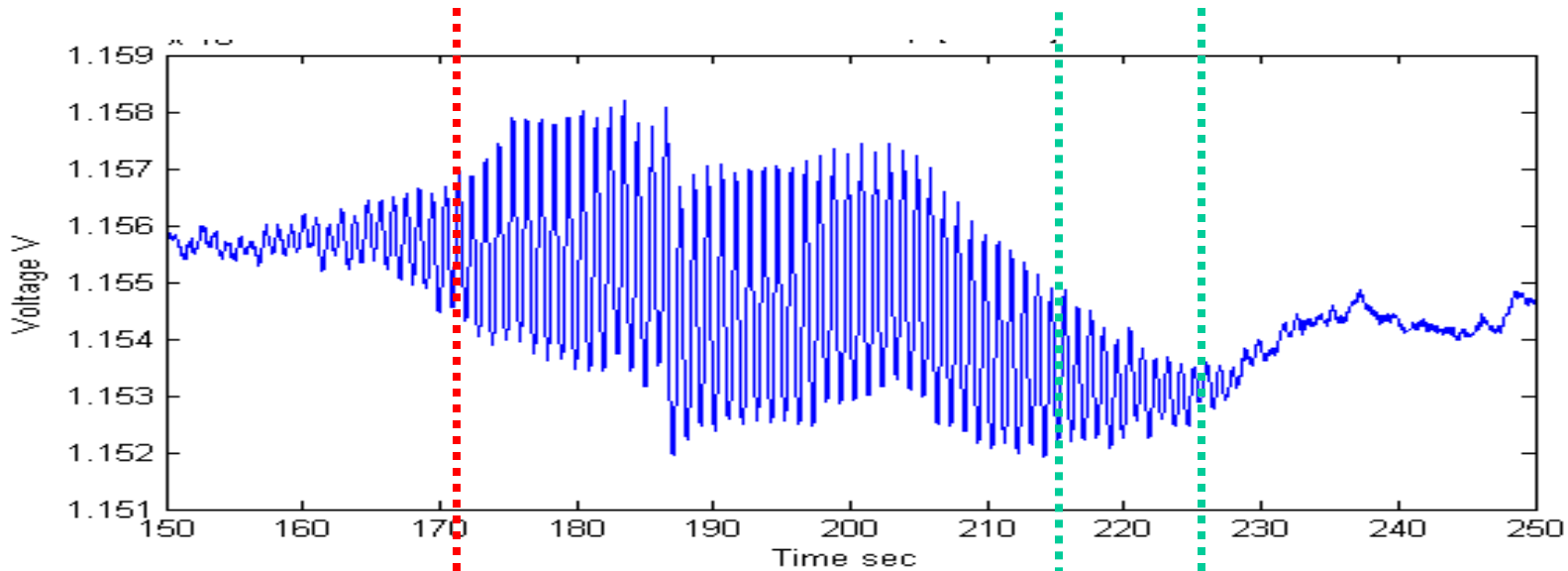


Consistent estimate
at 352 sec

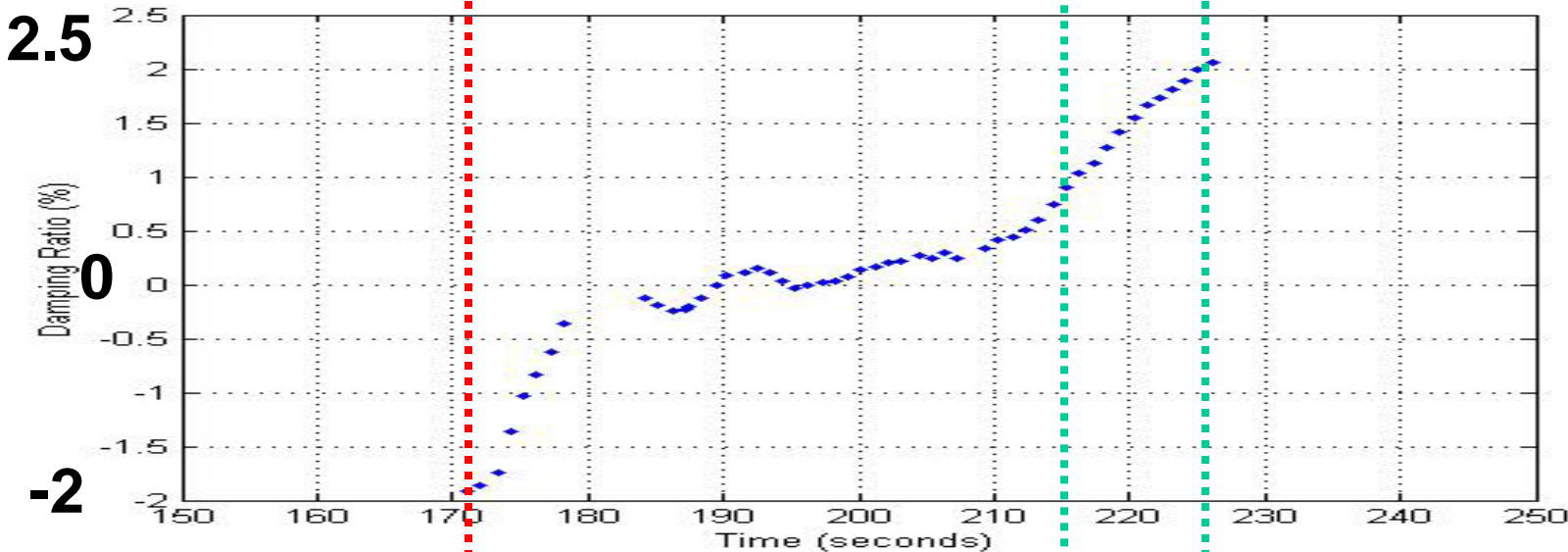
Oscillation frequency =
1.18 Hz

Mean damping ratio =
0.09%

Case Study 2 – Western event

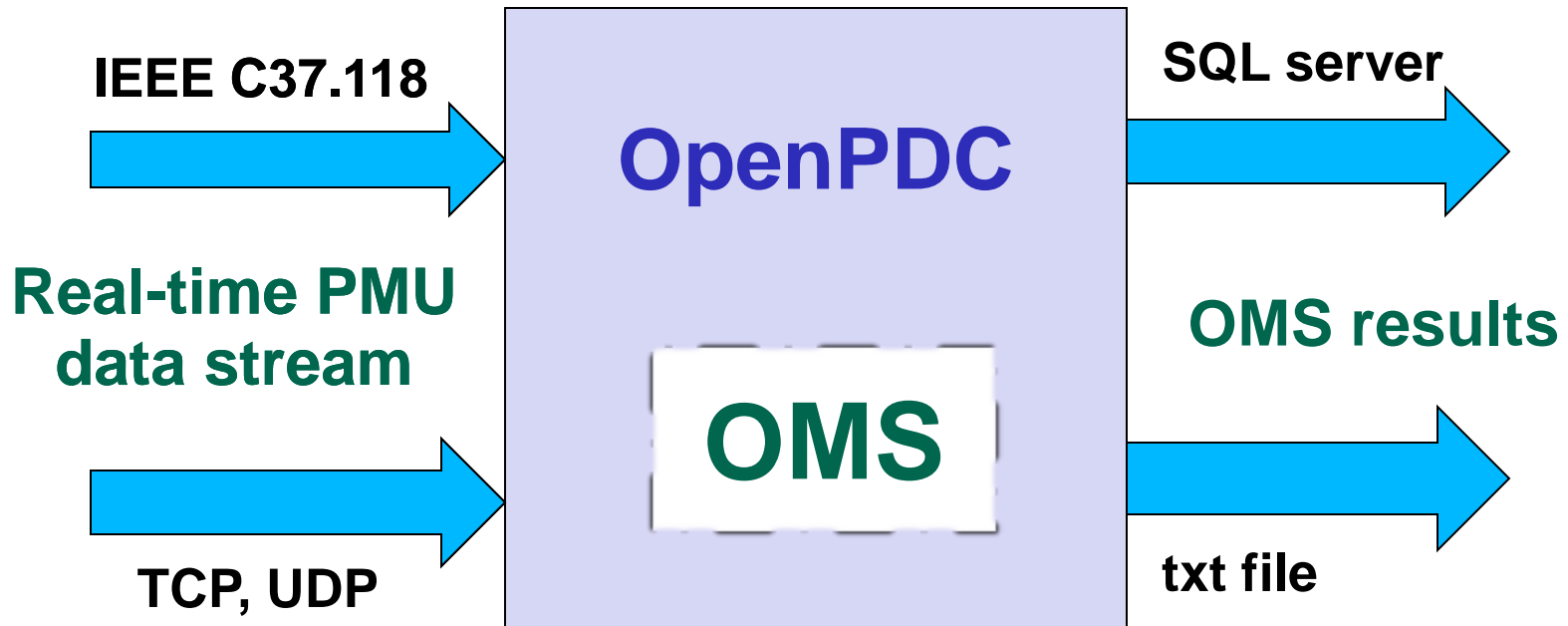


PMU
Bus
Voltage



Event
Analysis
Damping
Estimate

Oscillation Monitoring System



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