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Applications on openPDC platform at Washington State University

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WSU projects

- "OMS" - Oscillation Monitoring System
  - Stand-alone system for oscillation detection and analysis using wide-area PMUs
- "VSMS" - Voltage Stability Monitoring System
  - Stand-alone system for voltage stability stress indicator using wide-area PMUs
- "GridSim" – Large-scale real-time power grid simulator

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WSU projects

- "OMS" - Oscillation Monitoring System
  - Zaid Tashman, Lily Wu, Hamed Khalilinia, Arash Sarmadi
- "VSMS" - Voltage Stability Monitoring System
  - Tony Zhang, Hong Chun
- "GridSim" – Large-scale real-time power grid simulator
  - Chuanlin Zhao, Alex Ning

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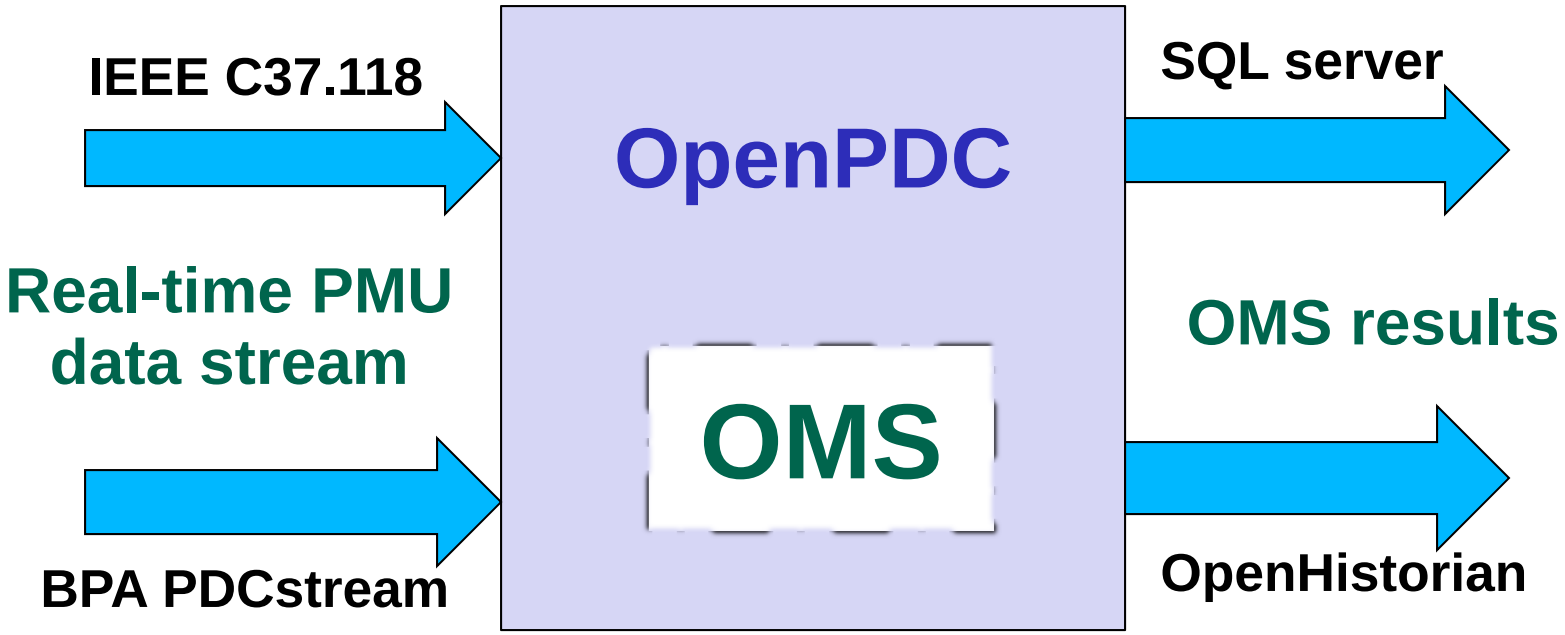
Oscillation Monitoring System



OMS action adapter built into OpenPDC 64 bit version 1.4 sp2 and 1.5 beta. Implemented at Entergy, WECC, TVA, …

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GridSim - Real Time Simulation of Power Grid Operation & Control

- Funded by USDOE
- Project team: Mani Venkatasubramanian (Project Lead), Anjan Bose, Dave Bakken, Carl Hauser, Chuanlin Zhao, Dave Anderson, *Zaid Tashman, Alex Ning, Ming Meng, Lin Zhang*
- Simulate PMU like real-time responses of large-scale power system including power grid dynamics and communication network
- Most of the GridSim slides contributed by Chuanlin Zhao

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Project Tasks

1. Real Time Power Grid Simulation
2. Streaming Measurement Data
3. Data Communications – Gridstat Middleware
4. Oscillation Detection – Wide Area Monitoring
5. State Estimation – Real Time Modeling

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Tasks 1 and 2

- Real Time Power Grid Simulation
  - Use commercial grade transient stability program – Powertech TSAT
  - Simulate a large real system in real time
  - Replace output file with streaming data
- Streaming Measurement Data
  - Streaming data needed at PMU locations
  - Measurement data in IEEE C37.118

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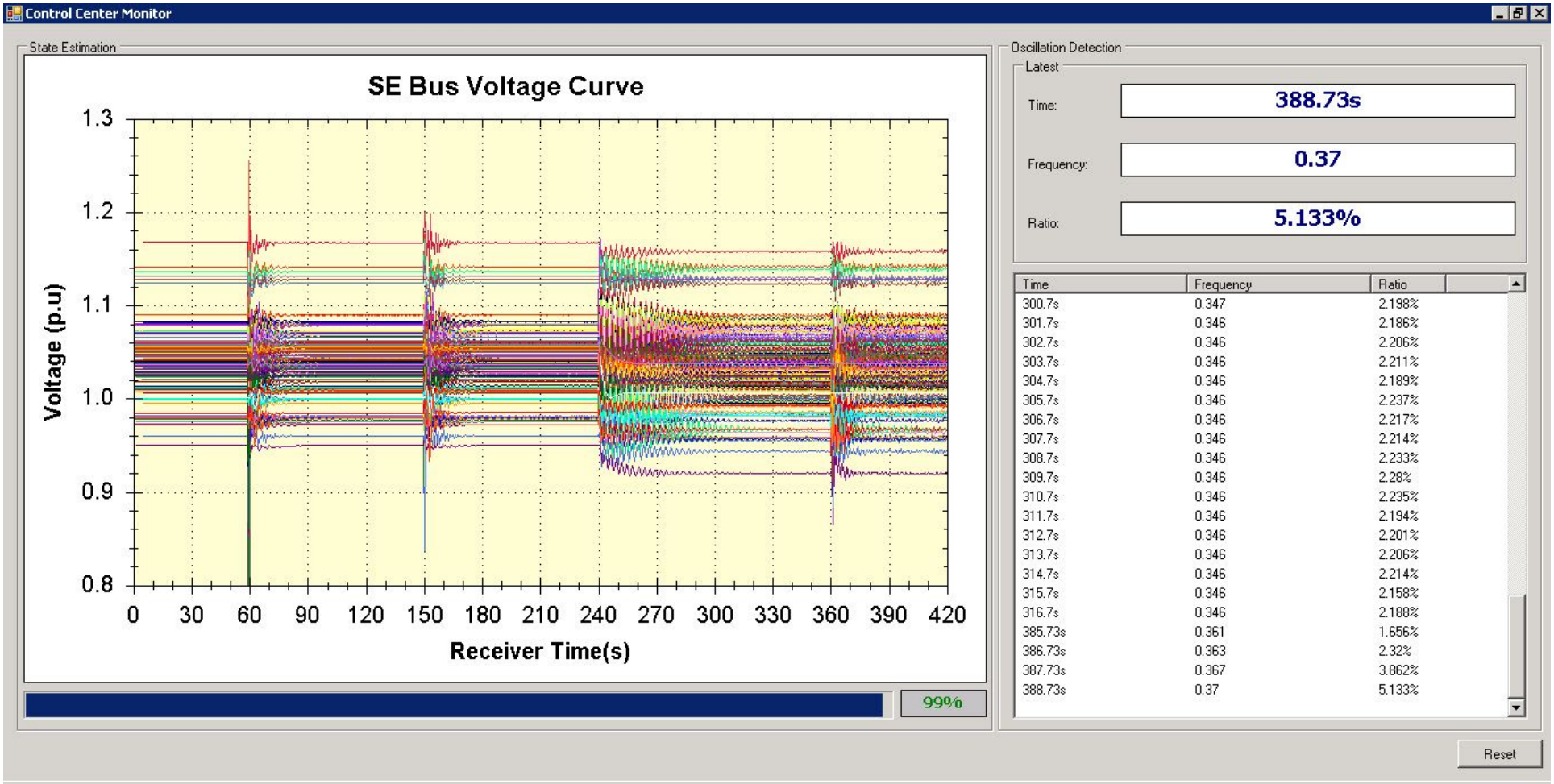
179 Bus Example



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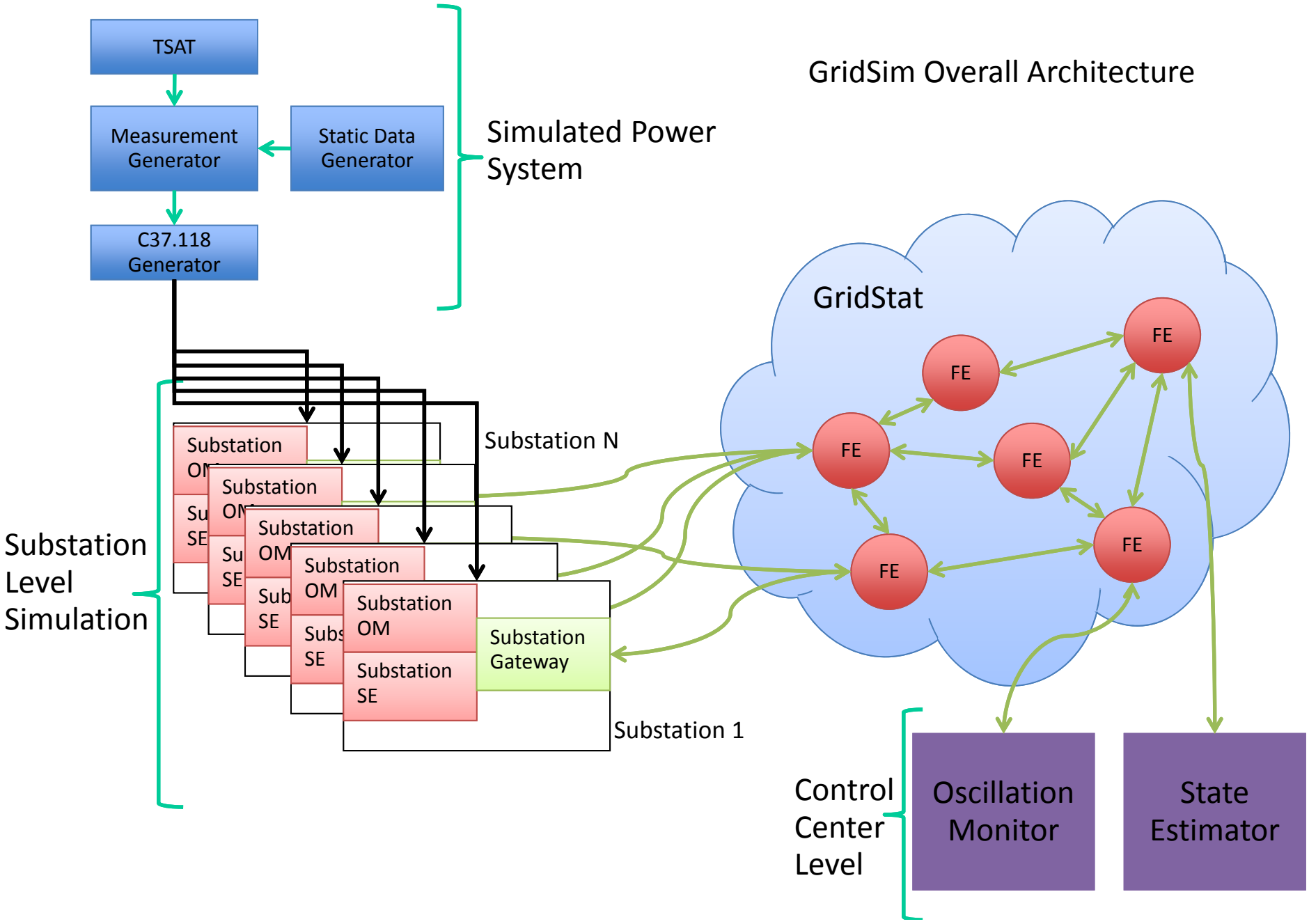
GridSim Overall Architecture



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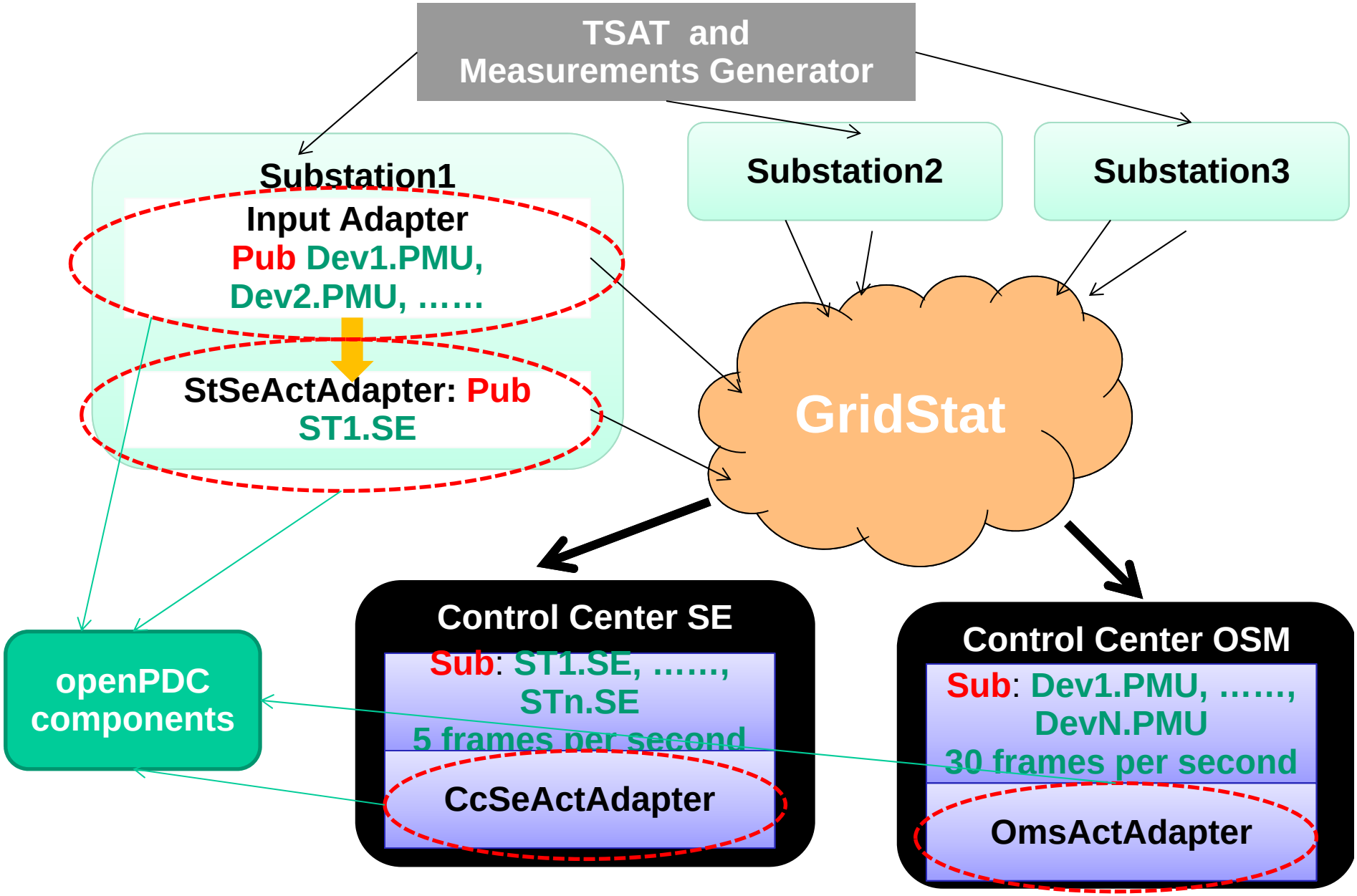
Overall Architecture



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New Adapters

Input Adapters

- New InputAdapters receives PMU data from GridStat. Supports Publish/Subscribe pattern.
- New InputAadpters receives substation-level SE result, other than raw PMU data.

Action Adapters

- Action adapters implements substation-level and control-center-level State Estimation
- Action adapters implements Oscillation Detection. Damping Monitor, Event Analysis.

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OmsLite

- We don’t use openPDC.exe directly. Instead, we use the libraries provided by openPDC to build our own host platform.
- Is this necessary?

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OpenPDC: powerful but huge

- Pros: enterprise-level software
  - Flexible: dynamic configuration changes without rebooting
  - Secure: user/password protection
  - Robust: runs as a service
- Cons:
  - Needs training
  - Difficult to debug and test
  - Resources expensive: advanced functions never come without a price

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OmsLite

- A light platform to host action adapters
- OmsLite:
  - Build based on the libraries provided by GPA
  - Remove the fancy components, and only keep the necessary ones
  - Its pros and cons are complementary to openPDC

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OmsLite

Cons

- Need to reboot after modification
- Not run as service, close it whenever you want

Pros

- Easy to use: modify the configuration file, save it and then click the icon again
- Easy to debug and test: set breakpoints, print error messages directly on the screen
- Save resources: Less fancy functions, Lesser resources needed
- Tested on SEL 3354 substation computer along with Oscillation Monitor Engine

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Useful Scenarios

- Research
  - Suitable for students and code developers
- For testing and development
- For light computer installations
- Seamless migration to OpenPDC
  - Share the same code base and database
  - Development period: debug and test using OmsLite
  - Deployment period: embed into openPDC with little additional effort

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Improvements

openPDCManager

- Manually configure each device one by one
- Batch configure. But we need connection file and configuration file first

For GridSim simulator

- Several thousand PMU devices
- Impossible for manual configuration
- No connection or configuration files

Tools are developed at WSU for automatic configuration

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Bug Fixes

- Detect an error, find and fix the bug, report fix plan to GPA, integrated into new version of openPDC
- Example:
  - Run more than 100 Action Adapters on a single computer
  - 100% CPU utilization: froze the computer
  - Reason: a wrong default value used in the concentrator settings

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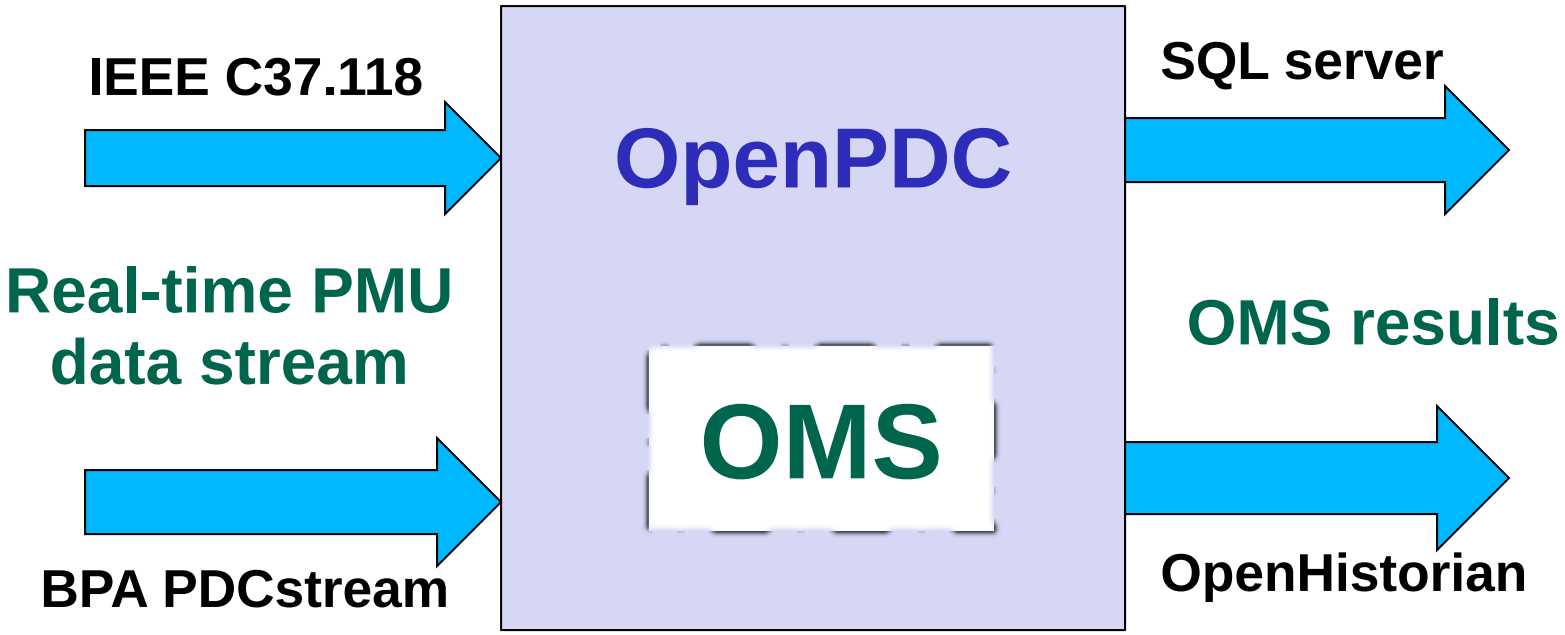
Oscillation Monitoring System



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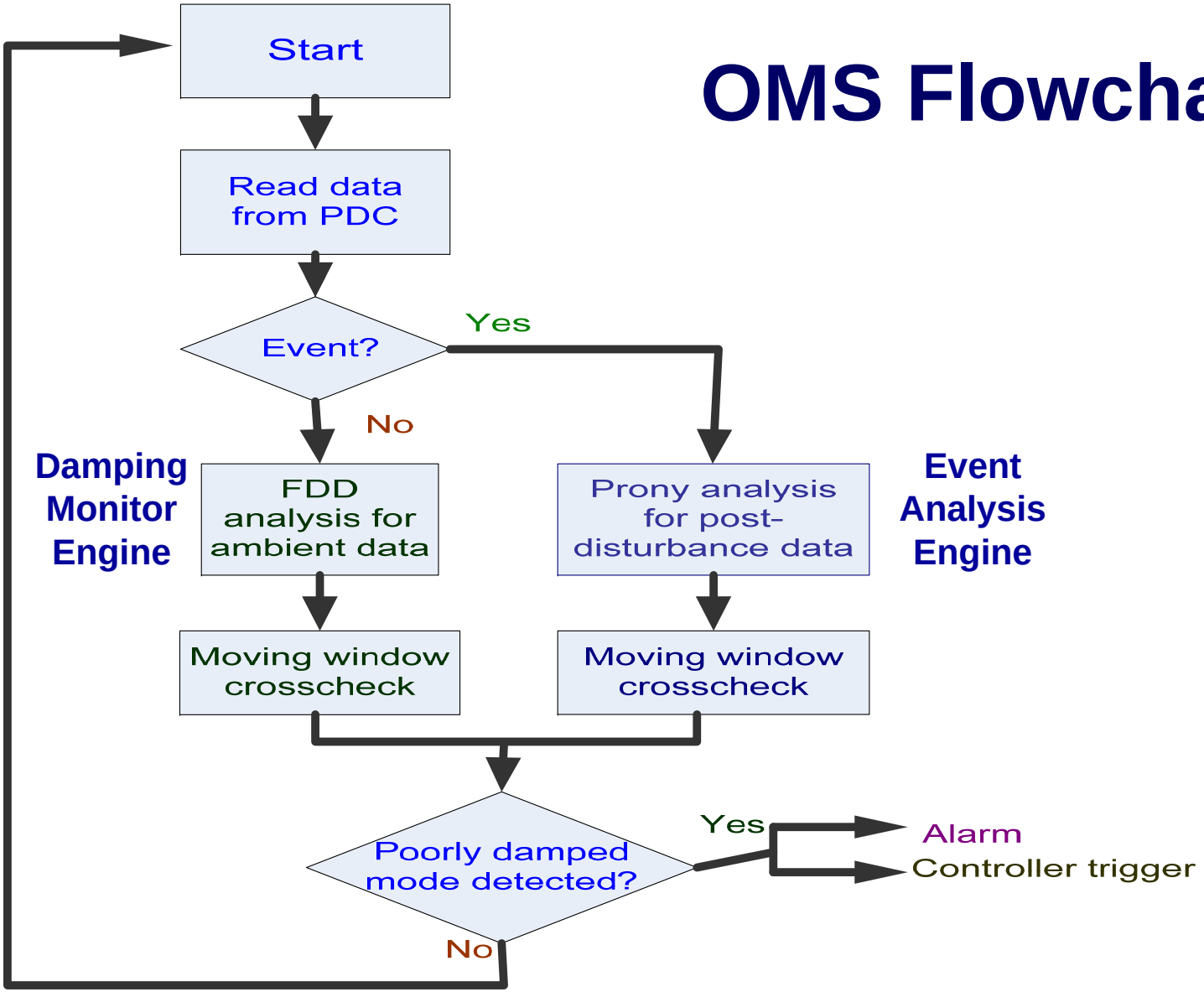
OMS Flowchart



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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.
  - Two algorithms: Frequency Domain Decomposition, Frequency Domain Optimization
  - Provides early warning on poorly damped modes

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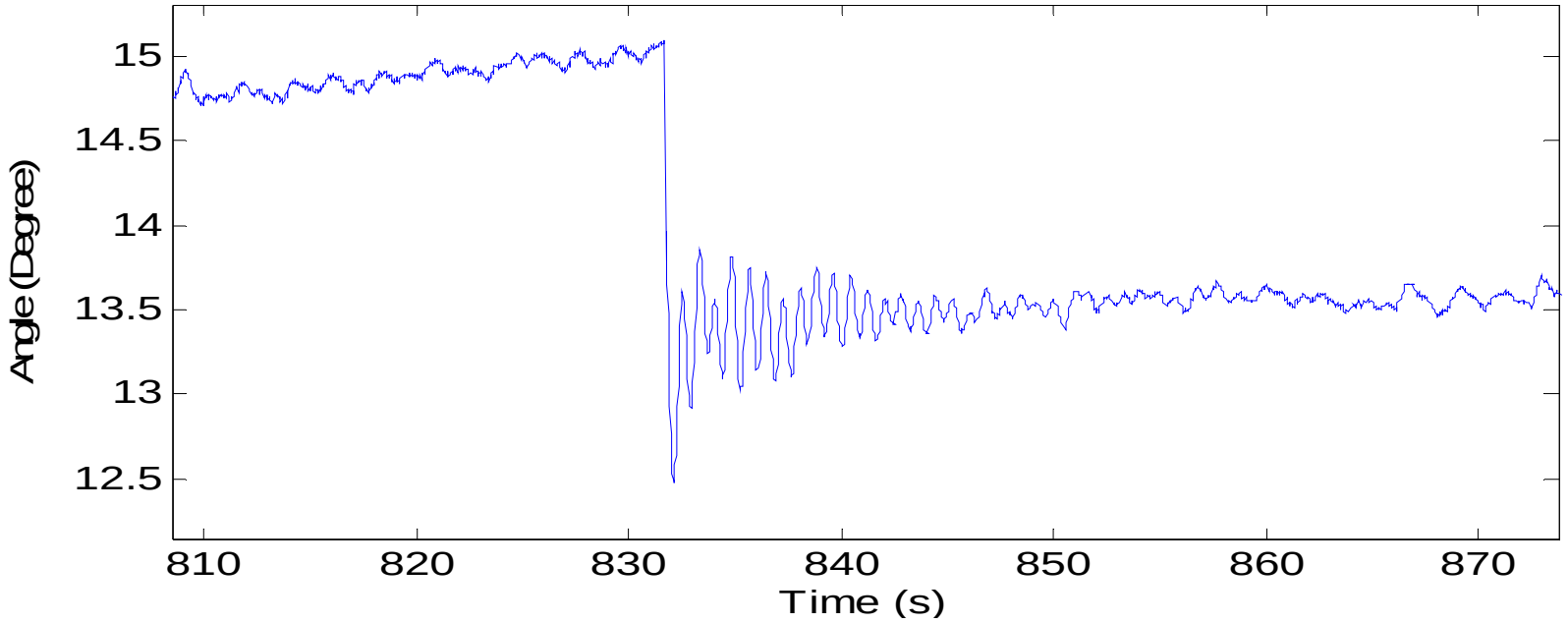
Case Study – TVA event



Prony analysis shows a poorly damped local mode at 1.25Hz with 1.5% damping ratio

The moving-window FDD gives the mean frequency of 1.2240 Hz and the mean damping ratio of 1.17%. The standard deviation of frequency estimates is 0.0049 Hz, and the standard deviation of damping ratios is 0.21%.

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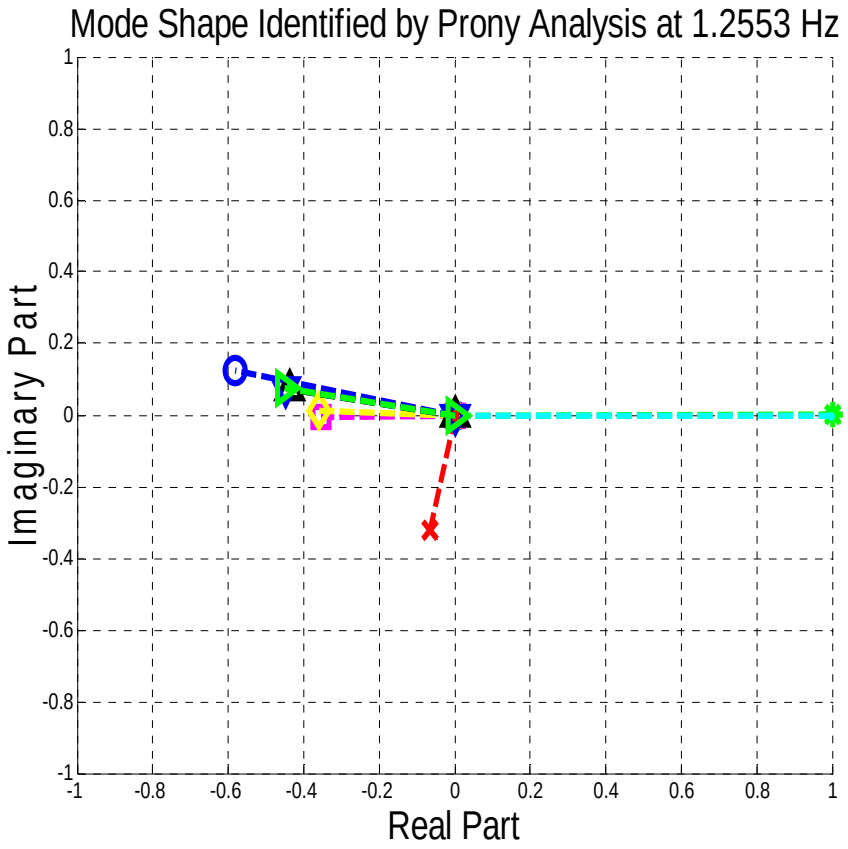
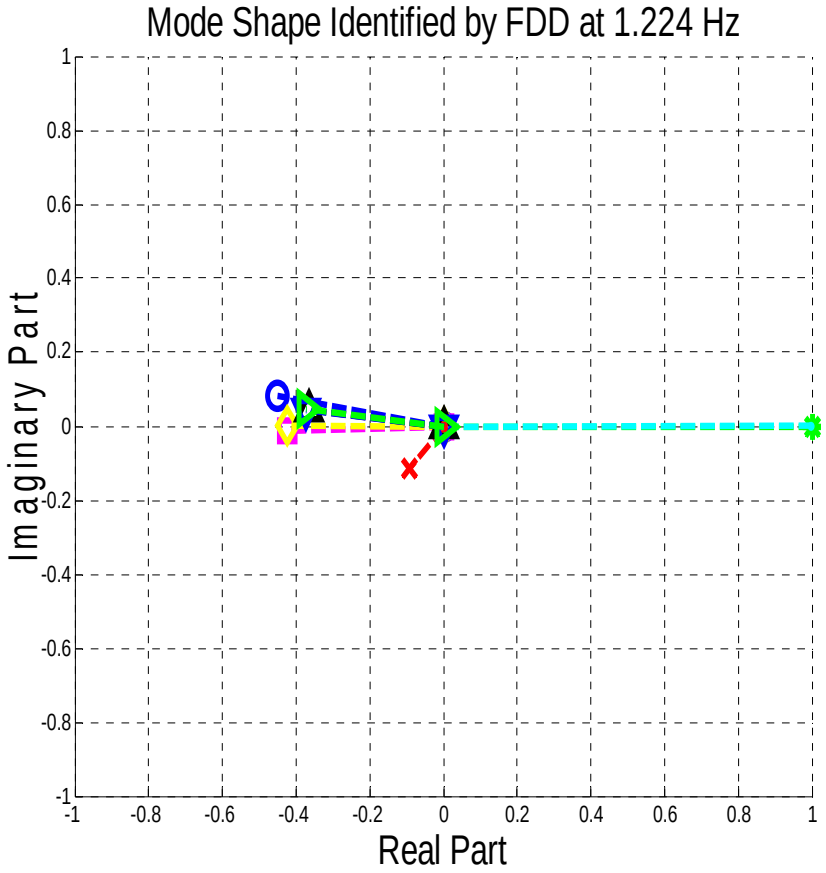
Mode Shape Estimation



Prony Mode Shape



FDD Mode Shape

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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

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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

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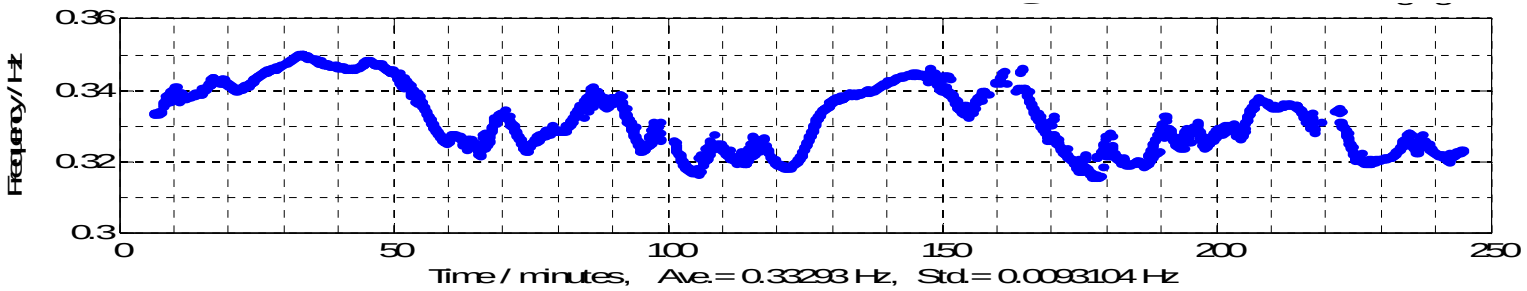
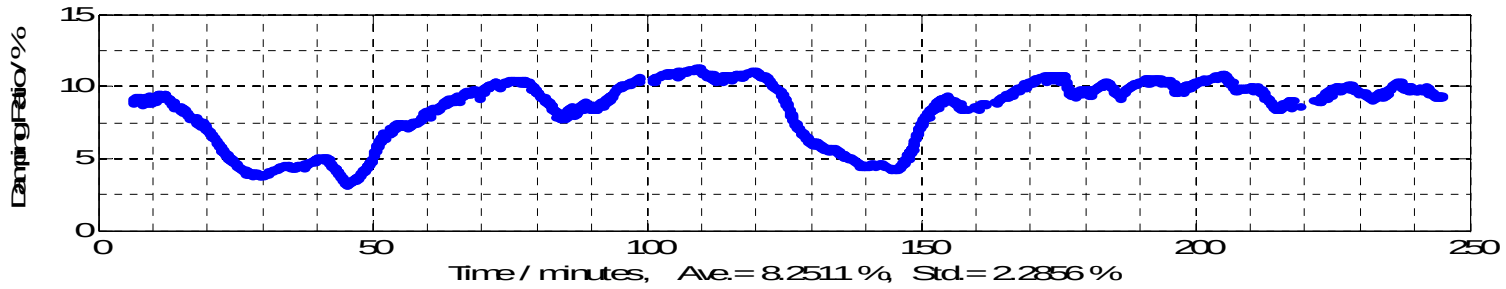
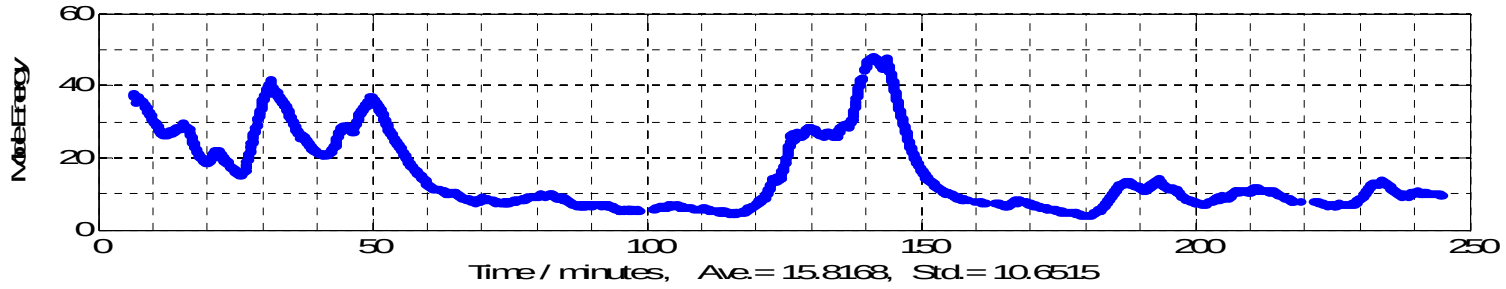
Western Data Analysis



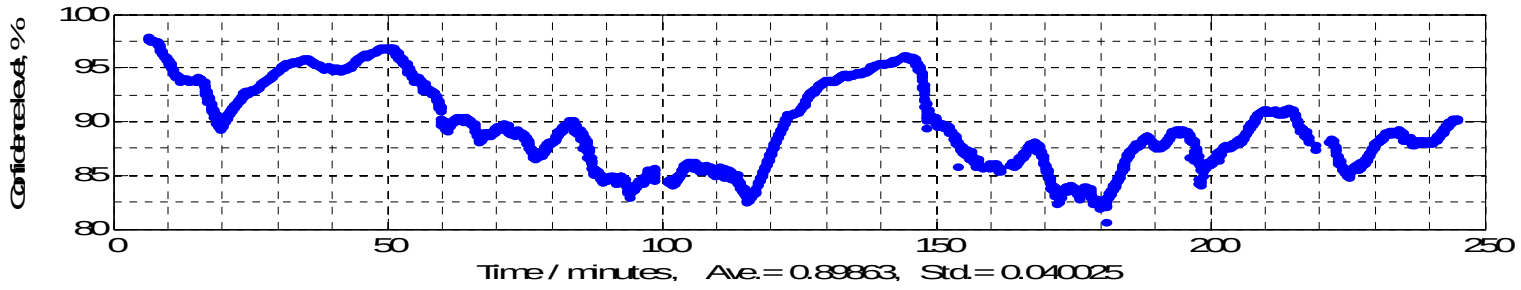
Mode Frequency



Damping Ratio



Energy Estimate



Estimate Confidence

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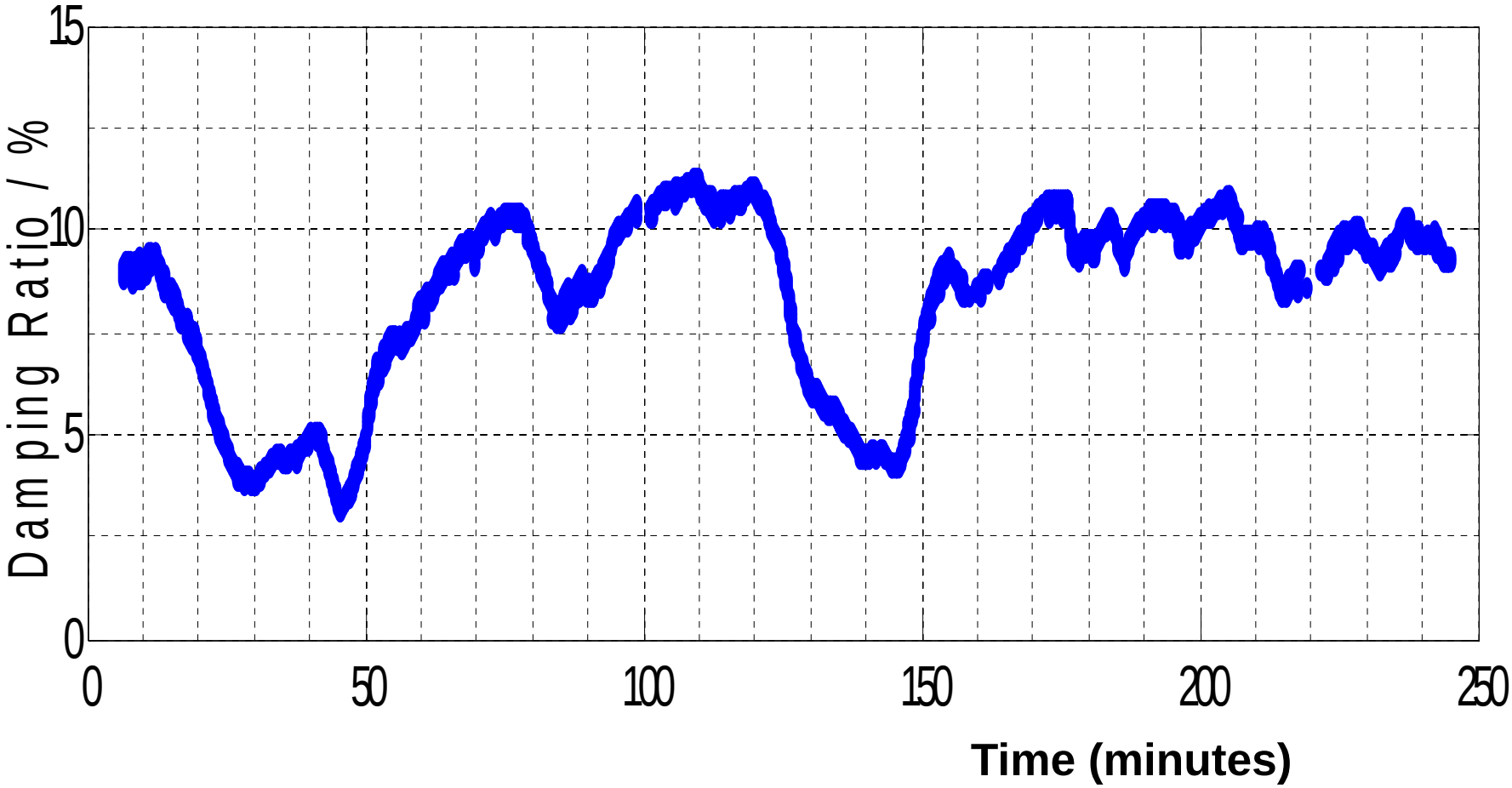
Rapid Changes in System Damping

Western System Event



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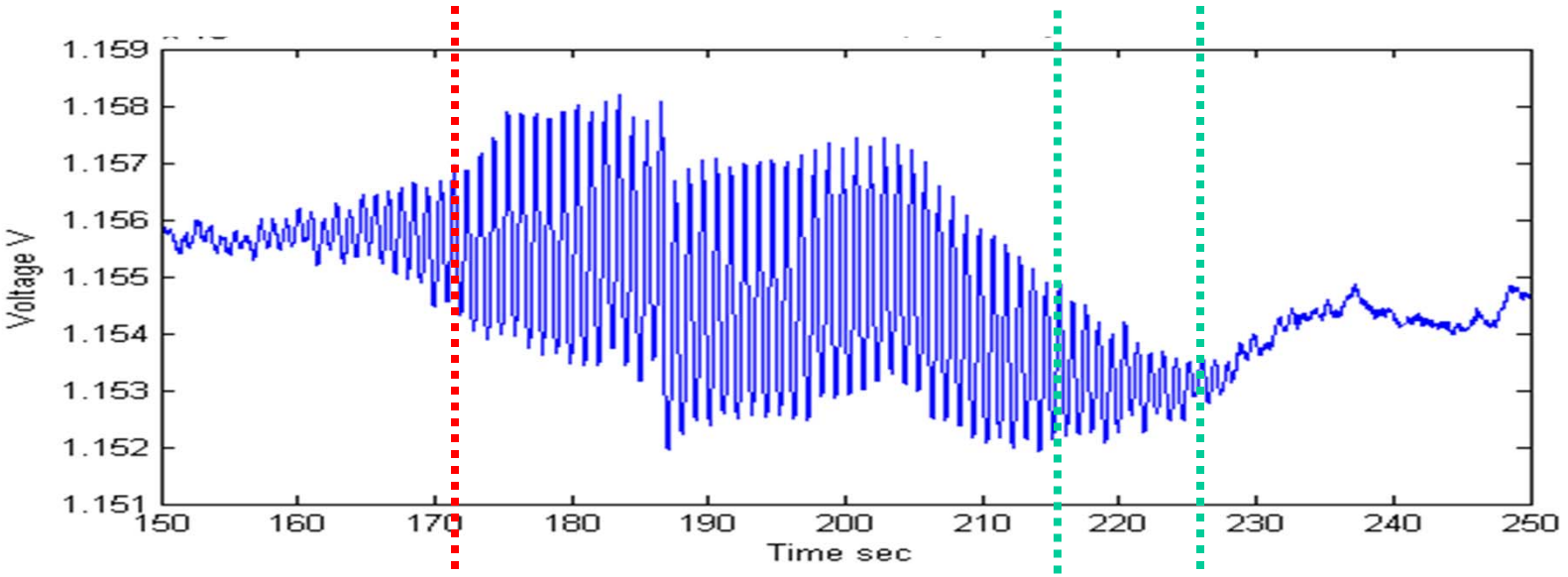
Power System Prony Analysis

- 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?

Case Study – Western event

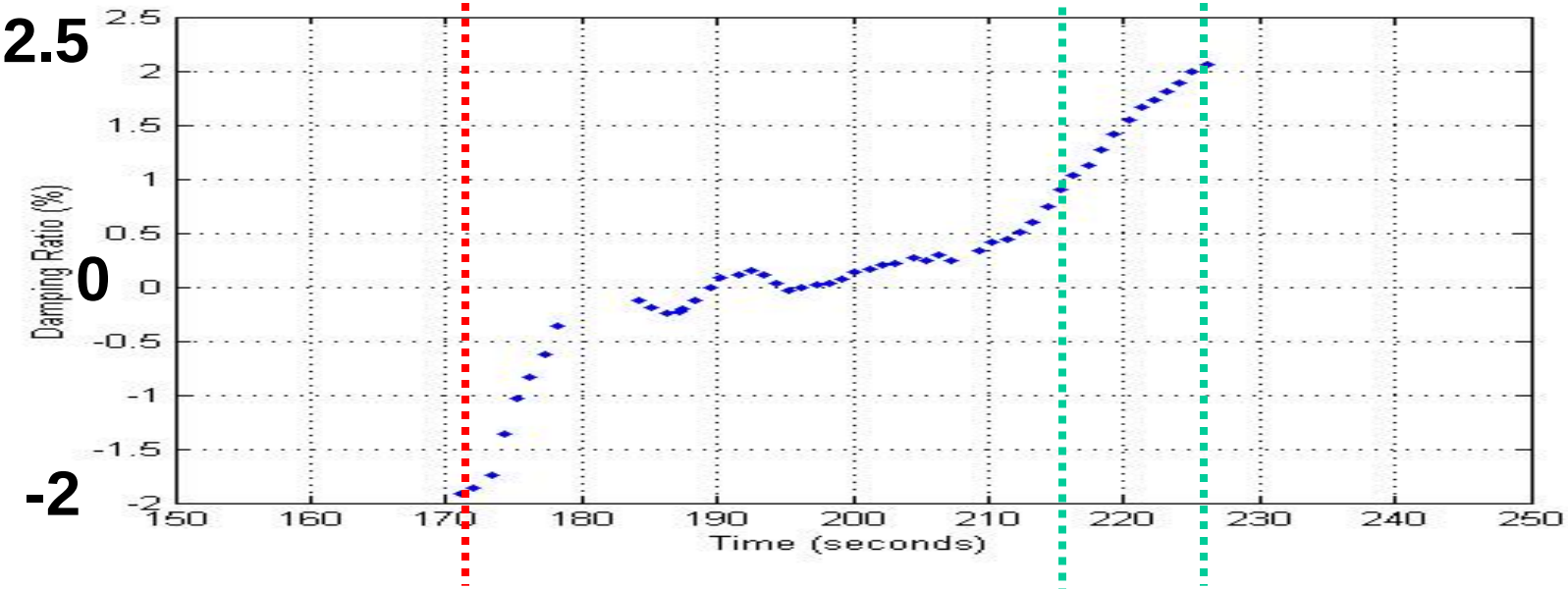


PMU Bus Voltage

2.5

0

-2



Event Analysis Damping Estimate

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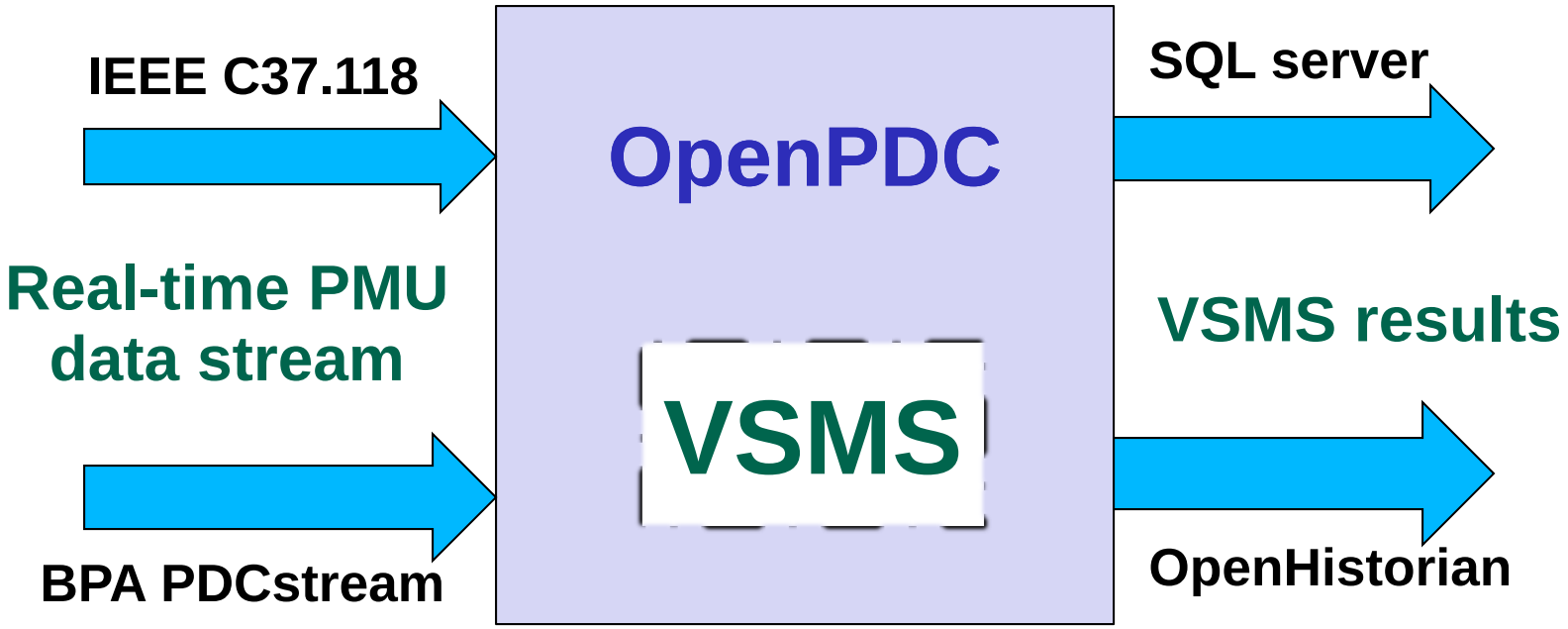
Voltage Stability Monitoring System



VSMS action adapter built into OpenPDC 1.5 beta. Implemented at Entergy and UNO.

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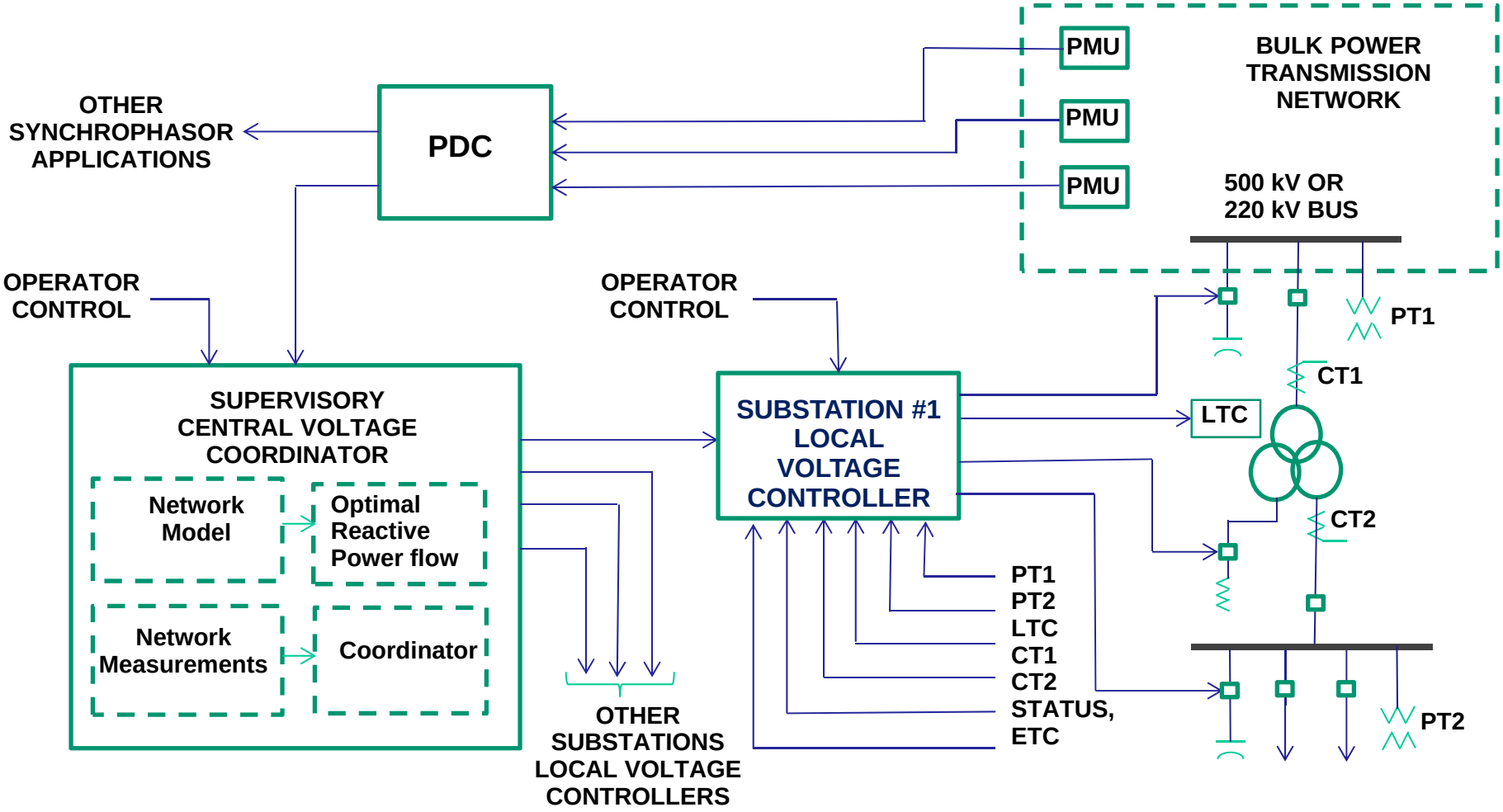
SCE Two-level Voltage Controller



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OpenPDC at WSU

- OpenPDC used extensively in several projects
- OpenPDC based PMU applications being installed at Entergy, TVA, and WECC
- GridSim – large-scale simulator of PMU data
- Substation Local Voltage Controller SLVC – controller based on local PMUs. Prototype implementation at SCE.