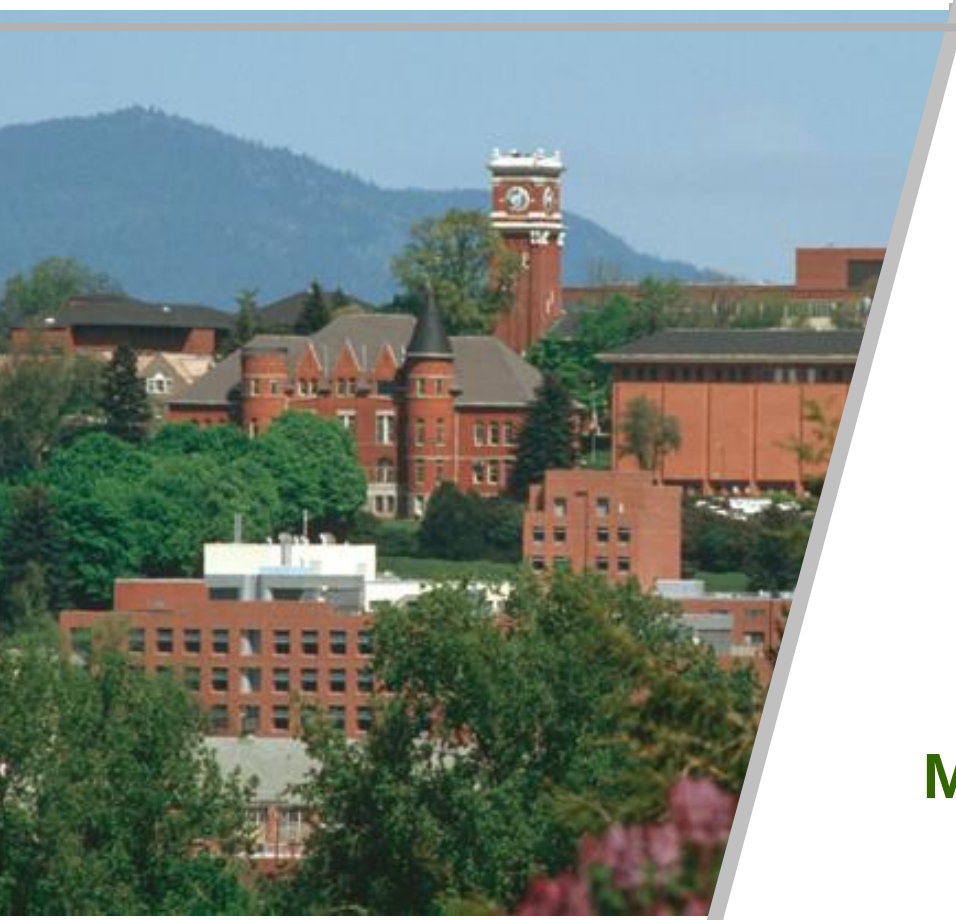


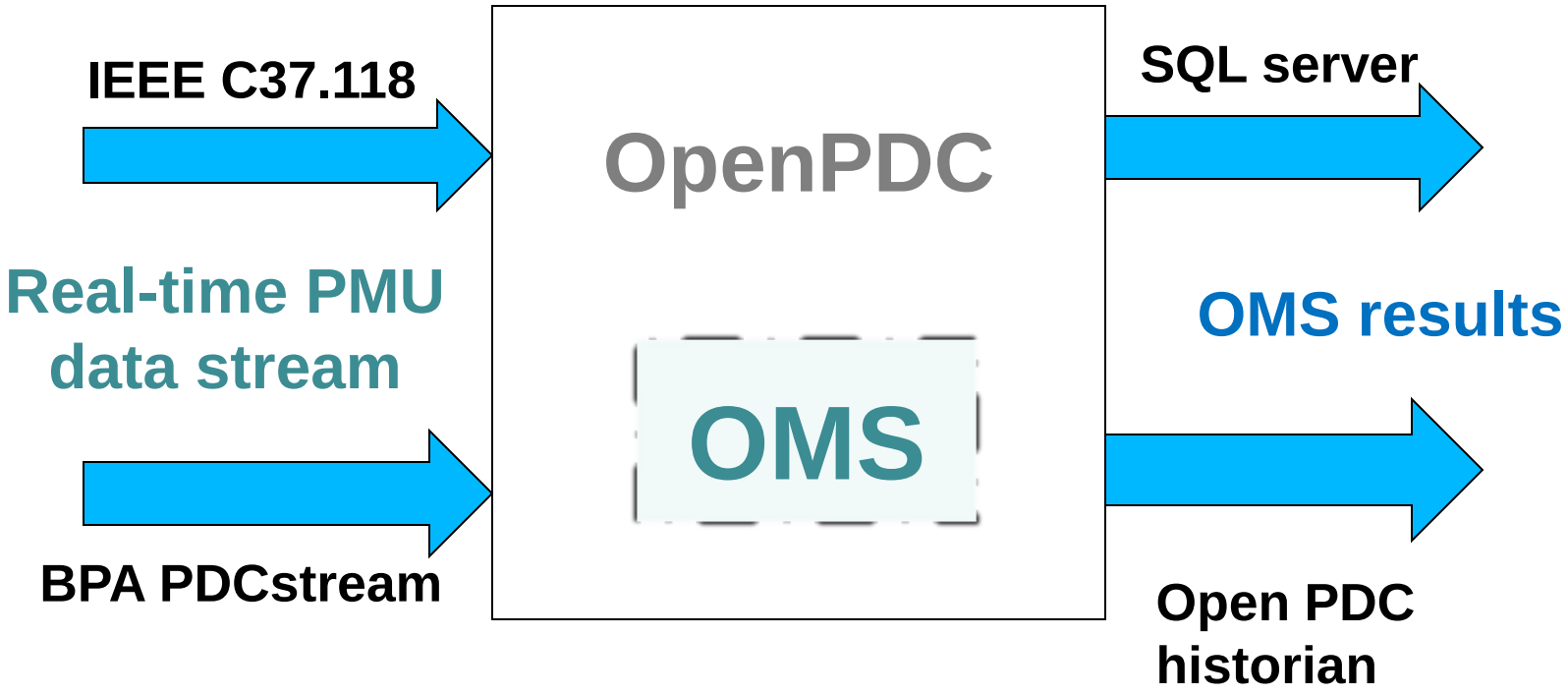
Turbo Oscillation Monitoring for Large-Scale Synchrophasor Data

Hamed Khalilinia
Mani V. Venkatasubramanian
Washington State University

Project Objectives

- **Oscillation Monitoring System for WECC and Entergy**
- **Monitoring hundreds of PMUs simultaneously**
  - **Helps pinpoint likely source of oscillations**
  - **Improves estimation accuracy**
- **Damping Monitor Engine – ambient data analysis**
- **Event Analysis Engine – detection and analysis of ringdowns and oscillations**
- **Real-time engines and off-line engines**

Oscillation Monitoring System

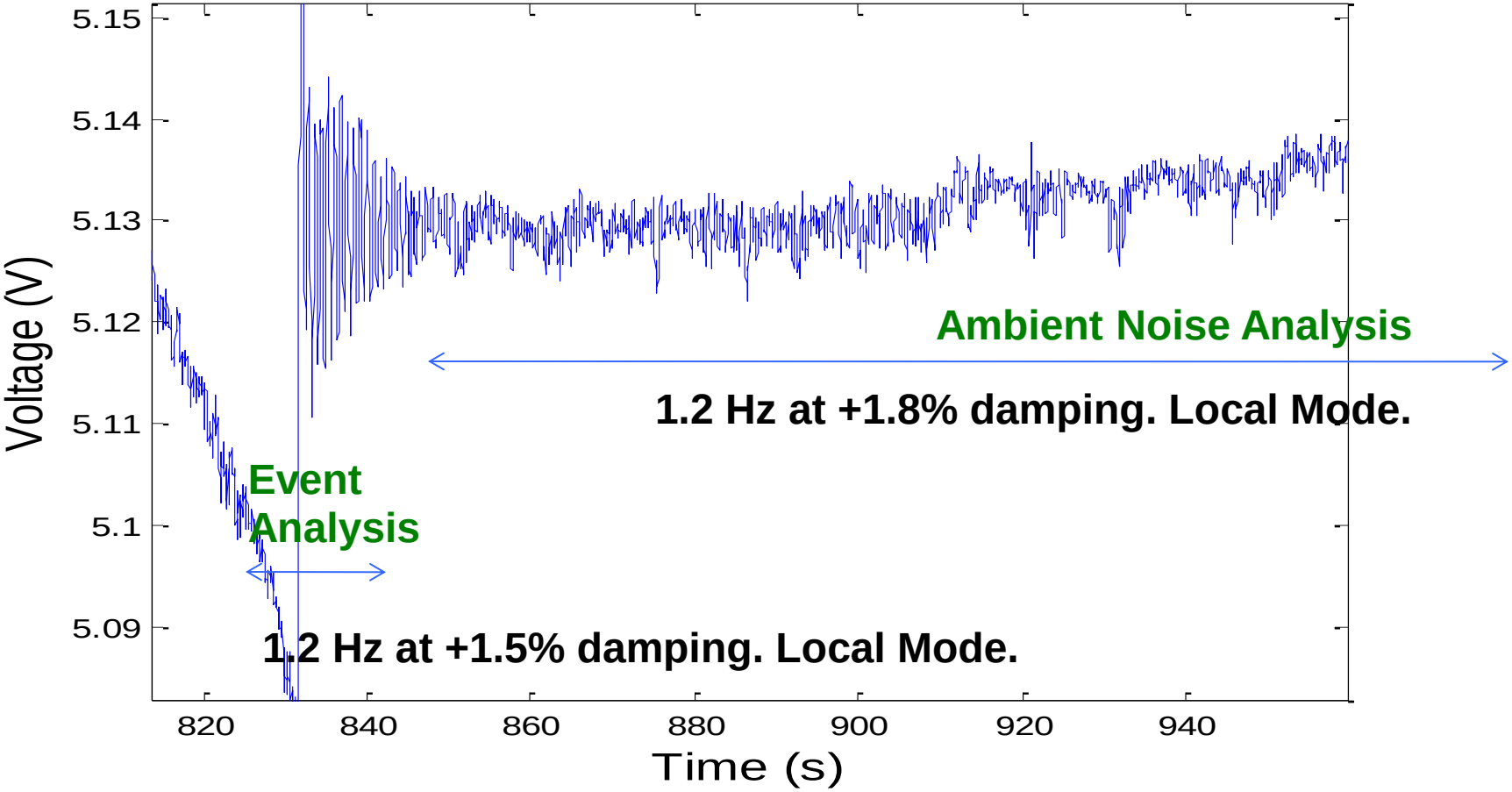


OMS action adapter built into OpenPDC 64 bit version 2.1.

Oscillation Monitoring Off-line

Stand alone oscillation analysis programs for analyzing historical PMU data either from Comtrade/CSV files or directly from PI historian.

Results from Two Engines



Complementary Engines

- Event Analysis Engine (EAE)
  - Multiple algorithms
  - Prony, Matrix Pencil, HTLS, ERA, MFRA, METRA.
  - Aimed at events resulting in sudden changes in damping
- Damping Monitor Engine (DME)
  - Ambient noise based. Continuous. Provides early warning on poorly damped modes.
  - Several algorithms
  - Fast Frequency Domain Decomposition (FFDD), DFDO, Recursive Adaptive Stochastic Subspace Identification (RASSI), DFDD, RFDD, DRSSI, FSSI.

Damping Monitor Engine

- Ambient noise based. Continuous. Provides early warning on poorly damped modes.
- Many multi-dimensional algorithms developed at WSU
- Time-domain algorithms:
  - Stochastic Subspace Identification (SSI-Covariance)
  - Recursive Adaptive Stochastic Subspace Identification (RASSI)
  - Distributed Recursive Stochastic Subspace Identification (DRSSI)
  - **Fast Stochastic Subspace Identification (FSSI)**
- Frequency-domain algorithms:
  - **Fast Frequency Domain Decomposition (FFDD)**
  - Distributed Frequency Domain Optimization (DFDO)
  - Decentralized Frequency Domain Decomposition (DFDD)

Frequency Domain Decomposition

- Collect and preprocess signals from PMUs
- Power spectrum matrix estimation by Multi-Taper Method
- Apply SVD on the power spectrum matrix
- Apply inverse FFT on largest singular values
- Extract pole frequency and damping ratio from exponential form by ringdown analysis
- Can process 100 signals simultaneously in real-time (fast)

Fast Frequency Domain Decomposition (FFDD)

- **Collect and preprocess signals from PMUs**
- **Power spectrum estimation by FFT and Multi-Taper Method**
- **Apply SVD on the power spectrum**
  - Approximate the largest singular value by the trace of the power spectrum matrix (**Fast FDD**)
- **Apply inverse FFT on largest singular values**
- **Extract pole frequency and damping ratio from exponential form by ringdown analysis**
- **Can process 1000+ signals simultaneously.**

Turbo Oscillation Monitoring

- Can process truly large number of signals 1000+ simultaneously in real-time: needed for source location.
- Offline mode: Can get a quick overview of system modal properties by fast analysis of historical data. Can study mode trends.
- An hour of data from 200 PMU signals can be analyzed in less than 2 minutes on a desktop
- Implemented in C# using Intel Math library. Multi-threaded. Scalable solutions offered.

FFDD Estimation Results

- Dominant modes are analyzed for each data set – four minutes of data updated every ten seconds
- For each mode:
  - Mode frequency
  - Mode damping ratio
  - Mode energy
  - Mode shape
  - Estimation confidence level

WASHINGTON STATE UNIVERSITY

Short Demos

Summary

- **PMUs enabling technology for online oscillation analysis**
- **System changing: fast responsive engines needed.**
- **Oscillation modes: analyze all available signals.**
- **Mode shape crucial for analysis: simultaneous processing of hundreds of PMU signals needed**
- **Scalable solutions needed.**