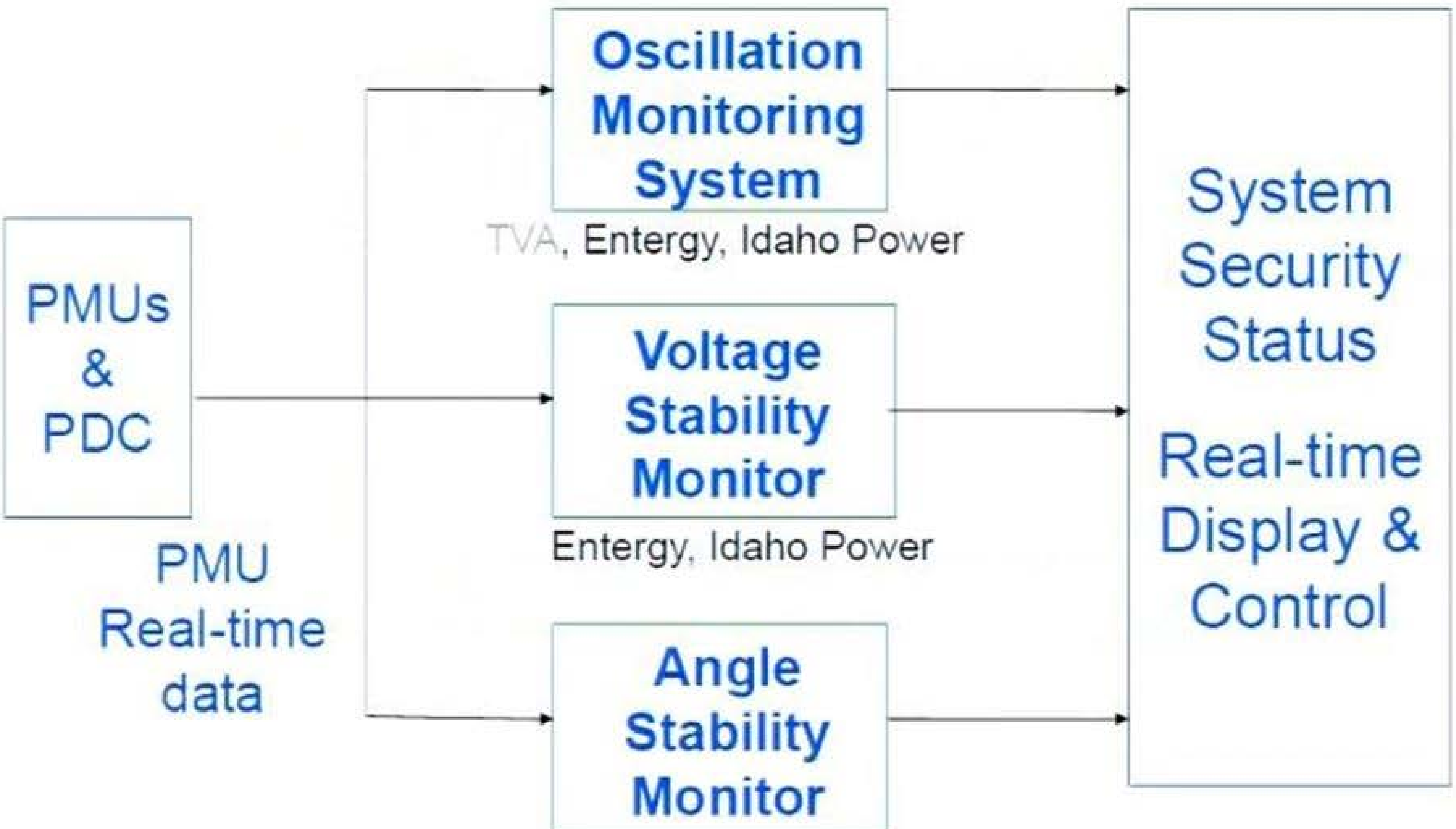
Washington State University

Fast Algorithms for Synchrophasor Computations

Mani V. Venkatasubramanian

Washington State University
Pullman WA

Real-time security monitors @ WSU



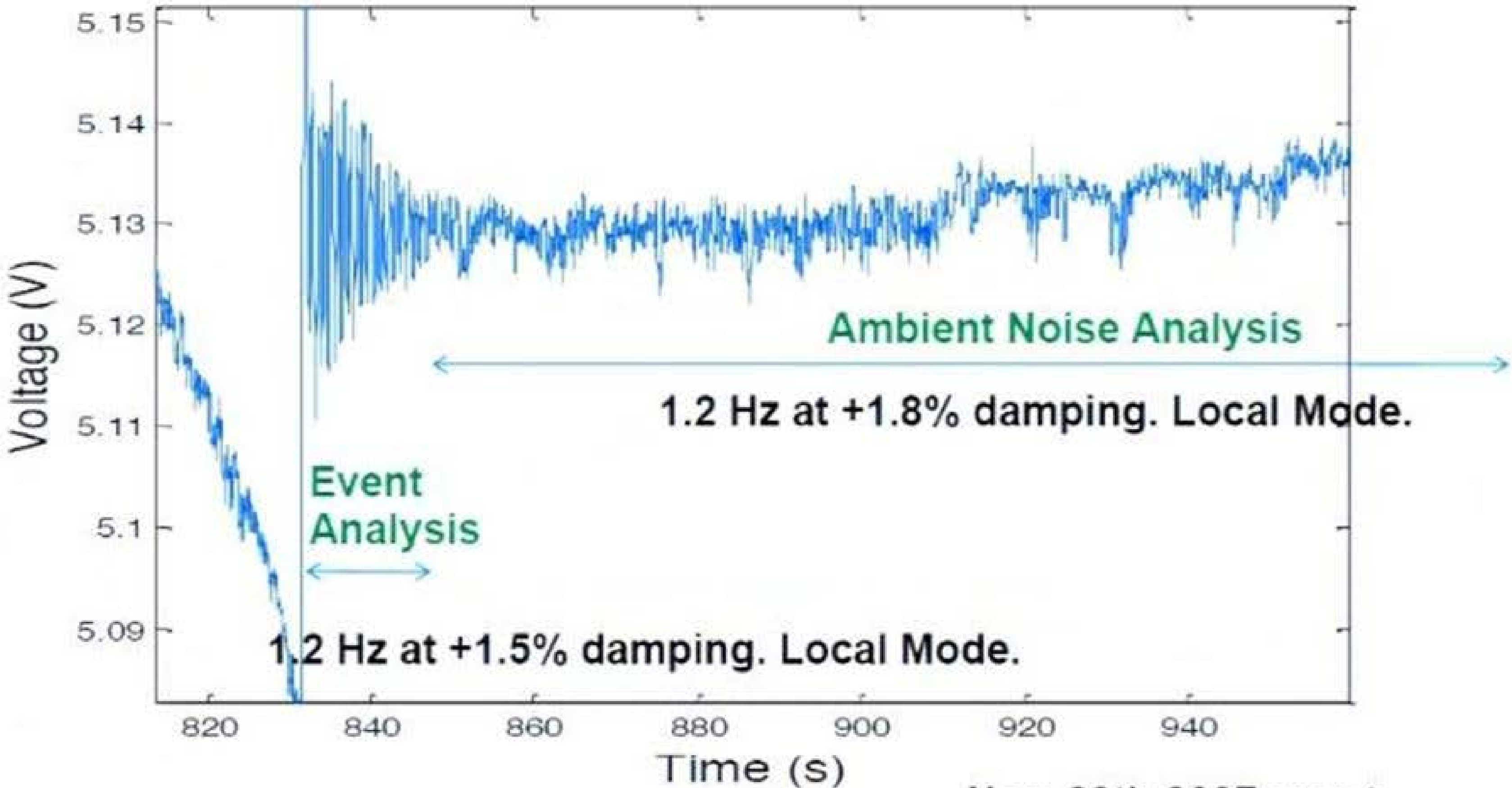
PMU Applications

- The computational complexity of PMU data based algorithms is not scalable as such.
  - # of PMUs ↗, Size of the matrix ↗
  - Large-scale dense matrix. Information sparse.
- Scalable solutions needed with urgency.
  - Custom designed scalable algorithms
  - Tailor existing algorithms to parallel platforms
  - New distributed algorithms

Small Signal Stability

- Oscillations must remain well-damped for stability
- Either sustained oscillations or growing oscillations called small-signal instability
- Caused by unusual operating conditions or poor control designs
- Some eigenvalues become negatively damped resulting in small signal instability
- August 10, 1996 WECC blackout a classical example

Results from Two Engines

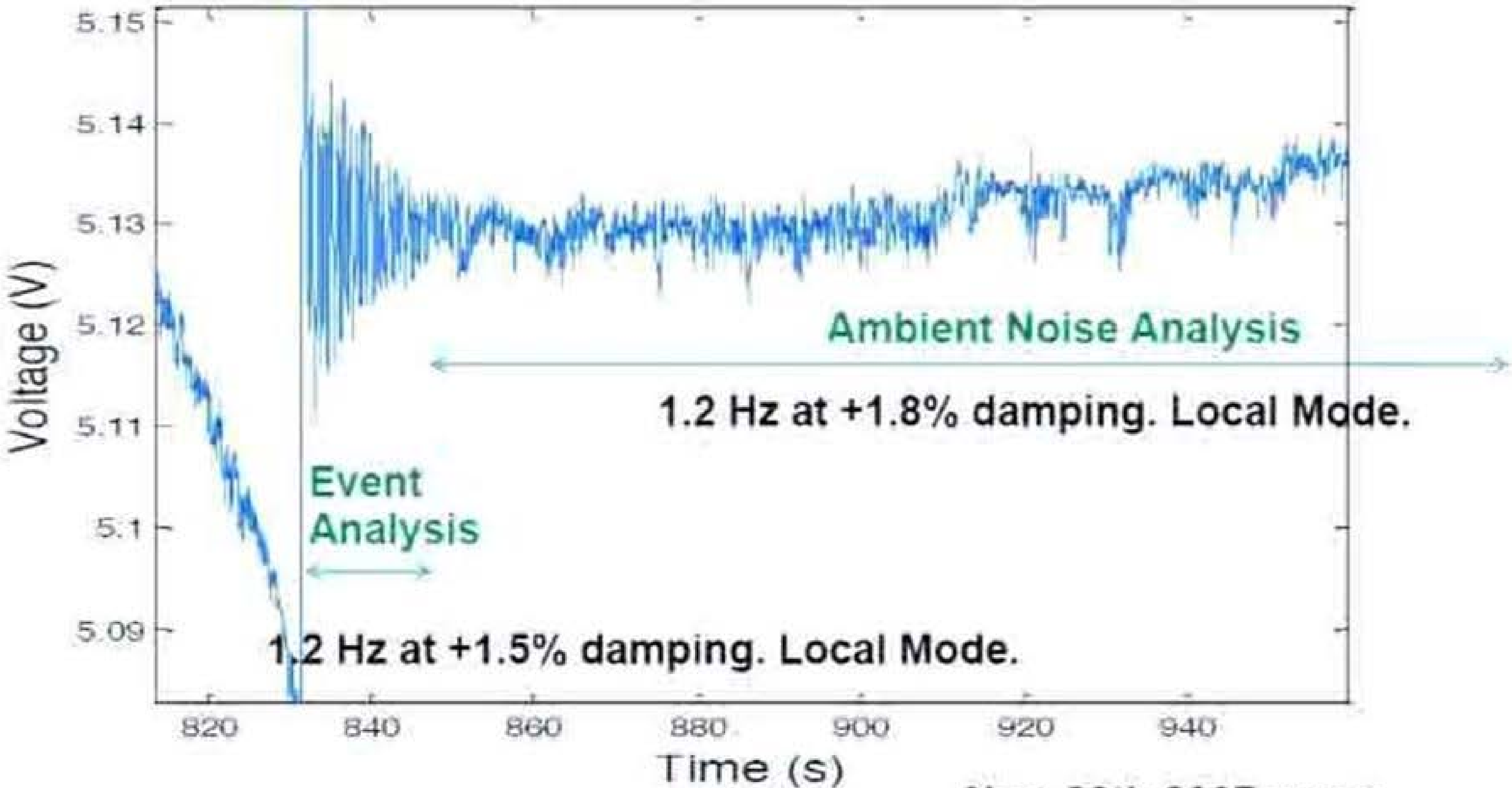


Nov. 29th 2007 event

Complementary Engines

- Event Analysis Engine (EAE)
  - Multiple algorithms
  - Prony, Matrix Pencil, HTLS, and ERA
  - Aimed at events resulting in sudden changes in damping
- Damping Monitor Engine (DME)
  - Ambient noise based. Continuous. Provides early warning on poorly damped modes.
  - Frequency Domain Decomposition (FDD), Stochastic Subspace Identification (SSI)

Results from Two Engines



Nov. 29th 2007 event

Frequency Domain Decomposition (FDD)

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

SVD in PMU Applications

- SVD → Fundamental feature extraction algorithm in many PMU applications
- Oscillation monitoring methods
  - Eigenvalue Realization algorithm (ERA)
  - Matrix Pencil algorithm
  - Hankel Total Least Square (HTLS) algorithm
  - Total least square estimation of signal parameters via rotational invariance techniques (TLS-ESPRIT)
  - Extended complex Kalman filter (ECKF)
  - Stochastic Subspace Identification (SSI) method
- Real-time voltage stability monitoring using PMUs, and PMU placement and ranking problem

SVD problem in SSI

- **SSI-COV method**

$$Y_p = \begin{bmatrix} y_0 & y_1 & \cdots & y_{J-1} \\ y_1 & y_2 & \cdots & y_J \\ \vdots & \vdots & \ddots & \vdots \\ y_{I-1} & y_I & \cdots & y_{I+J-2} \end{bmatrix} \in \Re^{Il \times J},$$

J is known as initial window

I is a user defined parameter

$$Y_f = \begin{bmatrix} y_I & y_{I+1} & \cdots & y_{I+J-1} \\ y_{I+1} & y_{I+2} & \cdots & y_{I+J} \\ \vdots & \vdots & \ddots & \vdots \\ y_{2I-1} & y_{2I} & \cdots & y_{2I+J-2} \end{bmatrix} \in \Re^{Il \times J}.$$

Each y_k in these two matrices is a vector of size l.

where l is the # of PMU signals

$$H = Y_f Y_p^T = O_I G,$$

$Il \times Il$

SVD problem in SSI

- $2I \longrightarrow$ 5 to 20 seconds × Sampling rate of 30 Hz

2 *I*	**# of Signals *l***	**Size of *H***
180	10	900×900
	100	9000×9000
	500	45000×45000
300	10	1500×1500
	100	15000×15000
	500	75000×75000

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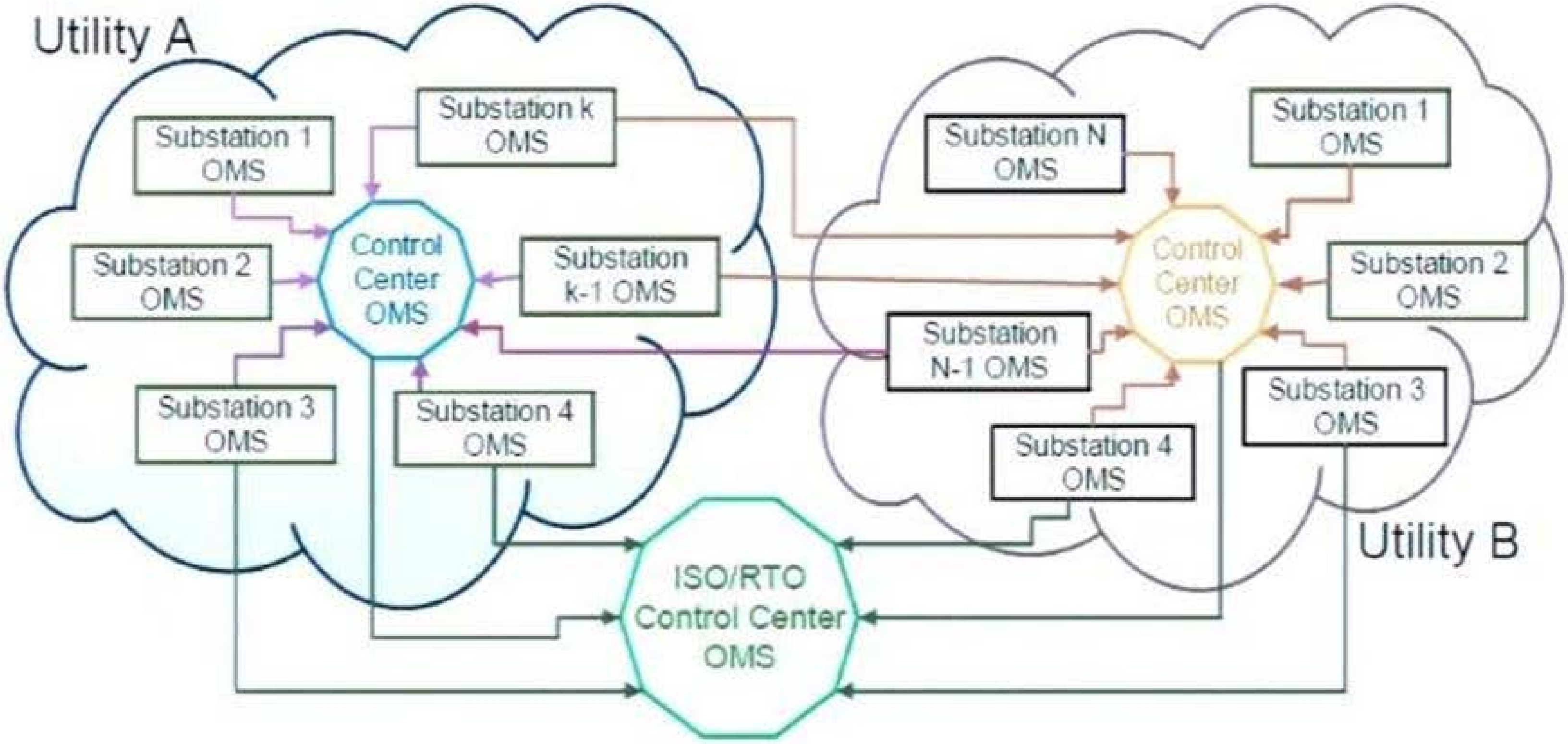
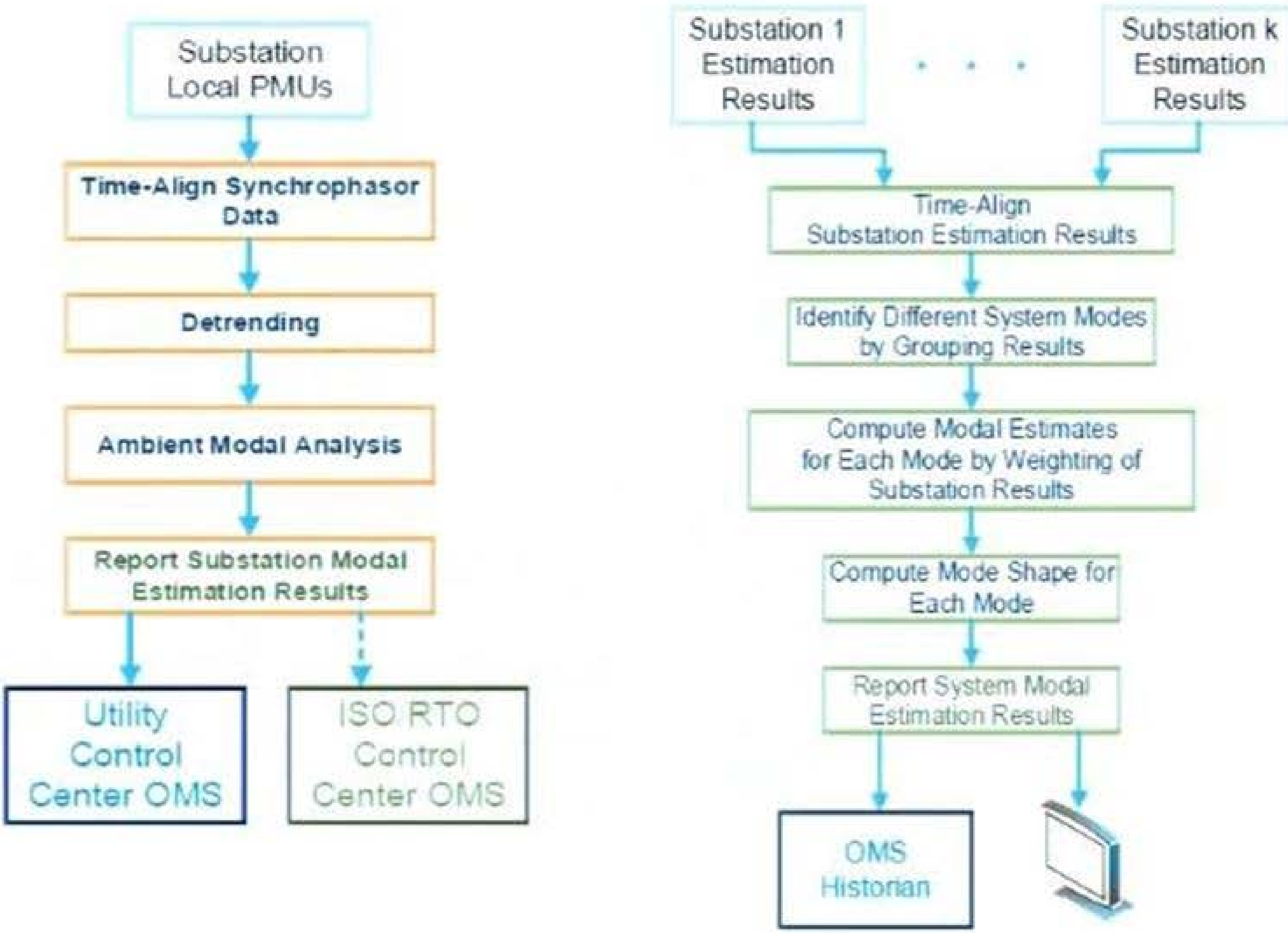
Fast SVD Algorithms

- Two fast SVD approaches have been used for speeding up PMU data based algorithms
  - Randomized SVD method
  - Augmented Lanczos Bidiagonalization method

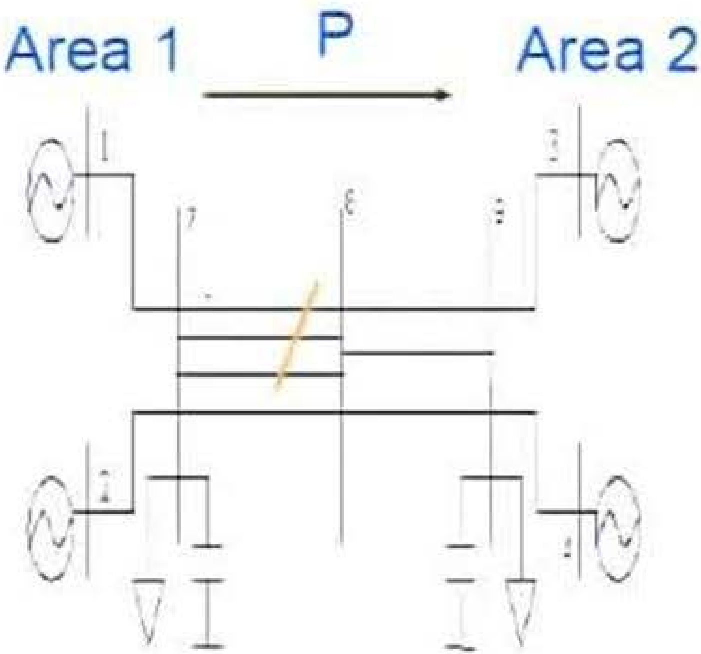
Distributed Algorithms



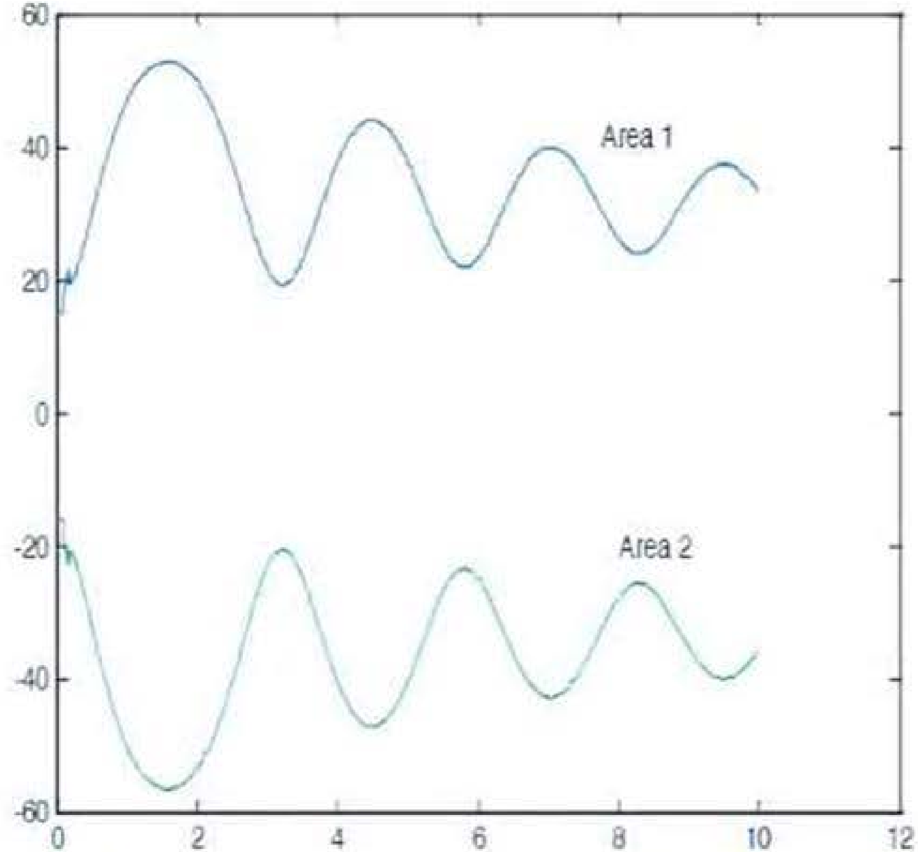
Distributed Algorithms



Angle Stability Detection



Low power transfer



Rotor phase angles stay together

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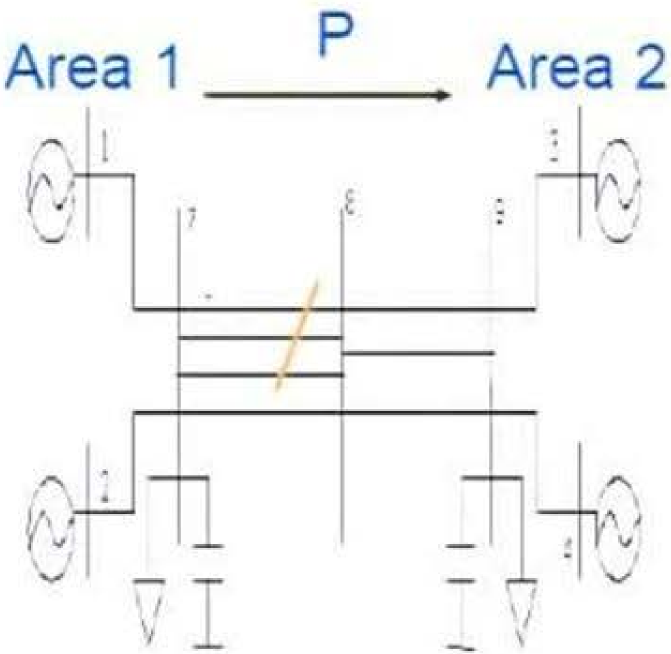
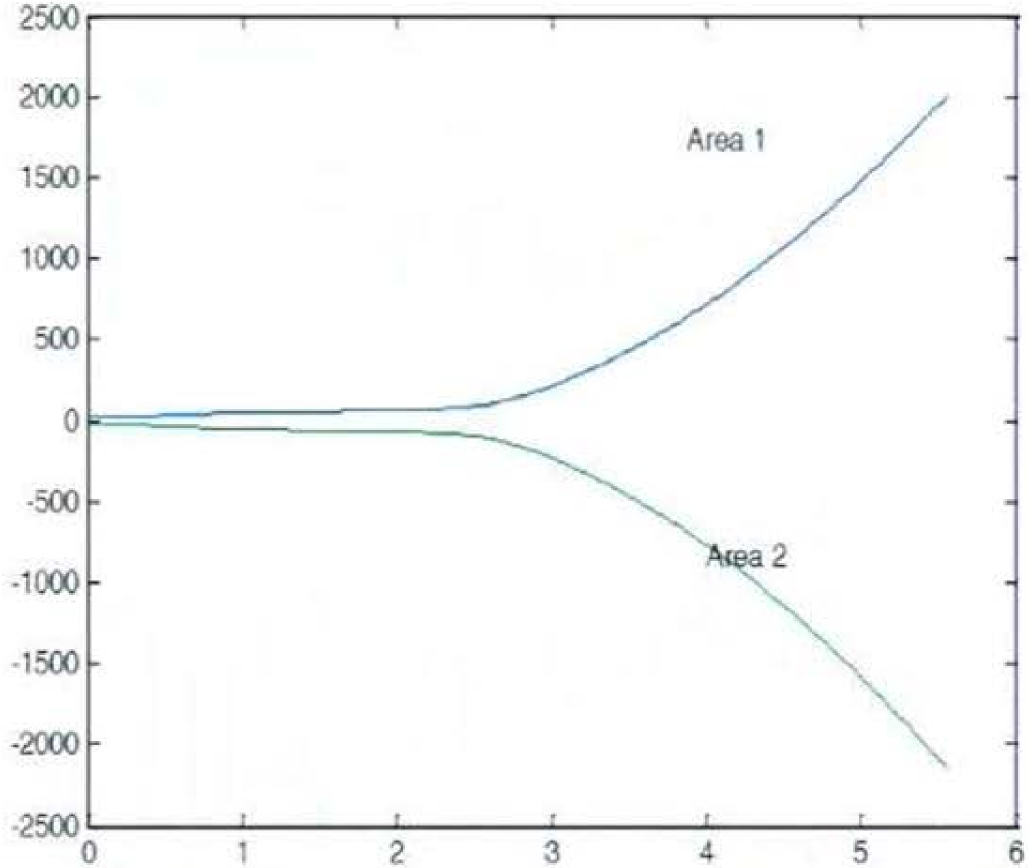
Transient unstable



Heavy power transfer



Rotor phase angles separate away

Critical Questions

- Angle instability phenomenon?
- Which area is accelerating?
- Which area is decelerating?
- Generator tripping? Which generator?
- Load shedding? Which load?
- All decisions made using real-time wide-area phase angle and frequency measurements