

Synchrophasor data-driven early anomaly detection via dimensionality reduction

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Acknowledgement

- BPA
- PJM
- ERCOT

Growth of Phasor Measurement Unit (PMU)

U.S.

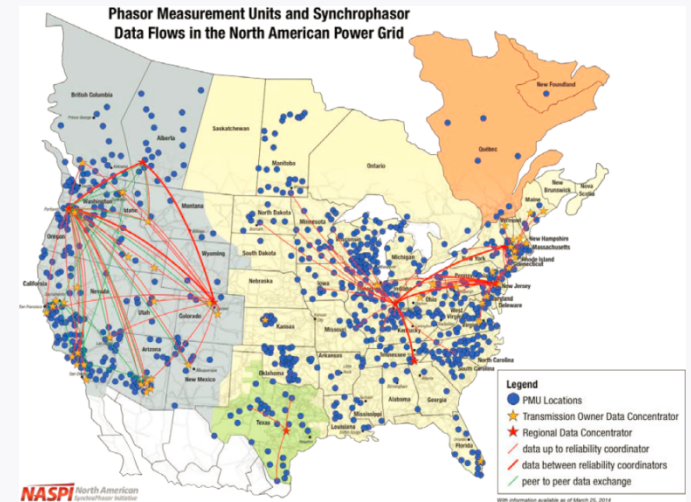
Reported by NASPI*

- From 2009 to 2014, 1400 PMUs installed across US.

China

- About 1717 PMUs coverage [2].

*NASPI: North American SynchroPhasor Initiative.

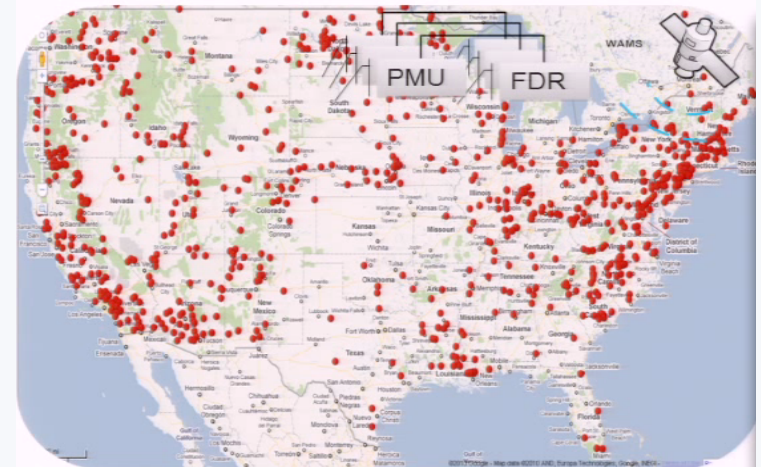


PMU map in North America as of Oct. 2014 [1].

Other Devices with PMU Functionality

Thousands of IED

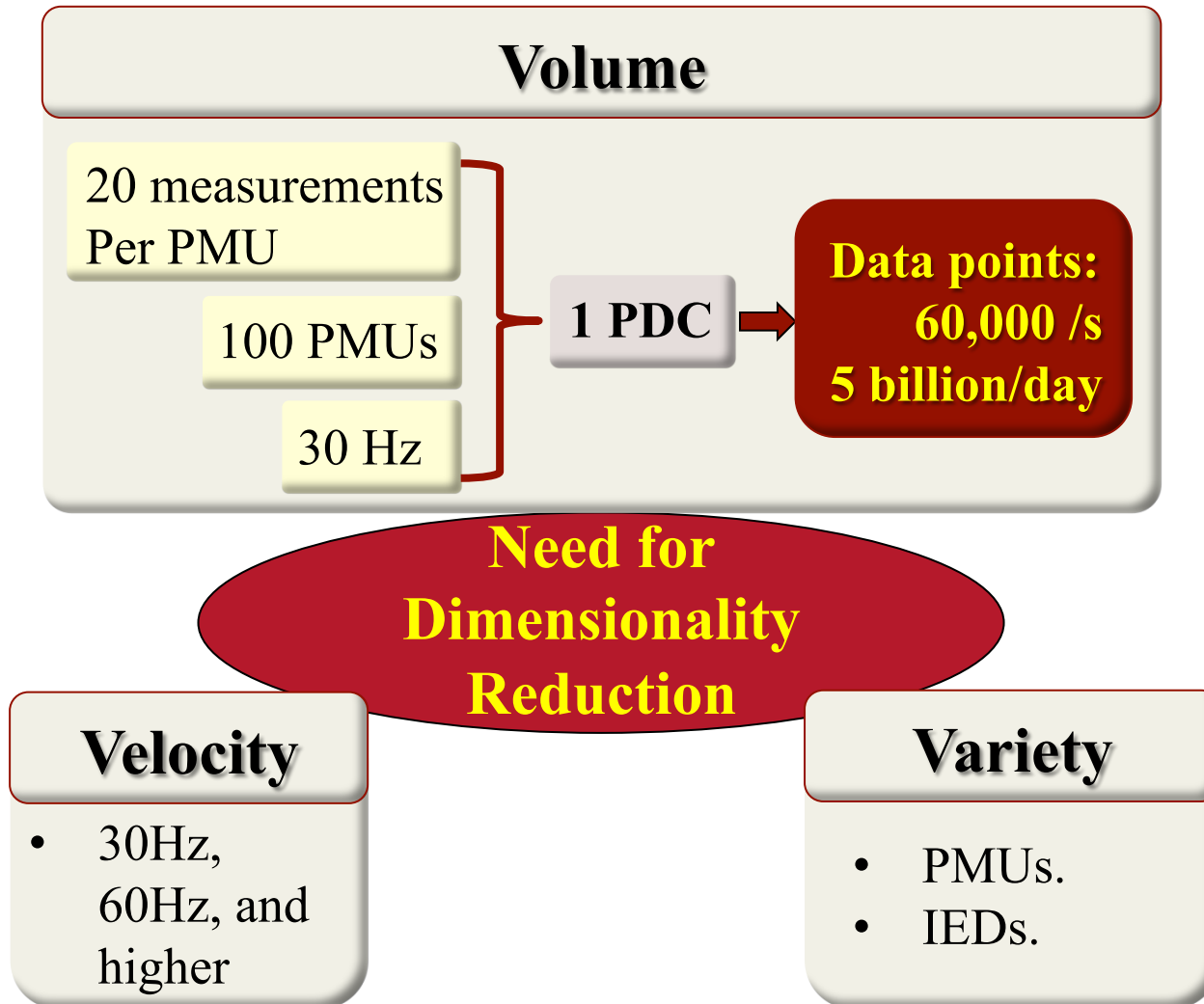
- Digital protective relay
- Digital fault recorder (DFR)
- Frequency disturbance recorder (FDR)



Wide-area measuring points [3].

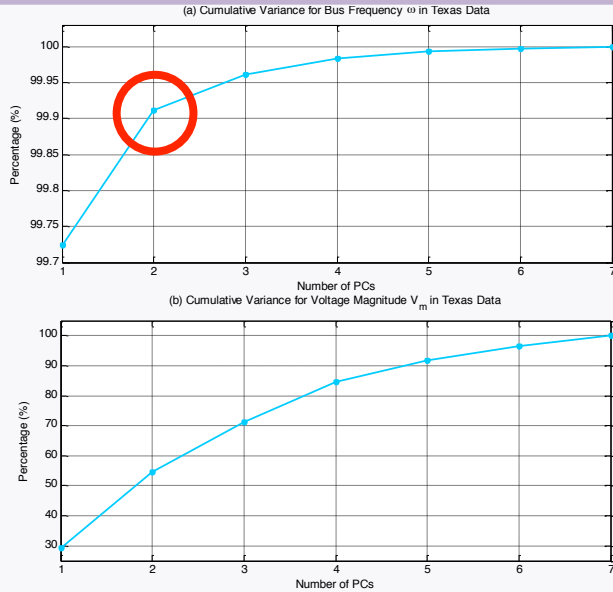
- [1] <https://www.naspi.org/documents>
- [2] Beijing Sifang Company, "Power grid dynamic monitoring and disturbance identification," in *North American SynchroPhasor Initiative WorkGroup Meeting, Feb. 2013*, 2013.
- [3] Y. Liu, "Overview of distribution level synchronous measurement applications," Sep 2012

Challenges of Real-time PMU Analytics

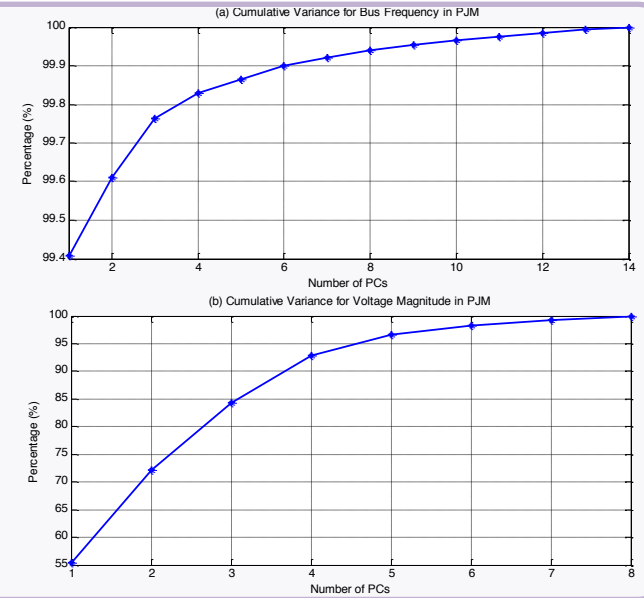


Dimensionality Reduction -- PCA

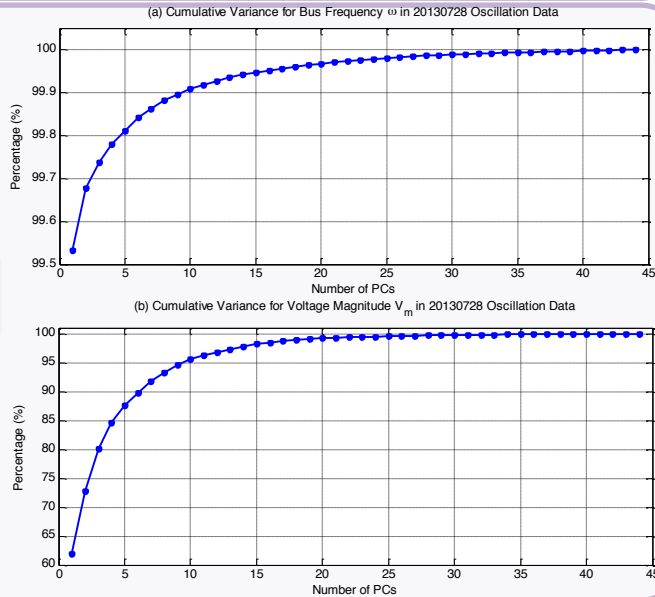
ERCOT



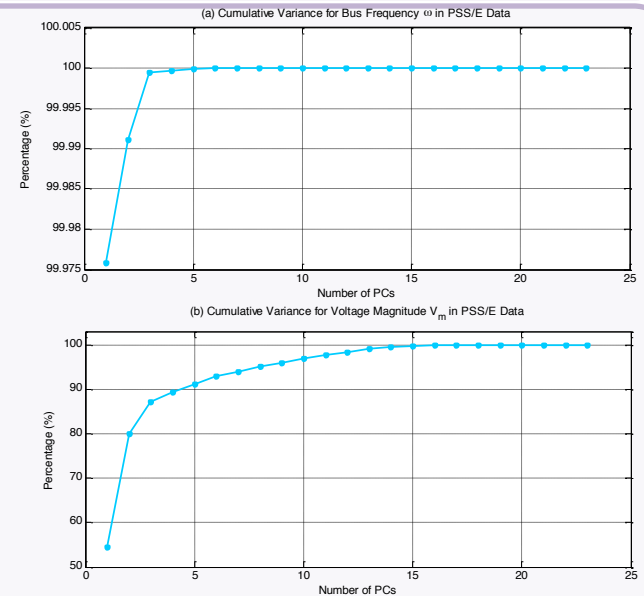
PJM



BPA



PSS/E



Cumulative variance for bus frequency and voltage magnitude data.

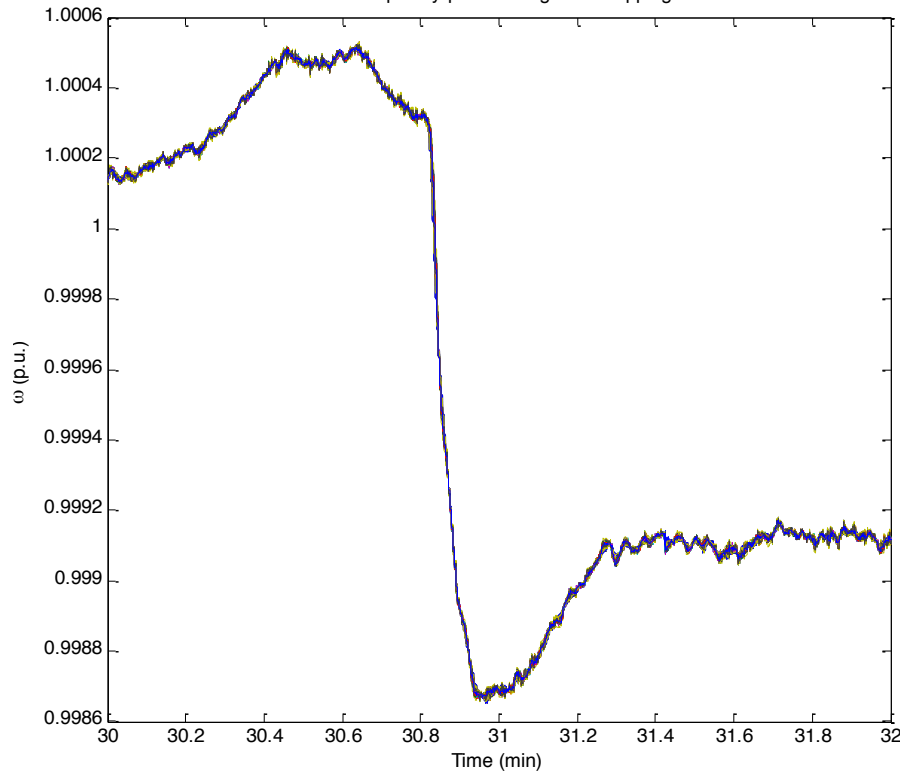
© 2015 Le Xie



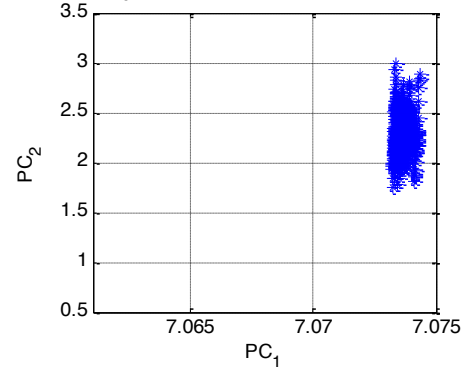
Indication of Anomaly from Scatter Plots

Unit Tripping: 48 PMUs, 60 Hz

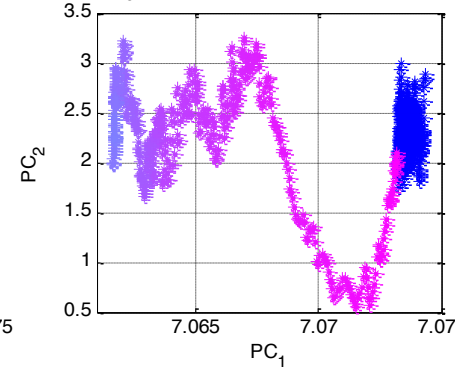
Bus frequency profile during a unit tripping.



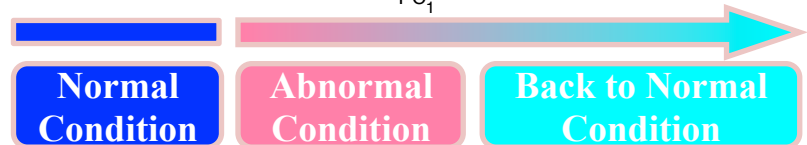
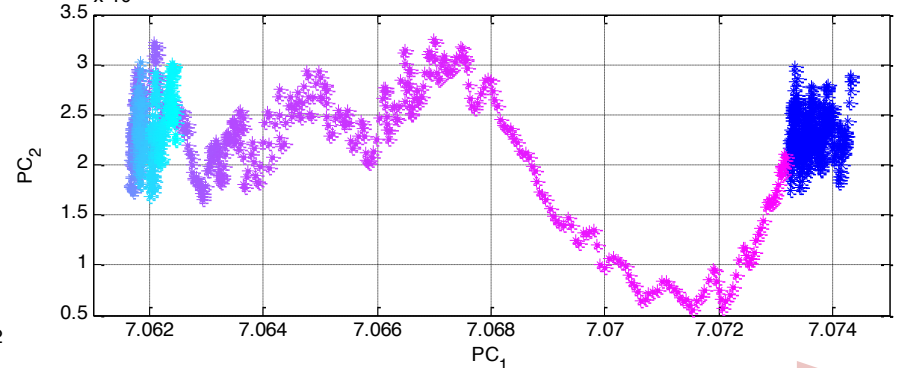
$\times 10^{-4}$ 2D Scatter Plot Pre-event



$\times 10^{-4}$ 2D Scatter Plot Transient

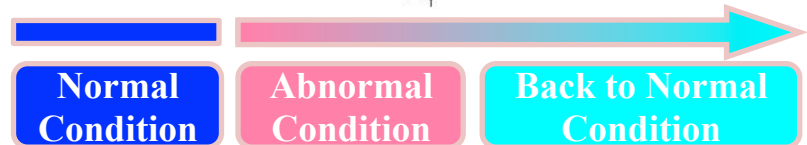
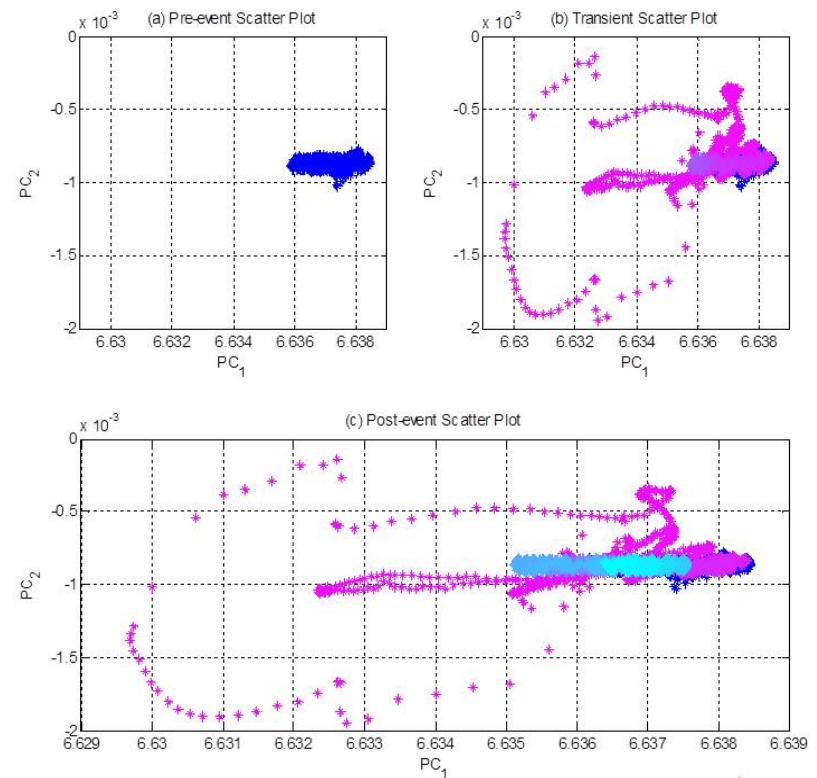
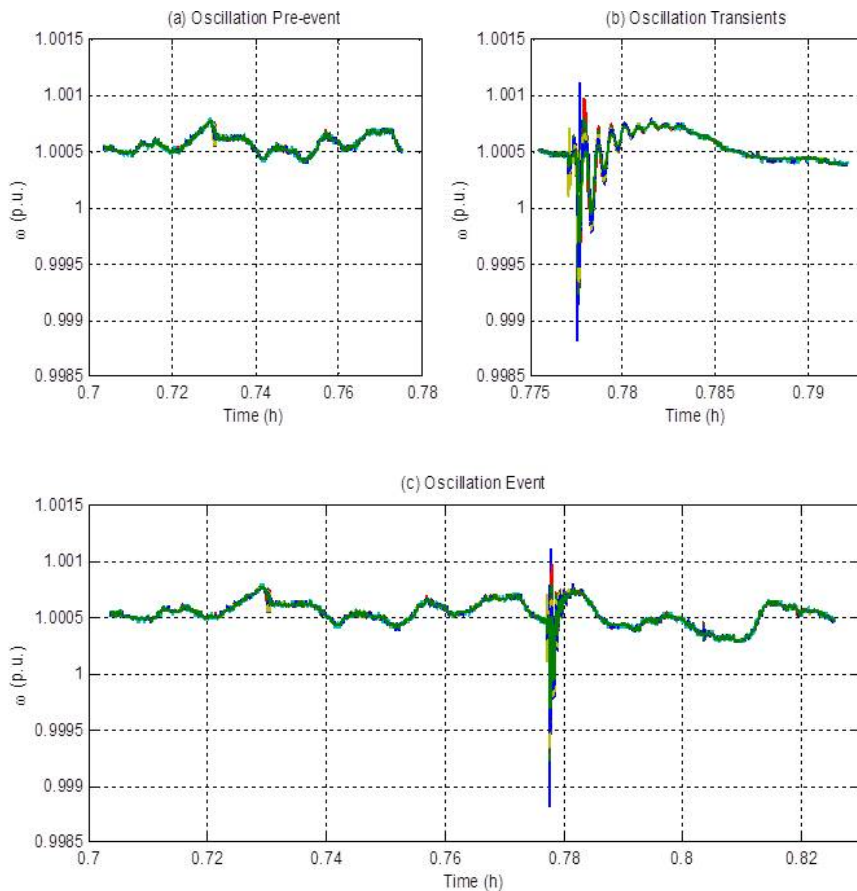


$\times 10^{-4}$ 2D Scatter Plot Post-event



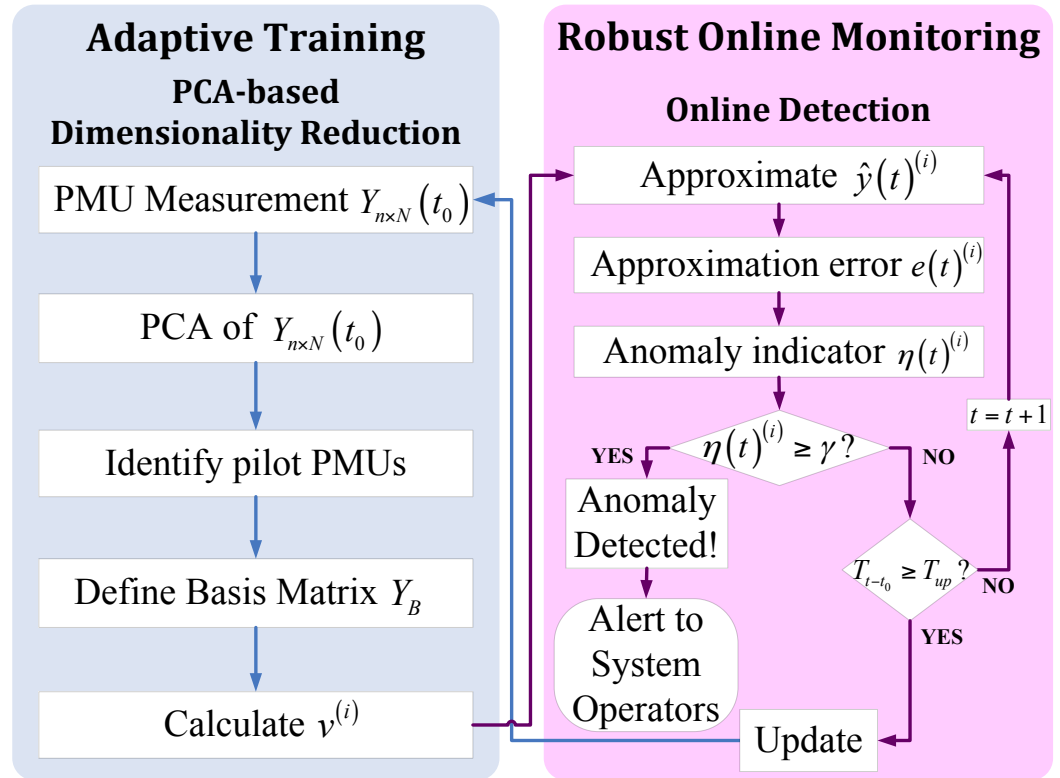
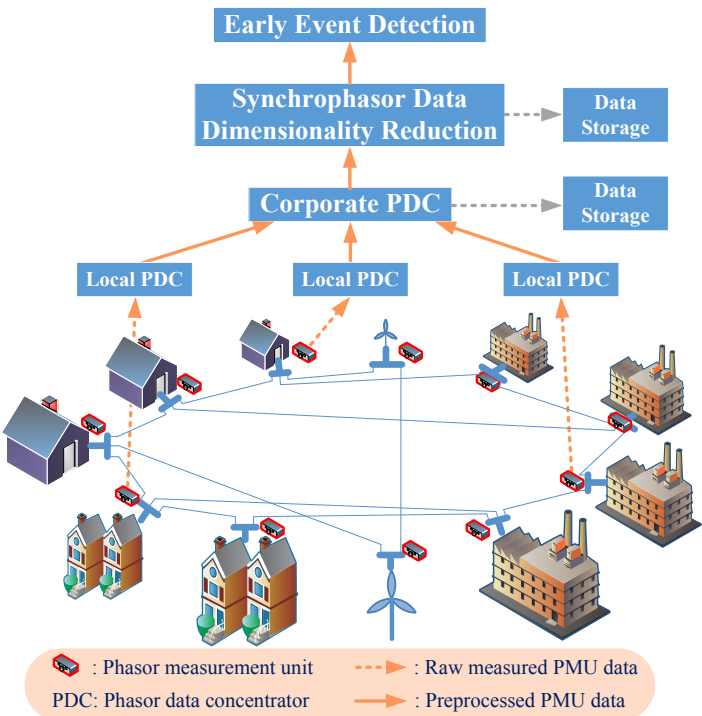
Indication of Anomaly from Scatter Plots

Ringdown Oscillation: 44 PMUs, 60 Hz



Early Event Detection Algorithm

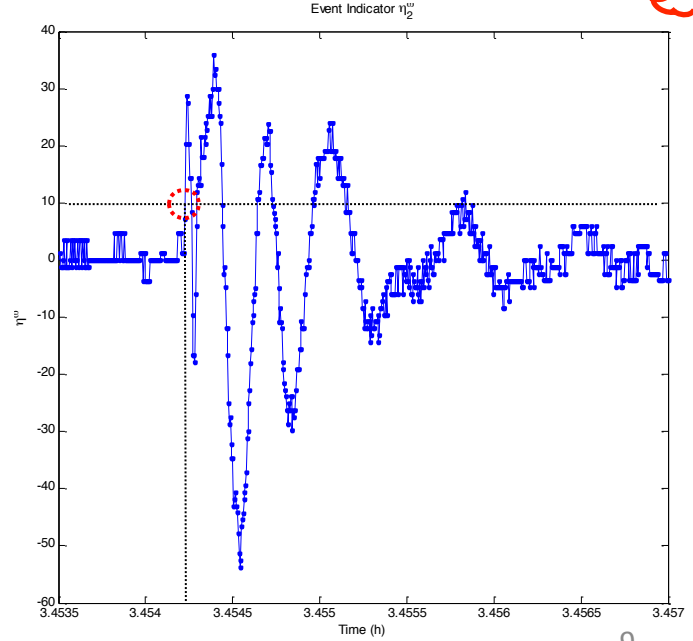
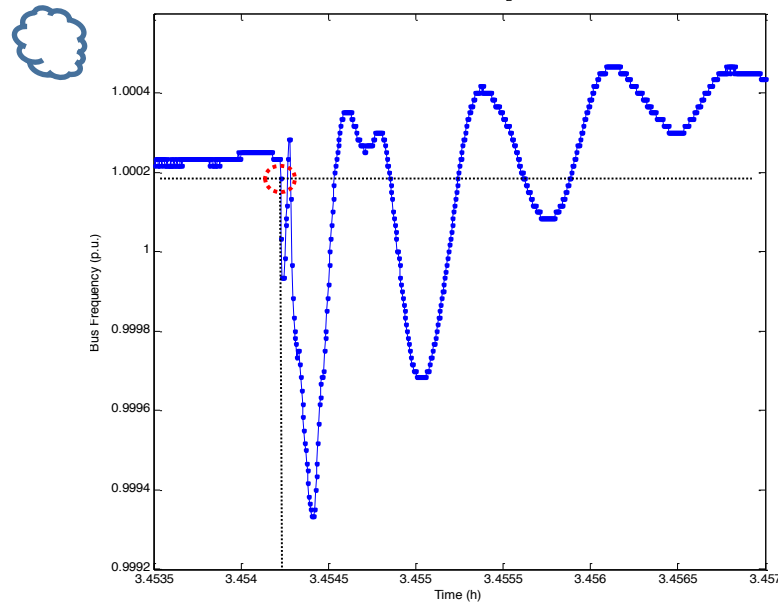
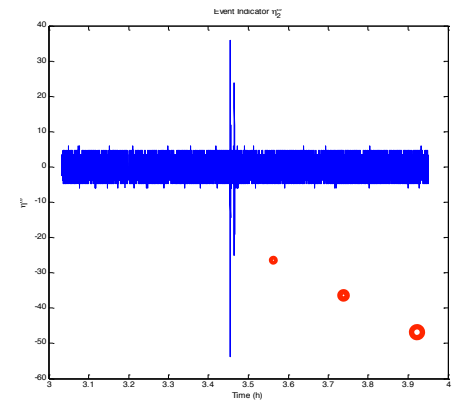
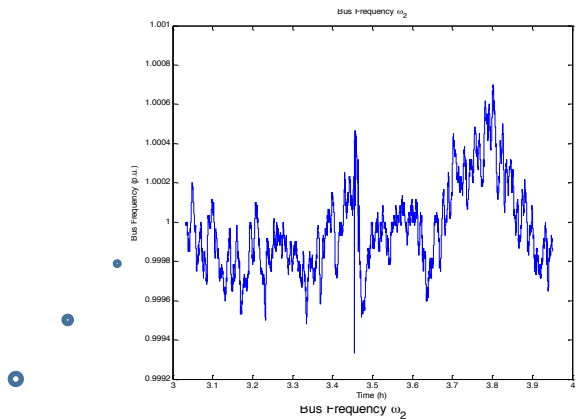
Early Anomaly Detection Algorithm



Theoretically justified using linear dynamical system theory.

BPA Case Study

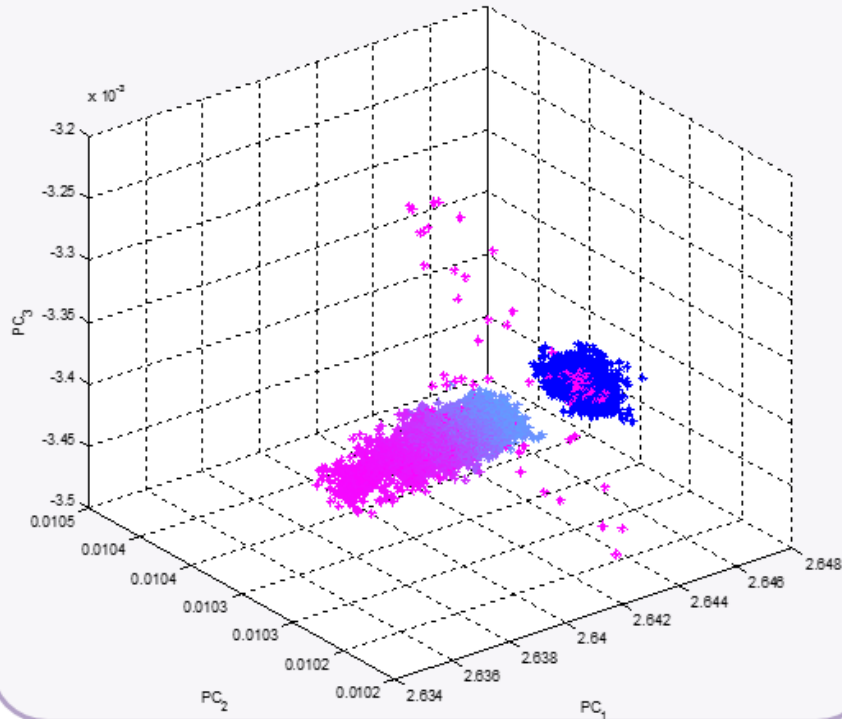
- 44 PMUs.
- Outage-induced oscillation.



Further Analytics: Event Classification

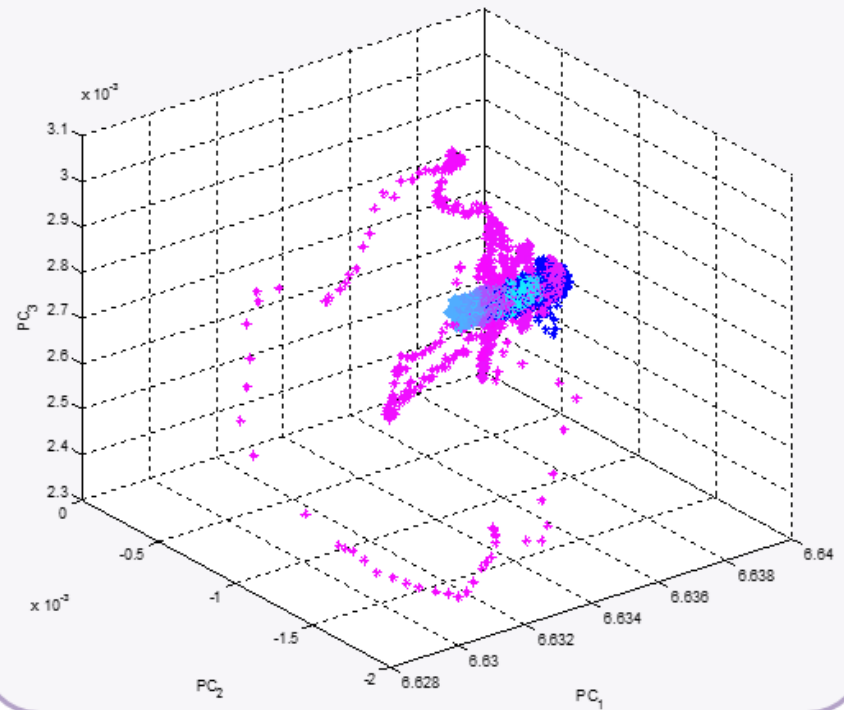
ERCOT

3D Scatter Plot for Bus Frequency in 20110919 Unit Tripping of ERCOT Data



BPA

3D Scatter Plot for Bus Frequency 20130728 Oscillation



Normal
Condition

Abnormal
Condition

Back to Normal
Condition

[7] Yang Chen, Le Xie, and P. R. Kumar, "Power System Event Classification via Dimensionality Reduction of Synchrophasor Data," *Sensor Array and Multichannel Signal Processing Workshop, 2014. SAM 2014. 8th IEEE*, pp. 57-60, 2014.

Summary

- Large-scale PMU data can be reduced to a space with much lower dimensionality.
- Dimensionality reduction leads to event detection at an **earlier** stage than would have been possible by monitoring raw data.
- **Theoretical justifications** from linear dynamical system theory is proposed.
- **Many possible extensions:**
 - PCA *de-noised* oscillation detection & specification.
 - Power system event *classification* from scatter plots of PMU data.
 - Learning-based identification of power grid dynamical model and *control*

[8] M. Wang, J. H. Chow, et. al., “A Low-Rank Matrix Approach for the Analysis of Large Amounts of Power System Synchrophasor Data,” *HICSS 2015*

[9] Y. Chen, L. Xie, and P. R. Kumar, “Integrating PMU-data-driven and Physics-based Analytics for Power Systems Operations.” Proceedings of the 48th Asilomar Conference on Signals, Systems and Computers,” Asilomar 2014 (invited)

Thank You!

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