A Measurement-Based Approach for Optimal Damping Control of the New York State Power Grid

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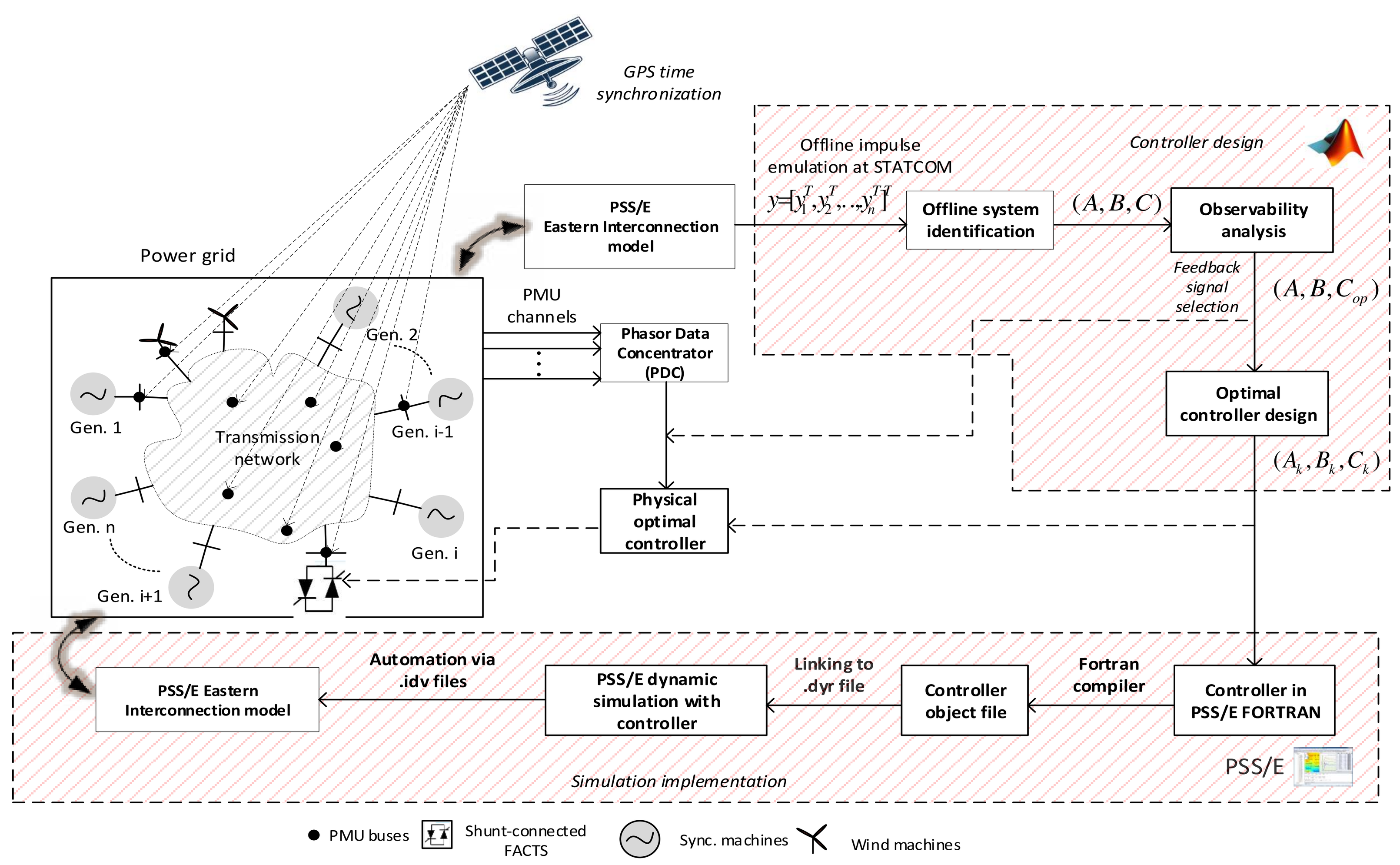
Motivation and challenges

- With more and more power electronics-interfaced renewables, grid inertia is getting reduced, which in turn may degrade the damping of the inter-area oscillation modes.
- The advent of Wide Area Measurement Systems (WAMS), commonly referred to as the Synchrophasor technology, enables us to design and implement closed-loop Wide Area Damping Control (WADC). This work uses the FACTS facility in central NYS as the actuation location for the supplementary controller.
- Most of the designs in the existing literature are performed on a relatively small system and based on the assumption that the dynamic model of the system is available. But the Eastern Interconnection (EI) model used for this work is ultra-large scale (more than 70,000 buses) and complex. Hence we resort to measurement-based approach using the Phasor Measurement Units (PMUs) installed in the grid.
- We perform the design on a practical full-scale transmission model in an effort to move towards the smart transmission infrastructure for the future power grid.

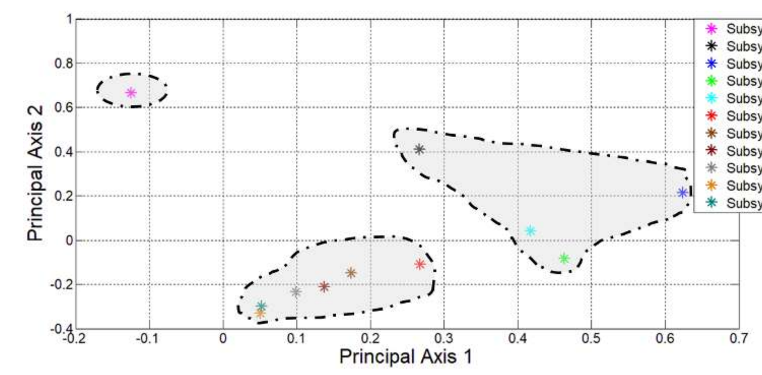
Visualization of control architecture and simulation setup



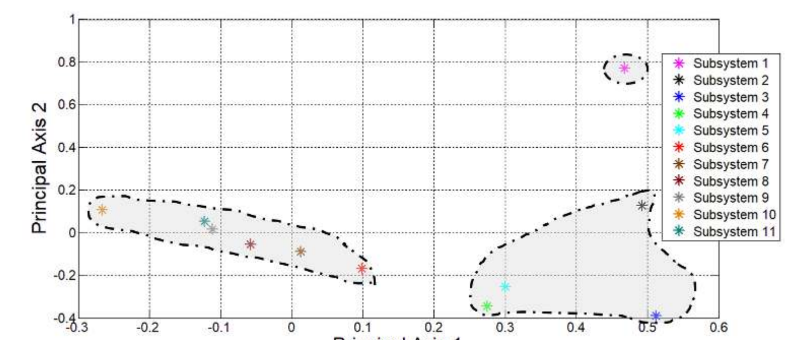
Design methodology

1. Coherency Structure of the NYS grid :

- The property of time-scale separated oscillation of generators is termed as coherency in power systems. This is characterized by inter-area oscillation modes across different coherent areas.
- We use a measurement-driven statistical tool, namely Principal Component Analysis (PCA) to find the coherency structure. It is used to measure the relative correlation between different channels and quantify the correlation index as coefficients/loadings.
- Coefficients of different PMU channels corresponding to the principle components with larger variances are considered. In our case, first two principal components are considered based on high variances.



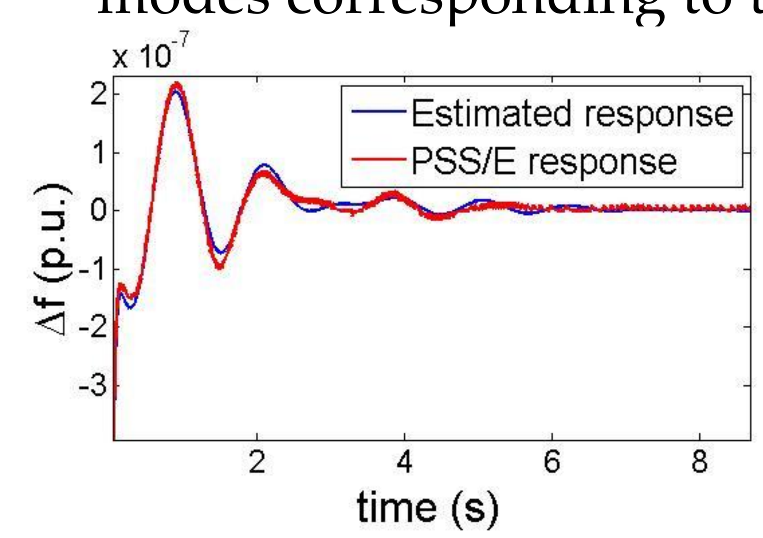
PCA weightings due to contingency 1



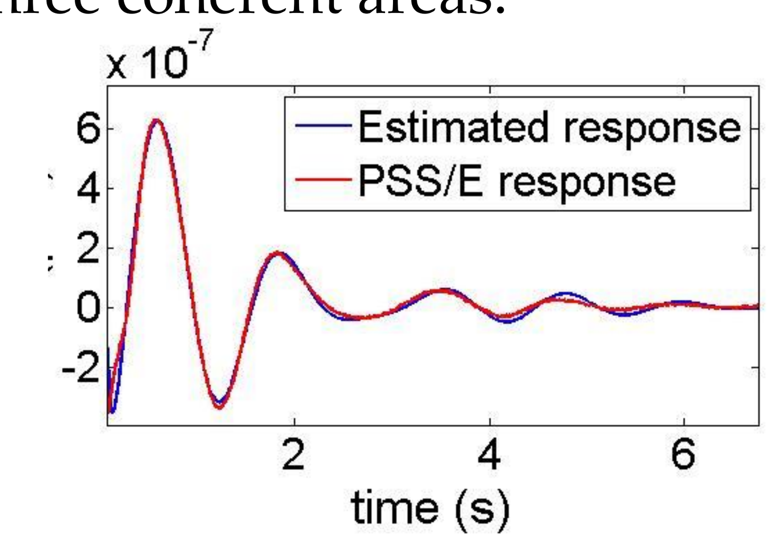
PCA weightings due to contingency 2

2. Reduced order system identification :

- The modulating input of the STATCOM in PSS/E EI model is excited with a short duration pulse (in order to emulate an impulse) and the responses are recorded from different PMU-enabled buses scattered all across the NYS power systems.
- These responses are passed through the Eigensystem Realization Algorithm (ERA) and impulse responses from identified system are matched with the PMU responses from PSS/E model. There are two inter-area modes corresponding to three coherent areas.



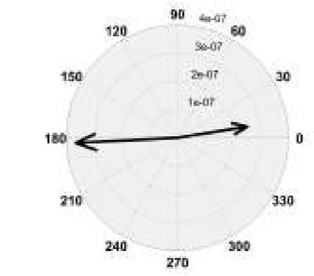
PMU at Southern NYS



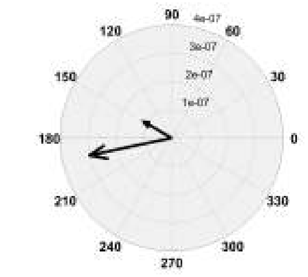
PMU at Central NYS

3. Feedback Signal Selection :

- We consider multiple PMU channels and perform the observability analysis using the identified model. The channel, which shows lower angular separation between residues corresponding to inter-area modes and higher *Geometric Observability*, is selected for control design.



Western PMU



Central PMU

PMU loaction	Angular separation of residues (degrees)	Obsv.[1] for mode 1	Obsv.[1] for mode 2	Joint Obsv. [1]
FACTS bus	41.43	0.17	0.31	0.35
Central	47.16	0.14	0.24	0.28
Northern	62.33	0.08	0.14	0.16
Western	173.94	0.45	0.47	0.65
Southern	78.54	0.18	0.25	0.30

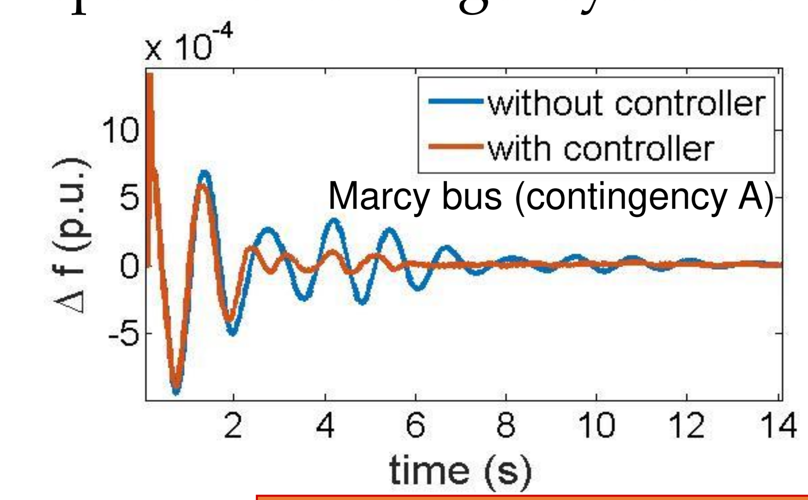
Observability analysis

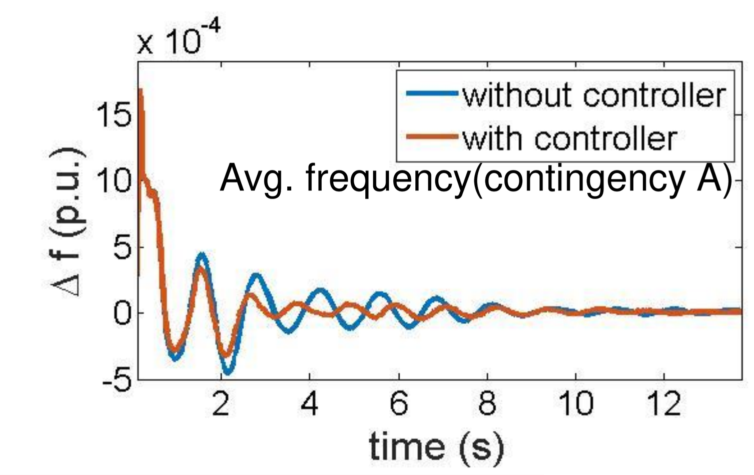
4. Optimal Controller Design:

- We design an output feedback dynamic optimal controller, namely the Linear Quadratic Gaussian (LQG) control. This is a combination of Linear Quadratic Estimator (LQE) and Linear Quadratic Regulator (LQR). The identified system is reframed in the required optimal controller setting.
- As the identified states are not physical states, a participation factor analysis is performed to find out states which have highest contribution to the inter-area modes.
- The controller is designed by solving the estimator and regulator *Algebraic Riccati Equations* (AREs).

Non-linear simulations

- The controller is coded in FORTRAN as a user-written model and compiled with the PSS/E EI dynamic suit.
- The controller performance is tested with different NYISO specified contingency scenarios.





Conclusion

We showcase a sequential data-driven damping control design approach on the FACTS facility in NYS using tools from machine learning, linear system identification and optimal control theory.