Optimal Multi-Channel Output Feedback Control to Damp Power System Oscillations using Battery Energy Storage

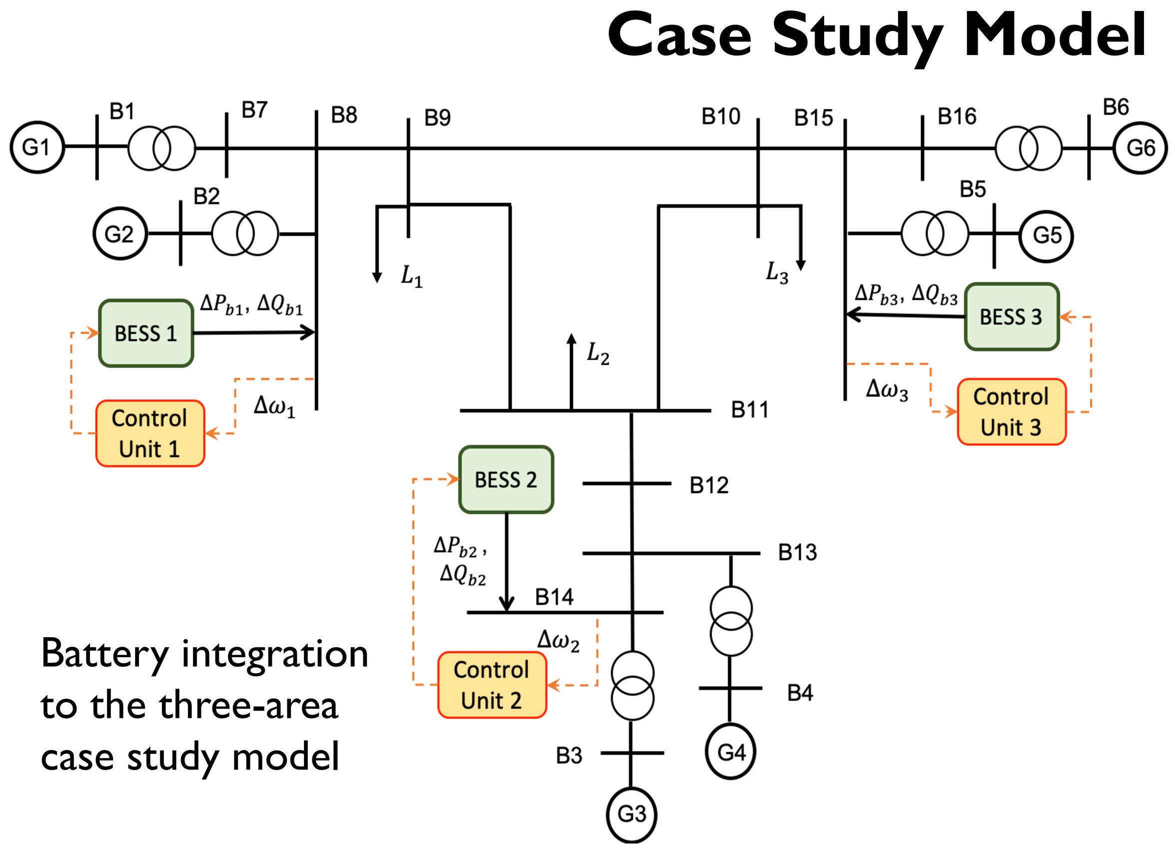
Roghieh Biroon, Pierluigi Pisu (Clemson University) and David Schoenwald (Sandia National Laboratories)
Email: rabdoll@Clemson.edu, pisup@Clemson.edu, and daschoe@sandia.gov

Abstract – This poster presents an optimal decentralized control design approach using battery energy storage to improve stability of power systems by mitigating the effects of small disturbances in the grid.

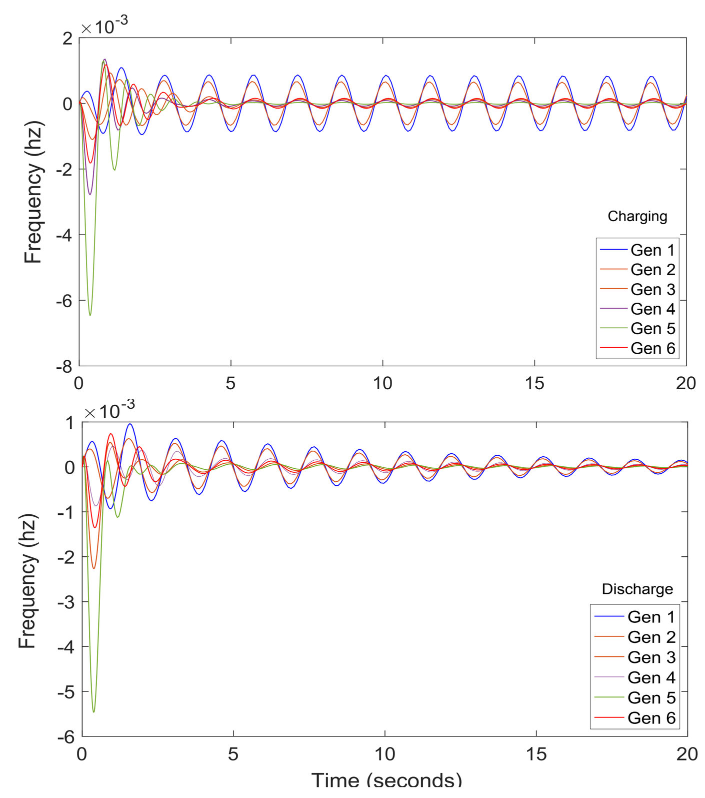
Project Overview

Motivation: A distributed approach to wide-area controls harnesses multiple actuators to improve grid stability and is robust to failure of any one actuator. Energy storage is an excellent choice to implement this strategy since it can absorb/discharge active and reactive power to the grid very fast.
Goal: Develop control algorithms for wide-area power grids using distributed energy storage to improve grid stability.
Schedule: Project is currently 18 months into a planned 3 year duration.
Year 1 Tasks: Develop battery model with inverter dynamics and use firing angle as an input. Simulate and analyze oscillation dynamics of case study.
Year 2 Tasks: Design decentralized control algorithms to damp inter-area oscillations in case study system.
Year 3 Tasks: Develop case studies for larger grid models. Extend control design to transient stability.

Case Study Model



Battery integration to the three-area case study model



Generators' frequency deviation in charging and discharging mode (no control)

Control Design Approach

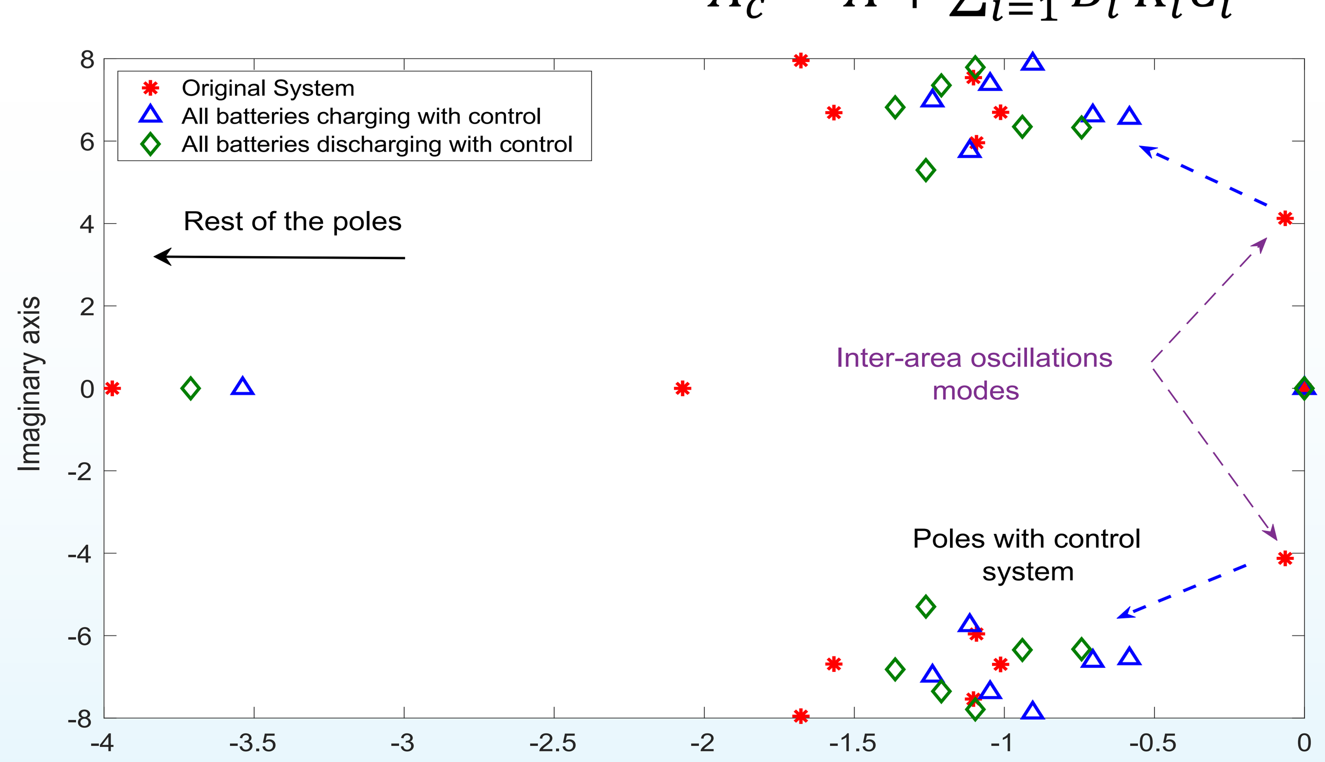
Power systems is a complex and large-scale system. It is unapplicable and uneconomic to have access to the system states. In this regard, a multi-channel optimal control is proposed to control the batteries output power based on power system existing measurements.
To design the hybrid decentralized optimal output feedback control, we implement the following steps:
Step-1: optimal multi-channel output feedback control considering the interconnectivity of the system;

System model

$$\begin{cases} \dot{x} = Ax + \sum_{i=1}^{v} B_i u_i \\ y_i = C_i x \end{cases} \quad for\ \forall\ i \in v$$

Control law

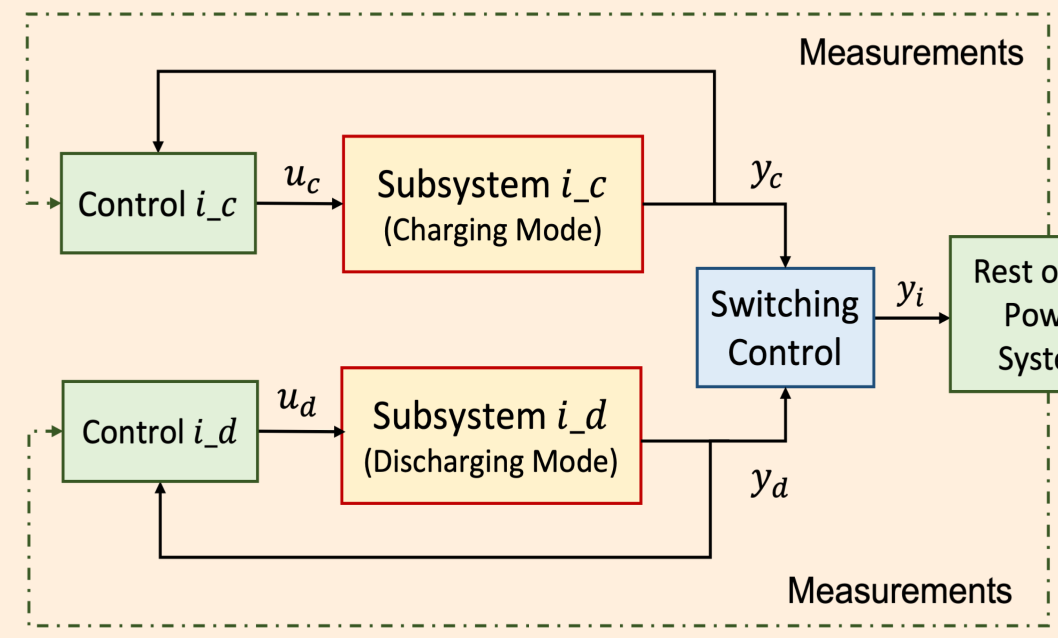
$$K_i = -R_i^{-1}(B_i^T P L C_i^T)(C_i L C_i^T)^{-1}$$
$$A_c = A + \sum_{i=1}^{v} B_i K_i C_i$$



Generators' frequency deviation in charging and discharging mode for decentralized optimal control

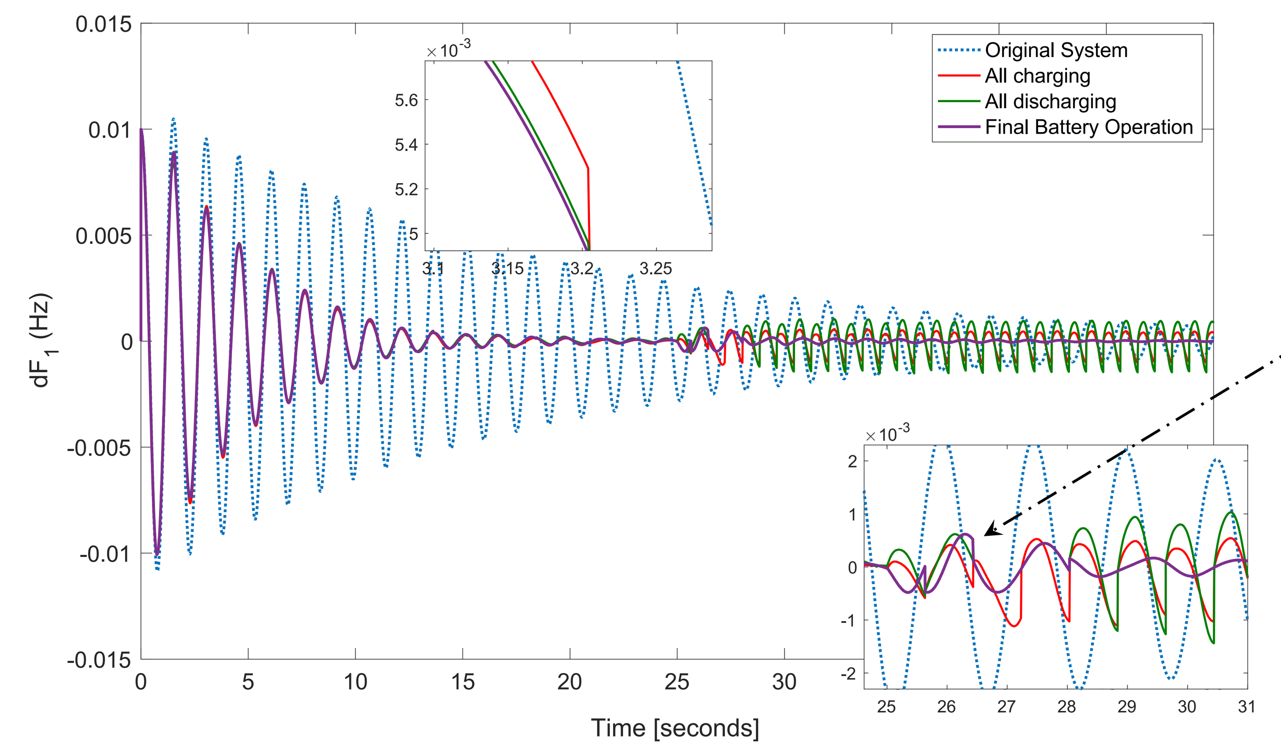
Step-2: hybrid control design for each battery to minimize the cost function of the optimal control for the full system.

$$J_{ci-j} = min\left(\int_{nT+t_k}^{\infty}\left(x_{i-j}^T Q_{ci-j}\, x_{i-j} + u_{ci-j}^T R_{ci-j}\, u_{ci-j}\right) d\tau\right)$$
$$J_{di-j} = min\left(\int_{nT+t_k}^{\infty}\left(x_{i-j}^T Q_{di-j}\, x_{i-j} + u_{di-j}^T R_{di-j}\, u_{di-j}\right) d\tau\right)$$
$$for\ j = 1{:}4 \ \ and \ \ i = 1{:}3$$

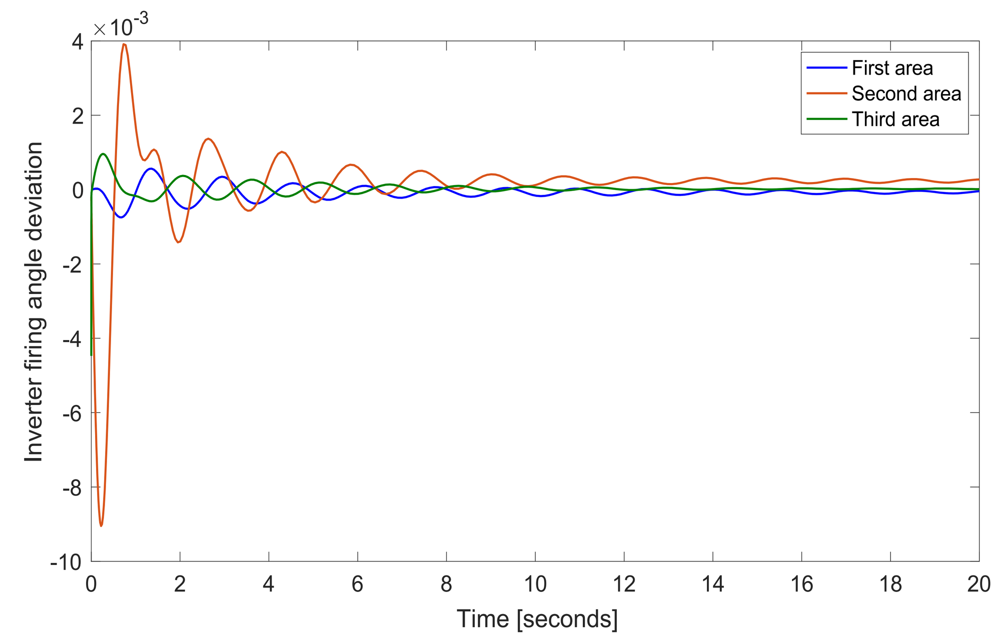


Control design approach based on decentralized control for interconnected systems in presence of the large-scale battery

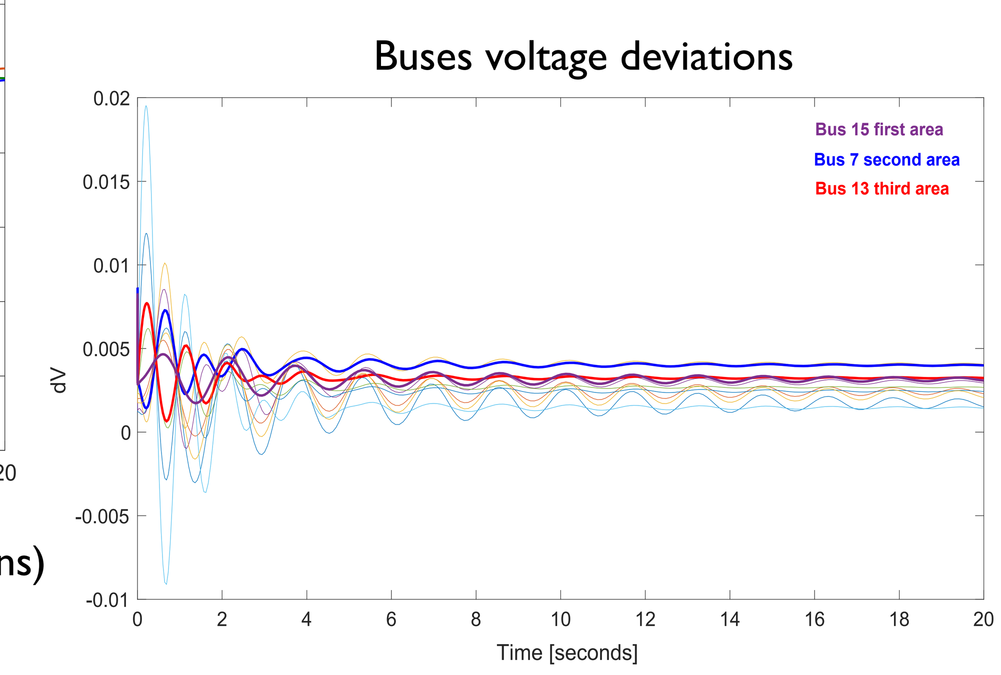
Results



Generators' frequency after applying the switching strategy between the charging and discharging scenarios



Batteries control effort (inverters' firing angle deviations)



Conclusions and Future Work

- A design strategy for a decentralized optimal multi-channel output feedback controller for an interconnected power system have been formulated.
- Active and reactive output power of the battery are regulated by the battery's inverter firing angle to control frequency deviations in each area.
- Results on a case study show notable improvements in damping of the generators' frequency deviations using the optimal switching approach.
- For future work, control design for transient stability of the system using decentralized and nonlinear control techniques will be studied.

Acknowledgements
Funding provided by US DOE Energy Storage Program managed by **Dr. Imre Gyuk**.

Sandia National Laboratories