Thesis Title: Dynamic Flexibility Studies in Power Systems

Thesis Abstract:

This thesis is focused to add a new paradigm in power system flexibility studies, by introducing the concept of dynamic grid flexibility (DGF). The proposed DGF framework incorporates operational flexibility with power system dynamics quantitatively, by defining two metrics – inertial index and flexibility index. These indices capture the impact of location-specific power fluctuation, which may arise due to demand variability or supply intermittency, on two system-inherent dynamic properties. The crux of the thesis is in developing these metrics of DGF using model-based and measurement-based methods, and showcasing their applications in various power system planning and operational studies. Some of the novel methods and key applications that have been discussed in this thesis are:

1) An analytical method of assessing the spatial distribution of inertia has been proposed. The method uses the notion of network sensitivity, to measure the locational capability of a system to resist fluctuations in bus voltage angle, and the location where these fluctuations are least is considered nearest to the center of inertia (COI).
2) An analytical method of calculating the capability of the system to tolerate power fluctuations due to demand variability or supply intermittency at a particular location. The flexibility index ranks the buses according to the impact of bus power injection changes on system stability. The system will exhibit the highest tolerance (or show highest flexibility) when change of injection level of a certain bus will have least impact on the damping of the most critical oscillatory mode, and this bus is designated as the most flexible bus (MFB) of the system.
3) Application of these indices could be instrumental for both planning and operational studies. Some of the applications that have been explored in this thesis using the information of these two indices are: optimal position for sitting of renewable energy sources (RES), impact of changing network topology and parametric variations on system dynamics, identification of coherent bus groups, mitigation strategies for the adverse effect of RES fluctuations on system stability, etc.
4) Using the notion of matrix perturbation theory for the first time in power system flexibility studies, a numerical-based method for calculating the metrics of DGF is proposed. The advantages of this method over its analytical counterpart are also highlighted.

5) A unified method with real-time capability for estimating effective nodal inertia under both ambient and transient conditions is proposed. The proposed method does not require additional noise-prone information like rate of change of frequency (ROCOF) and its threshold and rate of change of power and its threshold.

Key words: Power System Dynamics, Inertia Distribution, Power System Flexibility, Eigenvalue Sensitivity, Network Sensitivity, Center of Inertia, Coherent Bus Groups, Matrix Perturbation Theory, Condition Number, Online Inertia Estimation.