September 3, 2018

USF SPS Research Overview

1. Dynamic Modeling and Analysis of Converter Penetrated Power Grids High penetration of inverter-based generation (e.g., wind and solar) and delivery infrastructures (e.g., HVDC) introduced many new dynamic phenomena in power grids. First wind farm subsynchronous resonances (SSR) due to wind interactions with RLC circuit occurred in Texas in 2009. More SSR events were observed later on. Oscillations were also observed in wind and solar operating in weak grids. In microgrids, non-traditional stability issues were observed. All those stability issues call for adequate modeling and analytical methods for understanding phenomena and control strategy design to enhance stability.

In the wind grid integration research, we have been the leading group in the world in developing analytical models of wind farms for SSR analysis and weak grid analysis. We have the combined strength of power grid modeling and power electronic system modeling. Google scholar citation number for our 2010 paper "*Modeling of DFIG-based wind farms for SSR analysis*" reaches **250** as of August 2018. Strong collaborations with industry (ERCOT and AEP) have been established and our group is the key player of Wind SSO Modeling Taskforce, which was founded in 2017 with first meeting embarked in IEEE PESGM 2018. The TF consists of 43 members from wind manufacturers, consultants, utilities, government, and universities.

Two books in dynamic modeling of wind, power systems and microgrids have been written: *Modeling and Analysis of Double Fed Induction Generator Wind Energy Systems* (Academic Press, 2015), and *Control and Dynamics in Power Systems and Microgrids* (CRC Press, 2017). The latter received an outstanding review in IEEE Power and Energy Magazine (May/June issue of 2018).

In PV/battery grid integration research, Duke Energy sponsored several research projects on setting up SCADA system for real-world 1.6 kW PV/20 kWh battery systems, and on real-time digital simulation of a distribution system with PV and battery for dynamic assessment. The project results in a series high influential journal articles. In IEEE PESGM 2016's Panel Session "Microgrid Stability and Modeling", Dr. Fan presented the related research work in a presentation entitled "Modeling Methods for Microgrid Stability Analysis."

Dr. Fan was recognized as a leading expert in power system dynamics. She served as a consulting editor for IEEE trans. Sustainable Energy and the co-Editor in Chief for IEEE trans. on Sustainable Energy's special issue on *Dynamic Modeling, System Identification, Analysis, and Control of Renewable Distributed Energy Resources for Grid Integration* (2017-2018). She was invited to serve in a Ph.D external examining committee in NTNU Norway in July 017. She was invited as a keynote speaker in International Symposium on Renewable Energy Grid Integration at Shanghai in July 2018. She was a key member of IEEE PES Task Force on Microgrid Stability Analysis and Modeling with a final report entitled as "*Microgrid Stability Definitions, Analysis, and Modeling*" recently published. Most recently, Dr. Fan has recently completed a 3-hour video tutorial "*Wind in Weak Grids*" and the tutorial will be soon available in IEEE PES resource center.

2. Control Design and Prototyping Using Hardware In this area, several research projects have been carried out: mitigation of inter-area oscillations through type-3 wind converters (NSF grant #1005277 Control of Wind Generation for Inter-Area Oscillation Damping, 2009-2014); mitigation of SSR through type-3 wind converters (Fan, Lingling, and Zhixin Miao. "Mitigating

SSR using DFIG-based wind generation." IEEE Transactions on Sustainable Energy 3, no. 3 (2012): 349-358.); control of hybrid converters for PV charging stations (A. Tazay and Z. Miao, "Control of a Three-Phase Hybrid Boost Converter for a PV Charging Station ," to appear, IEEE trans. Energy Conversion).

While the first two controllers rely on high-fidelity computer simulation for validation, the last project adopts a hardware testbed employing National Instrument's general purpose converter board and sbRio control board to configure a multiple input multiple output hybrid converter and its control. Grid integration control (active power and reactive power regulation), dc-link voltage control can all be realized through the hardware testbed. USF SPS lab is equipped with RT-Lab and NI's sbRIO, cRIO, PXI control prototyping systems for controller-hardware-in-the-loop tests.

3. System Identification Using PMU Data Using 30 Hz PMU data to estimate a dynamic model for a generator or a subarea can be classified as an application of system identification. The obtained dynamic model is usually a reduced-order model. Such reduction can greatly save computing time when this model is used for large-scale computing. Further, this method can be used to find generator parameters, e.g., turbine's droop, and validate the existing model parameters. This project was sponsored by DOE/MISO 2010-2015. We developed Kalman filter approaches to estimate generator parameters online relying on local measurements only; we also developed efficient Prony analysis to identify oscillation modes using local PMU measurements and then conduct data fusion to find the best estimation. In both applications, the underlying math problem (non-constrained multi-objective optimization problem) was closely examined and efficient algorithms were developed. Finally, rigorous validation was conducted to show feasibility of the estimation methods.

Dr. Fan served as a panelist in PESGM 2015 panel entitled "*Estimating Dynamic States for Real-Time Power Grid Operation.*" The title of the panel presentation is "*Least squares estimation and Kalman filter based dynamic state and parameter estimation.*" Other panelists included T. Van Cutsom of University of Liege, Henry Huang of PNNL, Ali Abur of Northeast University, and S. Meliopoulos of Georgia Tech.

4. Algorithms for AC OPF Combining graph theory, sparse matrix handling techniques, positive semidefinite matrix completion theorem and convex relaxation methods such as semi-definite programming (SDP) and second order conic programming, we aim to design scalable algorithms to solve optimal power flow problems using convex relaxation and further find feasible solutions or achieve exactness should the global minimum is inexact. We have developed a convex relaxation solver that can achieve SDP tightness yet with only half of the computing time of other available sparse SDP solvers. Research achievements include:

1. Z. Miao, L. Fan, H. Ghassempour, B. Zeng, "Least Squares Estimation-based SDP Cuts for SOCP Relaxation of AC OPF ," *IEEE trans. Automatic Control*, vol. 63, no. 1, pp. 241-248, Jan. 2018.
2. M. Ma, L. Fan, Z. Miao, B. Zeng, and H. Ghassempour, "Strengthened SOCP Relaxation for AC OPF and Rank-1 Computing Based on 3-Node Cycles," under review, *IEEE trans. Power Systems*.