-- Toward Smart, Secure and Resilient Power and Energy Infrastructures: Controls and Dynamical Systems Challenges and Opportunities

Abstract:

Secure and reliable operation of complex interactive energy and power networks poses significant theoretical and practical challenges in sensing, analysis, modeling, simulation, prediction, control, and optimization. In addition, mathematical models of such interactive systems are typically vague (or may not even exist); moreover, existing and classical methods of solution are either unavailable, or are not sufficiently powerful.

From a strategic R&D viewpoint, a major challenge is posed by the lack of a unified mathematical framework with robust tools for modeling, simulation, control and optimization of time-critical operations in smart electric power grids (spanning from fuel source to end-use) as complex multi-component and multi-scaled networks. How can systems be developed that can sense, identify and build realistic models and anticipate impending failures? Will they be able to adapt, control and mitigate disturbances to achieve their goals?

Any complex dynamic infrastructure network typically has many layers, decision-making units and is vulnerable to various types of disturbances. Effective, intelligent, distributed sensing and control is required that would enable parts of the networks to remain operational and even automatically reconfigure in the event of local failures or threats of failure.

Furthermore, as the power grids become heavily loaded with long distance transfers, the already complex system dynamics become even more important. The potential for rare-events but high-impact cascading phenomena represent just a few of many new science and technology concepts that are under development. Analysis and modeling of interdependent infrastructures (e.g. the electric power, together with protection systems, telecommunications, oil/gas pipelines and energy markets) is especially pertinent.

During the past two decades, a new vision for the integrated sensing, communications and control of the power grid has been developed. Some of the pertinent issues are why/how to develop controllers for centralized vs. decentralized (via hybrid multi-agent models), associated architectures, and issues involving adaptive operation and robustness to disturbances that include various types of failures.

Our work in this area draws from methods in statistical physics, complex adaptive systems, discrete-event dynamical systems, and hybrid, layered networks. Modeling complex systems is one of three main areas in our ongoing work. The others are measurement-to know what is or will be happening and develop measurement techniques for visualizing and analyzing large-scale emergent behavior-and management-to develop anticipatory distributed management and control systems to keep power and energy infrastructures robust and operational.

In this presentation, we will present recent advances in distributed sensing, modeling, and control, particularly at both the high-voltage power grid and at consumer level. Such advances may contribute toward the development of an effective, intelligent, distributed control of power system networks to achieve the overall objectives of efficiency, robustness, and reliability. From a broader viewpoint, agility and robustness/survivability of smart grids as large-scale dynamic networks that face new and unanticipated operating conditions will be presented.