Cyber-Physical Design Methodologies and Tools for Distributed Smart Grids

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The design of large-scale, geographically dispersed cyber-physical systems requires advances in tools and methodologies. State-of-the-art CPS methodologies focus on vehicles, which differ in two important respects from energy systems: energy system developers have less control over the characteristics of components connected to the energy grid; and the wide geographic distribution of components results in more variation in network delays.

We will start with a brief discussion of our evolving views on CPS design methodologies. Software-oriented system design methodologies provide many useful tools but require some adaptation for cyber-physical systems. Hybrid machines provide a useful abstraction for state-oriented cyber-physical system specification, but a variety of models such as use cases and sequence diagrams need to be adapted to the characteristics of CPS.

The design of smart grid and other large-scale CPS will necessarily be simulation-oriented. Given the complex physical plants and their interactions with algorithms, analytical methods are insufficient to properly characterize the design space or verify a design. We have developed a cyber-physical simulation system for use in smart grid design; this tool set can be used for other CPSs as well. Control system stability crucially depends on closed-loop delays. A key goal of our simulator is to model delay in both the physical plant and the cyber controls. Our simulator combines several subsystems:

- A packet-based network simulator allows a wide range of communication networks to be modeled. Utilities today already use communication links ranging from dedicated lines to Zigbee and cellular telephony. We expect the use of non-dedicated lines to increase as the granularity of components in the smart grid decreases.
- An RTOS delay simulator allows us to simulate computational delays. Accurate modeling of system delay requires coupled modeling of delays on the computing nodes and the network.
- An interface to a physical power grid simulator. We have connected our network/computing simulator to PowerWorld and are constructing a Simulink interface.

We will discuss the design of our smart grid simulation framework and illustrate its use.