An Integrated Approach to Design and Analysis of Intelligent Future Energy Systems

Brian Johnson, Santiago Grijalva
Distributed Energy Systems Integration Group
Power Systems Engineering Center, National Renewable Energy Laboratory
Golden, CO 80401, email: {brian.johnson, santiago.grijalva}@nrel.gov

Background and Introduction

The energy industry is currently undergoing a fundamental transformation in the way energy is generated, delivered, and consumed. Energy infrastructures constitute phenomena across large and small geographic regions – from transmission networks which stretch across continents to individual residential loads. The emergence of renewable energy devices, demand response technologies, communication networks, and hybrid/electric plug-in vehicles facilitates sustainability and empowers consumers to localize energy generation and storage across the power system. In such a setting, the interdependencies among various sub-domains, such as communication networks, intermittent renewable generation, and markets, can have an immense impact on how systems and devices should be controlled to optimize system performance and reliability.

Our Approach and Position

Given the unprecedented scale and complexity of the challenges in cyber-physical energy systems, it is our position that these problems cannot be addressed by ad-hoc industry approaches. Accordingly, we believe that a coordinated and integrated investigation is needed which takes into account interactions across all relevant energy and cyber subsystems. Furthermore, in contrast to conventional approaches which tend to focus exclusively on modeling, we advocate a theory-to-demonstration approach which recognizes the pivotal importance of cyber-physical testbeds in accelerating industry adoption. Towards that end, the National Renewable Energy Laboratory (NREL) has assembled a team with a diverse set of expertise, from communications to power electronics and power systems, and is currently developing an experimental platform to analyze, develop, and validate intelligent energy systems within NREL's Energy Systems Integration Facility (ESIF).

The main objective is to create a flexible and modular testbed which captures interactions and information flows between the multiple cyber and physical subsystems within an energy infrastructure (Figure 1 shows the relevant cyber and physical layers). In contrast to existing testbeds which typically represent a single testcase and are often focused on the device layer, the proposed testbed at NREL will be highly reconfigurable and offer a suite of communication capabilities to enable intelligent control at all levels. The flexible nature of the testbed will allow for the testing of various types of installations and allow researchers to assess emerging control paradigms, cyber layer architectures, system control approaches, and market propositions.

As illustrated in Figure 1, the emergence of distributed communications and intelligence enables an integrated approach to system control and design across all physical and cyber layers. To enable the analysis of both large- and small-scale behavior in unified laboratory setting, hardware-in-the-

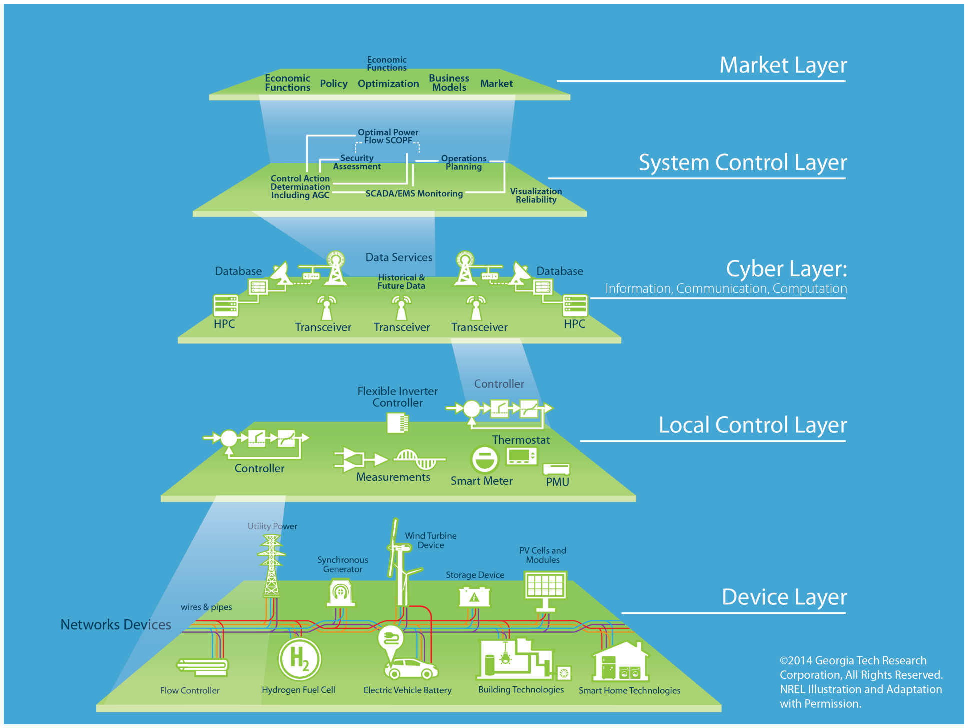

Figure 1: Layered architecture of an integrated and intelligent future energy system.

loop and high performance computing platforms will be used to conduct real-time co-simulations of system-level phenomena (e.g., market emulation, optimal power flow, etc...) which then interact in a bidirectional manner with hardware components in the ESIF laboratory. With such an approach, a megawatt-scale distribution-level microgrid composed of various hardware (multiple load types, generation sources, storage devices, power electronic converters, and communication hardware) will interact with a transmission-level simulation in a unified environment.

Ultimately, the layered system in Figure 1 should enable interoperability of various device types, bidirectional message passing when necessary, data management and acquisition, and computation. In such a setting, pricing signals generated by a utility would be broadcasted and processed by intermediate layers and devices before reaching distributed energy resources in the physical layer. Conversely, distributed measurements on the physical layer will be aggregated, processed, and communicated upwards to higher-level system controllers. In this context, it is clear that system components and functions will be heterogeneous and, consequently, research must be aimed at ensuring protocol compatibility at all levels.

Concluding Statement

To develop the technologies necessary for emerging energy infrastructures, advancements within the fields of computer science, informatics, complex networks, power systems, economics, dynamics, controls, and power electronics will need to be unified. Given the scope of the challenges which lie ahead, a coordinated effort across industry, government, and academia will be needed. The intelligent future energy systems testbed at NREL will be a national asset to facilitate these collaborations and to reach the goal of developing a sustainable, reliable, and cost-effective energy infrastructure.