The Need for Grid Architecture

The U.S. electric power system has steadily increased in complexity for most of the 20th Century, but was designed and operated on certain fairly simple principles that included centralized dispatchable generation, passive loads, virtually no storage, load-following balance, and operation for reliability. Changes in priorities and societal needs are not only driving utilities to violate all these assumptions, they are also leading to a massively more complex grid where a great many hidden interactions can occur and new ones can arise as fundamental structural changes to the grid occur.

The penetration of distributed generation and other forms of distributed energy resources is already changing the structure of the grid at the electric infrastructure level, necessitating changes to grid protection and control. Emerging forms of prosumer interaction are creating a need for coordination of potentially huge numbers of devices and systems that are connected to and which impact grid operations but are not owned by the utilities. Changes are being considered in definitions of utility roles and responsibilities at the distribution level, potentially leading to both regulatory and industry structure changes. At the same time, in parts of the country, natural gas systems are heading toward convergence with electric power systems, as are electric transportation systems. Social networks are beginning to impact all of the above. It is critical that these changes be viewed, understood, re-architected, and managed simultaneously due to the deep interconnection and interaction of these and other associated networks.

Traditional methods of dealing with grid interaction were siloed into those related to circuits and controls and those related to information systems. In the present grid modernization environment however, it has become clear that electric grids have reached or are about to reach Ultra-Large Scale complexity (a concept developed at Carnegie Mellon University) with changes occurring simultaneously in electric infrastructure; industry and market structure; protection, control, and coordination, and digital superstructure, in addition to undergoing convergences with other networks, such as transportation, water, natural gas, and social networks. Key characteristics of Ultra-Large-Scale systems include:

- Decentralization and distributed control as opposed to centralized organization and control
- Unclear and diverse requirements that may change during the life of the system
- Continuous evolution and deployment as opposed to rebuild and replace
- Heterogeneous, inconsistent, and changing parts as opposed to single sourced solutions
- Failures as part of normal operation as opposed to being strictly exceptions

Because complexity management has become a significant issue for grid modernization, powerful new methods are needed to represent the form and evolution of modern grids; consequently paradigms and methods from the discipline of *system architecture* have been adapted to provide the means to create whole system models for modern power grids. We refer to the discipline involved as *grid architecture* and the work product of this discipline as being a grid architecture. Grid architecture provides the framework to manage the complexity and the risk associated with making grid changes and helps to identify hidden interactions and technical gaps so as to reduce the likelihood of unintended consequences and stranded investments.

A grid architecture is a system level model which contains multiple simultaneous views of electric grid systems. It takes a largely structure-focused (as opposed to component-focused) approach, viewing the grid as a Network of Structures. It does not mandate specific designs, nor does it force users to adopt any particular view about implementation methods. It does focus on the overall “shape” of the grid, thereby facilitating both the removal of unnecessary limits inherited from the 20th Century grid and the creation of new structure that enables capabilities needed in the modern grid.

Grid architecture empowers all stakeholders to understand the emerging grid. Some examples of how it can be used are:

- System designers and utility engineers can use it to understand their subsystems in the context of the whole grid
- Utility executives can use it to relate grid changes to overall utility strategy, goals, and constraints
- Regulators and legislators can use it to appreciate interactions and consequences of potential changes and directives
- Suppliers, product vendors, and third party services companies can use it to identify value flows and product/service opportunities
- Researchers and technology developers can use it to identify technological gaps and develop compatible solutions
- All stakeholders, especially users, customers, and prosumers can use it to understand and communicate via a common vision of the grid

The discipline of grid architecture provides a modern set of methods to assist in thinking about grid complexities, to aid in understanding interactions and technical gaps, to enable new capabilities and remove old unnecessary limits, and to support communication among stakeholders.