The Network of Structures Grid Model Paradigm

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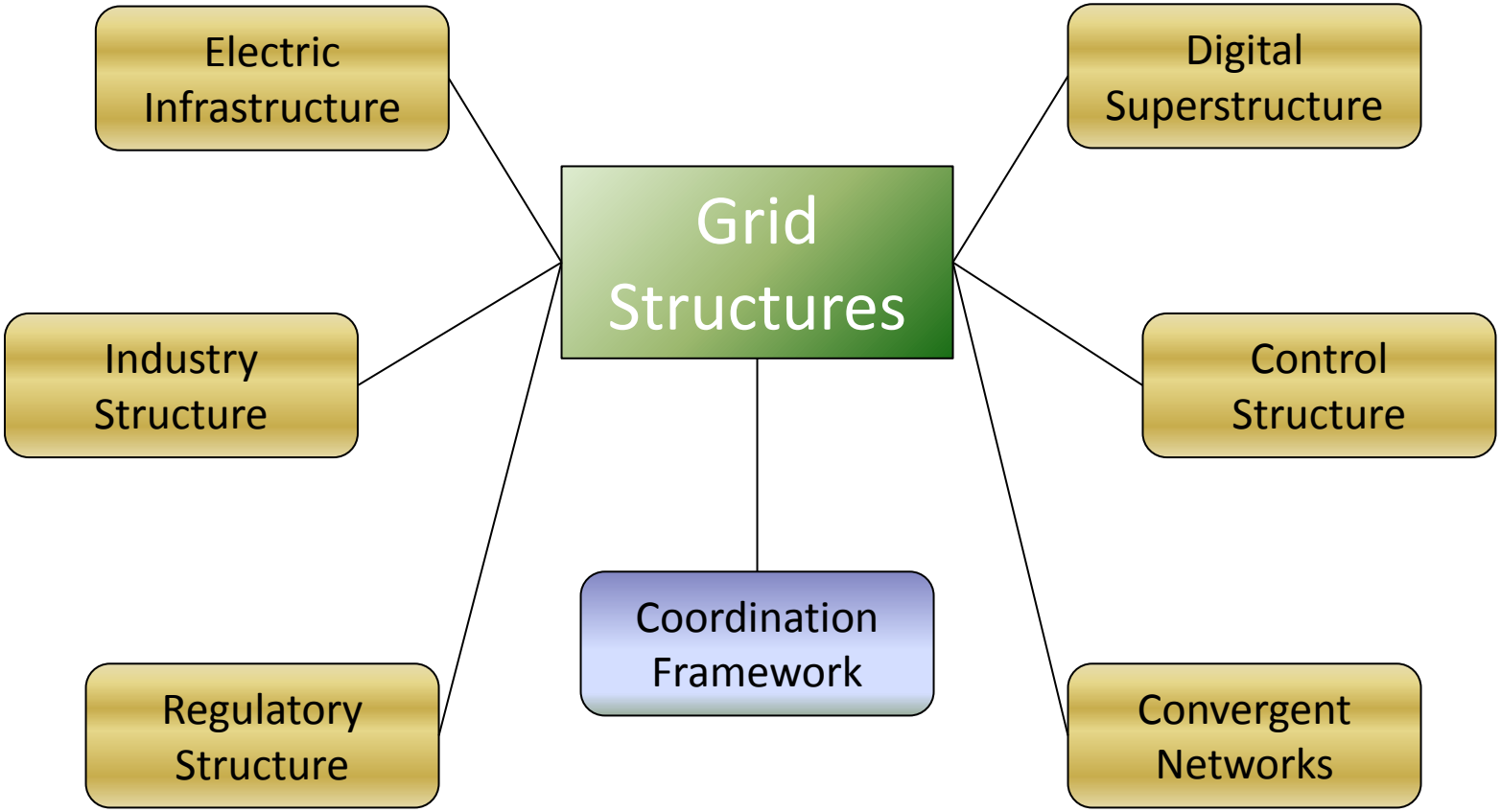
Network of Structures Paradigm

- Grid complexity is well beyond that of ordinary systems. In fact grids exhibit Ultra-Large Scale complexity[1,2].
- Grid architecture must consider effects in multiple domains *simultaneously*, taking ULS complexity into account. Many previous models are inadequate for this purpose.
  - The System of Systems (SoS) model has some value as a design paradigm but does not address the complexity issues at stake in grid modernization. SoS is essentially the software engineering module strength/module coupling concept for systems
  - Layer and matrix abstraction models do not address the essential cross-coupling and dependency issues and in fact mostly obscure them
- We represent the grid as an Ultra-Large Scale *network of structures*, subject to hidden and overt interactions and cross-couplings, complex constraints, dependencies, and convergences.

1. JD Taft and A Becker-Dippmann, Grid Architecture, p. A1, available online: http://energy.gov/epsa/downloads/grid-architecture

2. Mark Klein, Linda Northrop, et. al, Ultra-Large-Scale Systems, Software Engineering Institute, Carnegie-Mellon University, 2006.

Network of Structures Scope



Electric Infrastructure

- Primarily about circuit topology
- DER provides significant considerations
  - Load composition
  - Generation structure
  - Locational value of DER
- Bulk systems well defined
  - Documented via widely available bus-and branch models
- Distribution systems not as well documented
  - Wide variety of circuit structures in use; more possible
- Changes due to emerging availability of storage and DER penetration
- Strong ties to Industry Structure and Control Structure

Industry Structure

- Shows how organizations relate to each other in an industry segment
- Multiple views are needed:
  - Operations
  - Planning
  - Markets
- Markets are strongly connected to grid control and coordination
- Insights about Coordination Framework may be extracted from Industry Structure

Regulatory Structure

- Regulatory structure is about jurisdictions, boundaries, and scope. It is not about specific regulations.
  - Regulations are the design level components that exist one level down in abstraction from the regulatory structure
- Federal – U.S. government oversight, mostly for the bulk systems
  - FERC, NERC, EPA, IRS, USDA, etc.
- State – oversight in each of the states, mostly for Distribution systems
  - Public Utility Commissions/Public Services Commissions
- Consumer Owned Utilities: Co-op's, Muni's, CCA's…
  - Municipal/Co-op/PUD oversight boards
- Other – Federal power marketing authorities
  - Operated by DOE

Digital (ICT) Superstructure

- Information and Communication Technology
  - Networking – multiple tiers of communications requirements[1]
  - Processing – computing and applications
  - Persistence –storage for data at various levels of latency hierarchy[2]
- ICT convergence with the grid was the essence of the "Smart Grid" phase of grid modernization
- Several emerging trends are continuing to affect and reshape this convergence
  - Smart edge devices and systems
  - DER integration
  - Distributed computing and control paradigms
- ICT is foundational for further convergences because convergence has to occur in the digital control systems

1. See the GridBlocks Reference model: http://www.cisco.com/web/strategy/docs/energy/gridblocks_ref_model.pdf
2. J Taft, P De Martini, L von Prellwitz, Utility Data Management & Intelligence: http://www.cisco.com/web/strategy/docs/energy/managing_utility_data_intelligence.pdf

Control Structure

- Focus on control forms and patterns, not control algorithms or theory
- 12 classes of control:
  - Unit commitment
  - Primary generator control
  - Dispatch/scheduling
  - Balance and interchange
  - Load sharing
  - Power flow control
  - System frequency regulation
  - Voltage regulation
  - Stabilization
  - Synchronization
  - Direct load and DER control
  - Indirect DER management
- Protection also included
- Strong connection to power/energy markets
- Treated at times as a subset of Coordination

Convergent Networks

*Convergence is the transformation of two or more networks or systems to share resources and interact synergistically via a common and seamless architecture, thus enabling new value streams.**

- Multiple networks have converged already with the grid (e.g., ICT networks, financial [market] networks)
- Additional networks are converging or may converge
  - Fuel (especially natural gas)
  - Transportation
  - Water
  - Social

* P De Martini, J Taft, "Value Creation Through Integrated Networks and Convergence," available online: http://smart.caltech.edu/papers/ElectricNetworksConvergence_final_022315.pdf

Coordination Framework

- Coordination framework is the full set of operational directive flows in a grid system. It can be though of as a control superstructure.
- It includes dispatch and scheduling, supervisory and closed loop control, certain notices or indications from one organization to another, and signaling to effect cooperation.
  - The key issue is whether the message or signal causes a specific immediate or scheduled grid action
- Coordination is sometimes viewed as a subset of control, but here we invert that paradigm to make it a superset and generalize it because of its importance to modern grids with DER.
- Legacy coordination framework can be explicit; can be hidden inside something else, or can be missing entirely in some places.
- Coordination framework can be the collection of control structures or a new structure in itself.