The Network of Structures
Grid Model Paradigm
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.

Network of Structures Scope

Electric Infrastructure

Industry Structure

Regulatory Structure

Digital Superstructure

Control Structure

Convergent Networks

Coordination Framework

Grid Structures
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

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

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.