Grid Architecture as a Means to Understand the Interactions of Power Systems, Markets, and Grid Control Systems

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How Do We Understand Issues Like These?

- What does the control structure for the whole grid look like? How does the grid behave as a whole system?
- What limits the ability of commercial buildings to supply energy or other services to electric grids?
- How do grid controls and wholesale markets interact?
- How does generation bifurcation impact regulation/oversight?
- How do DER’s interact with ISO/RTO functions?
- How do agent-based autonomous distribution devices impact the Bulk Energy System?
- Are electric and gas networks converging or is generation just a downstream use of gas?
- Should distribution company roles and responsibilities be changed, and if so, how does this impact grid control, markets, and oversight?
A system architecture is a set of views of a (complex) system whose purpose is to help think about the overall shape of the system, its attributes, and how the parts interact.

The discipline arises from work at various organizations:
Components are Abstractions, Not Magic

Beware of Two Traps

- The individual parts, viewed as “black boxes”
- Example: storage battery
  - At this level we do not specify how the battery works
  - Care about externally visible characteristics like storage capacity, max power rating
- But thoroughly grounded in reality
  - no “magic” boxes or anti-gravity devices
- Over abstraction
  - DR is not a form of storage

Source: Sidney Harris
System Architecture Synthesis

- System Qualities come from the consumer viewpoint
- System Properties come from the provider viewpoint

Diagram:
  - Architectural Elements include Structures and their properties, and Components and their properties.
- Problem domain and Solution domain are connected.
Complexity for Ordinary Systems

Definition: Having many interrelated, interconnected or interwoven elements and interfaces

- Measured by the amount of information needed to fully describe a system
- Complexity is an absolute and quantifiable system property (once a measure and atomic level are defined)

- Complexity Measures:
  - Number of things: \( N_{\text{things}} \)
  - Number of types of things: \( N_{\text{types_of_things}} \)
  - Number of connections among things: \( N_{\text{connections}} \)
  - Number of types of connections: \( N_{\text{types_of_connections}} \)

- Simple measure that captures all of these is the sum:
  \[
  C = N_{\text{things}} + N_{\text{types_of_things}} + N_{\text{connections}} + N_{\text{types_of_connections}}
  \]

- Example: washing machine
Ultra Large Scale Complexity

- Decentralized data, development, and control
- Inherently conflicting diverse requirements
- Continuous (or at least long time scale) evolution and deployment
- Heterogeneous, inconsistent, and changing elements
- Geographic distribution
- Wide time scales

Source: Alexandra von Meier
**Grid Architecture** is the application of system architecture, network theory, and control theory to the electric power grid. A grid architecture is the highest level description of the complete grid, and is a key tool to help understand and define the many complex interactions that exist in present and future grids.
Some Uses of Grid Architecture

- Help manage complexity (and therefore risk)
- Assist communication among stakeholders
- Remove barriers and define essential limits
- Identify gaps in theory, technology, organization, regulation…
- Identify/define interfaces and platforms
- Enable prediction of system qualities

The architect is primarily a specialist in managing complexity.
Paradigm Changes

Old paradigms
- Grids are big circuits; control is just an app
- Systems of systems
- Data tsunami
- Cylinders of excellence (i.e. siloes)
- Architectural “elegance”
- System integration

Modern paradigms
- Ultra-Large Scale complexity
- Network of Structures
- Market/Control Interactions
- Convergence and platforms
- Architecture quantification
- Value stream analysis
The Grid is a Complex Network of Structures

- **Electric Infrastructure**
  - Circuit topology
  - Load composition
  - Generation structure

- **Industry Structure**
  - Operations
  - Planning
  - Markets

- **Regulatory Structure**
  - Federal
  - State
  - Other

- **Digital Infrastructure**
  - Networking
  - Processing
  - Persistence

- **Control Structure**
  - Protection
  - Control
  - Synchronization

- **Convergent Networks**
  - Fuels
  - Transportation
  - Social

- **Coordination Framework**
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.
recent work
Grid Architecture Work with DOE

- Done as part of QER
  - Work focused on selected issues
  - 115 page main document plus support documents
  - 47 diagrams, 7 tables, 20 alternate architectures reviewed, 18 emerging trends and 39 systemic issues analyzed
  - Referenced and quoted in QER Report

- Work has started to go viral – has been referenced in conferences and is even being used in an energy law class at GWU

- Presented to NY REV working group, resulting in engagement with NY REV on architecture

- Engaged with Duke Energy OpenFMB project

Notes: 1) Markets incl. bilateral and structured markets.
2) Other relationships exist for utility planning.
Existing Coordination Framework

- Structurally problematic
  - no formal basis
- Tier bypassing leads to destabilization
- Ad hoc form limits understanding of properties
  - emergent (read unintended) behavior
- Scalability problems
- Unnecessary connectivity raises extra cyber-security issues
DSO-Based Coordination Framework

- Structurally sound
  - formal basis available
- No tier bypassing
- Normalized form allows for property design and analysis
  - Boundary deference
  - Coordination/constraint fusion
- Scalable implementations available
- Connectivity and data flow patterns easier to secure
Summary

- Grid architecture is a combination of system architecture, network theory and control theory
- It provides a new way to think about electric grid complexity
- It also introduces rigor into the evaluation of architectural alternatives
- It is intended for use by many differing stakeholders, with the architect as a “guide through the jungle”
- It addresses a real need in the industry
thank you

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