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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?

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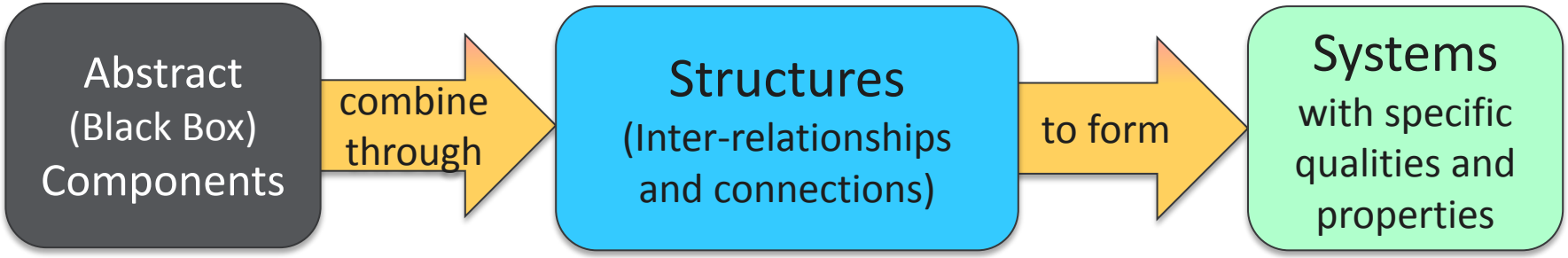
- What does the control structure for the whole grid look like? How does the grid behave as a *whole system*?
- What limits the ability of commercial buildings to supply energy or other services to electric grids?
- How do grid controls and wholesale markets interact?
- How does generation bifurcation 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?

System Architecture Definition/Purpose

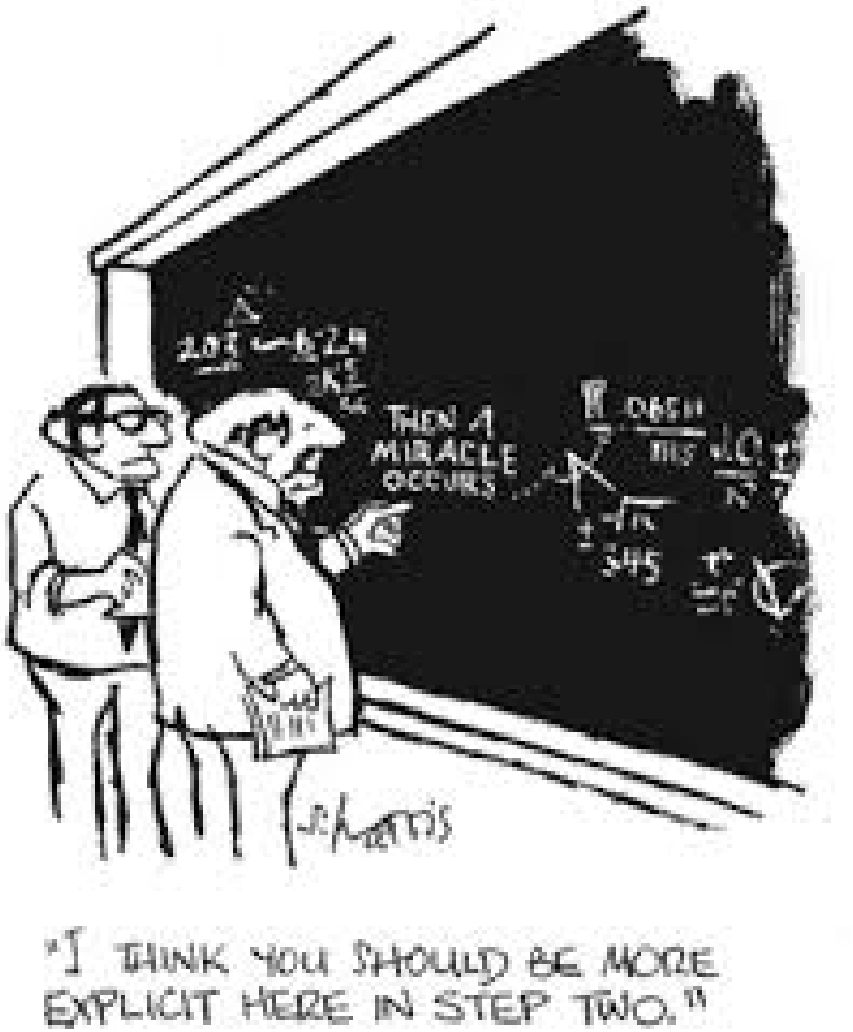
- A *system architecture* is a set of views of a (complex) system whose purpose is to help think about the overall shape of the system, its attributes, and how the parts interact.



The discipline arises from work at various organizations

Components are Abstractions, Not Magic

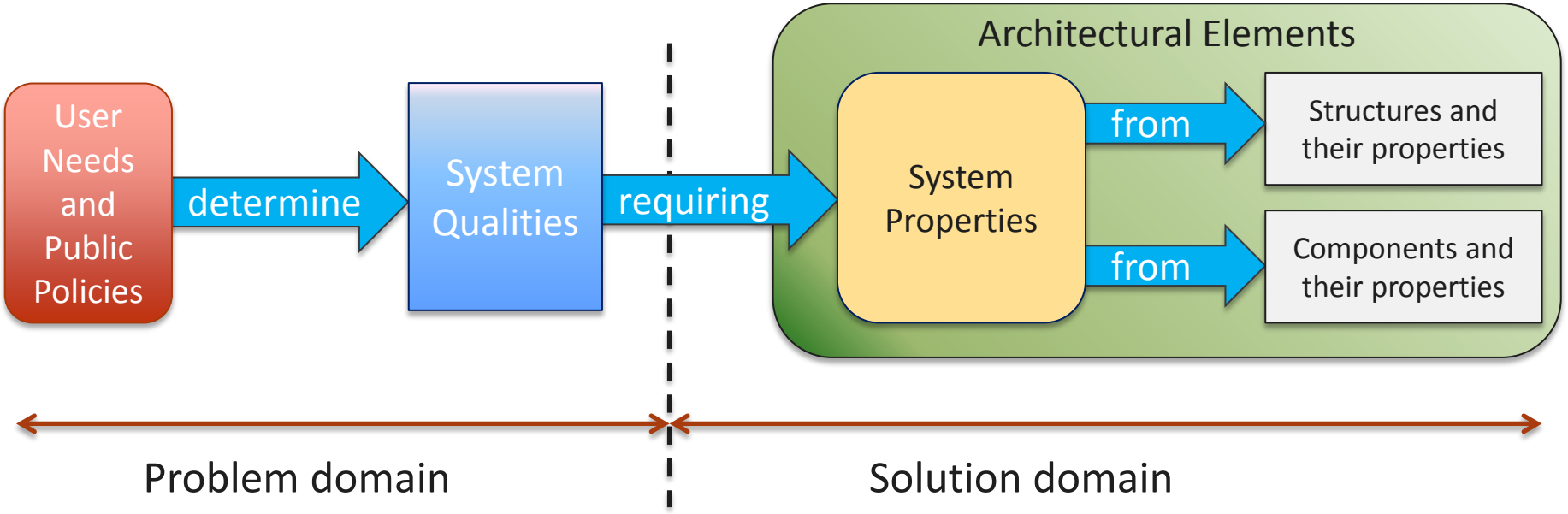
- Beware of Two Traps
  - The individual parts, viewed as “black boxes”
  - Example: storage battery
    - At this level we do not specify how the battery works
    - Care about externally visible characteristics like storage capacity, max power rating
  - But thoroughly grounded in reality
    - no “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



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_{things}
  - Number of types of things: $N_{types\_of\_things}$
  - Number of connections among things: $N_{connections}$
  - Number of types of connections: $N_{types\_of\_connections}$

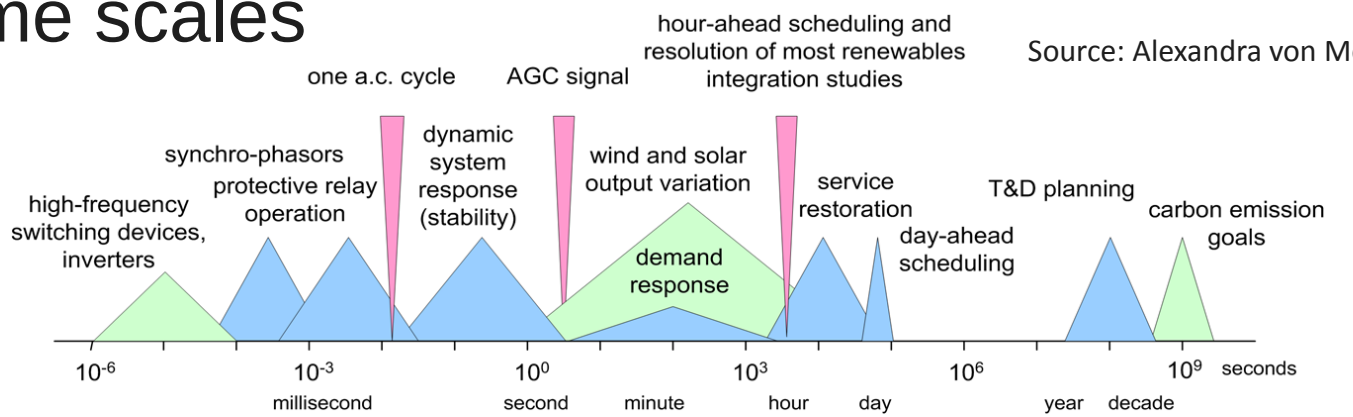
- Simple measure that captures all of these is the sum:

$$C = N_{things} + N_{types\_of\_things} + N_{connections} + N_{types\_of\_connection}$$

➢ Example: washing machine

Ultra Large Scale Complexity

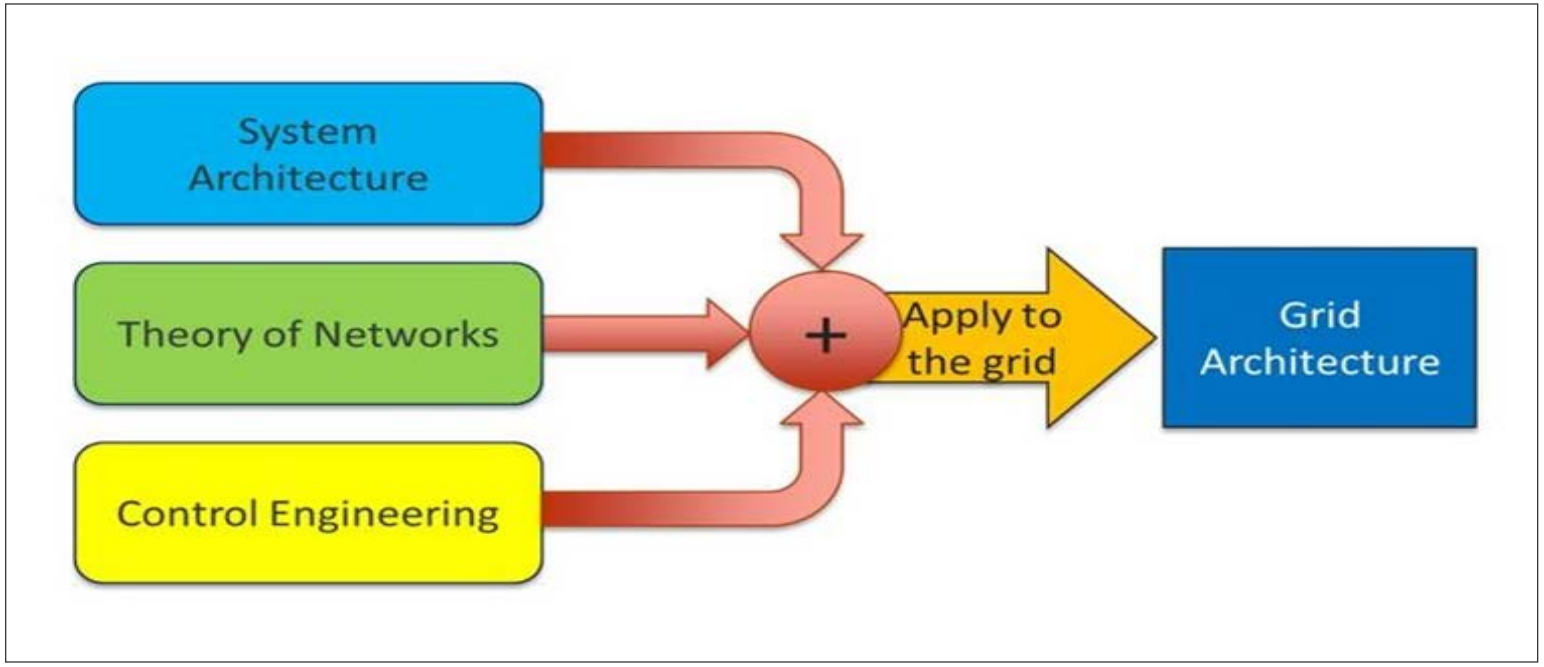
- Decentralized data, development, and control
- Inherently conflicting diverse requirements
- Continuous (or at least long time scale) evolution and deployment
- Heterogeneous, inconsistent, and changing elements
- Geographic distribution
- Wide time scales



Source: Alexandra von Meier

What is Grid Architecture?

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

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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

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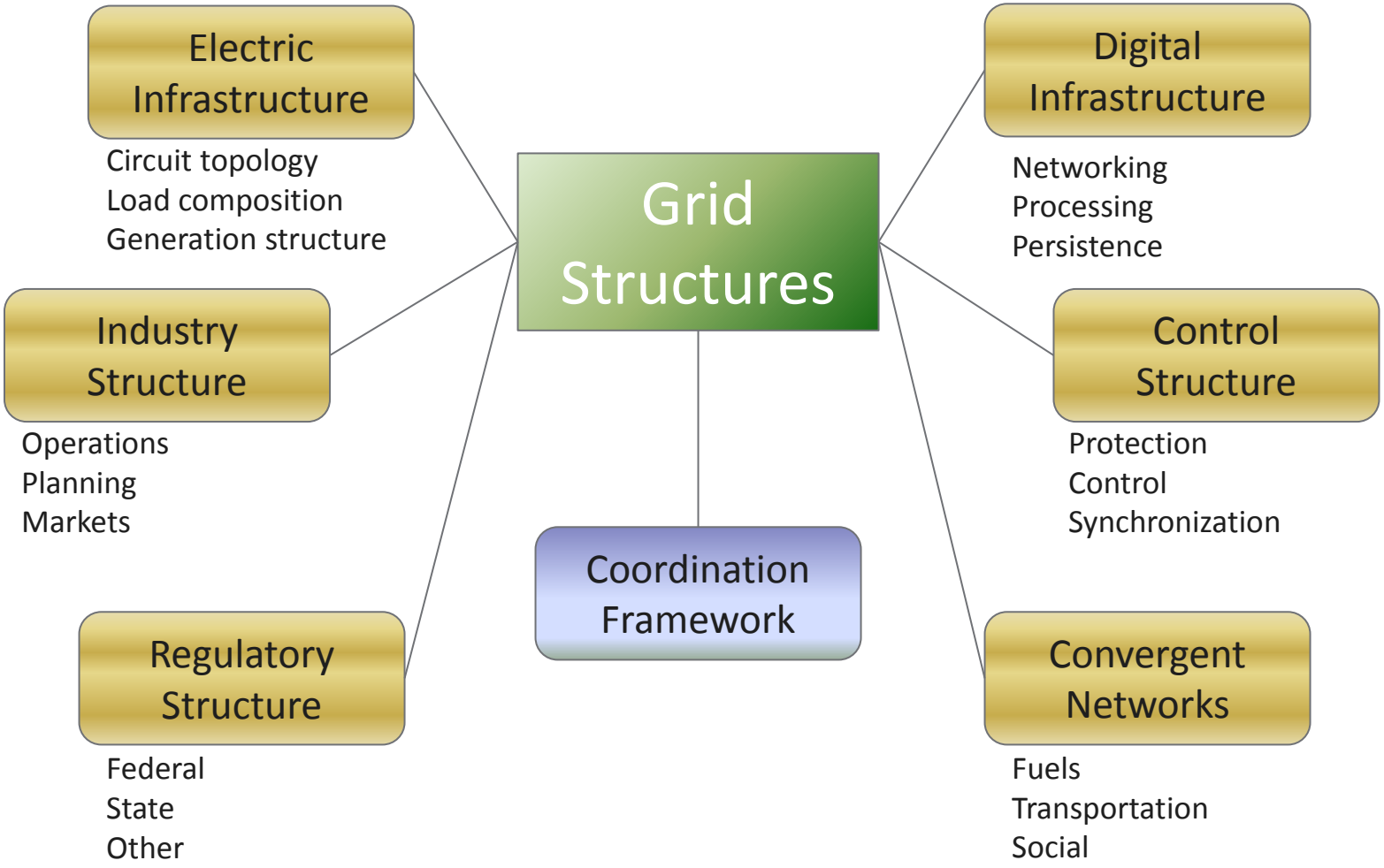
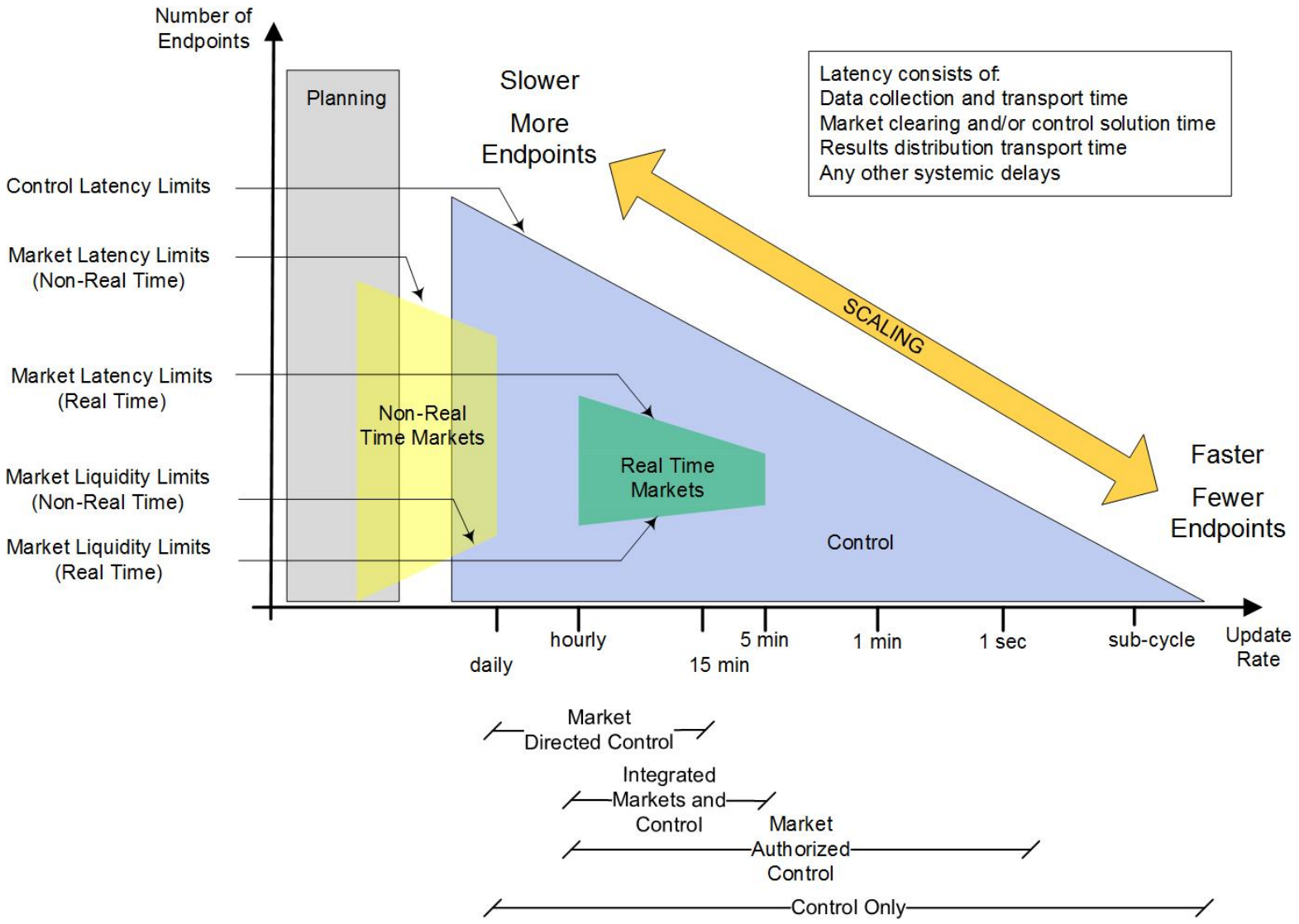
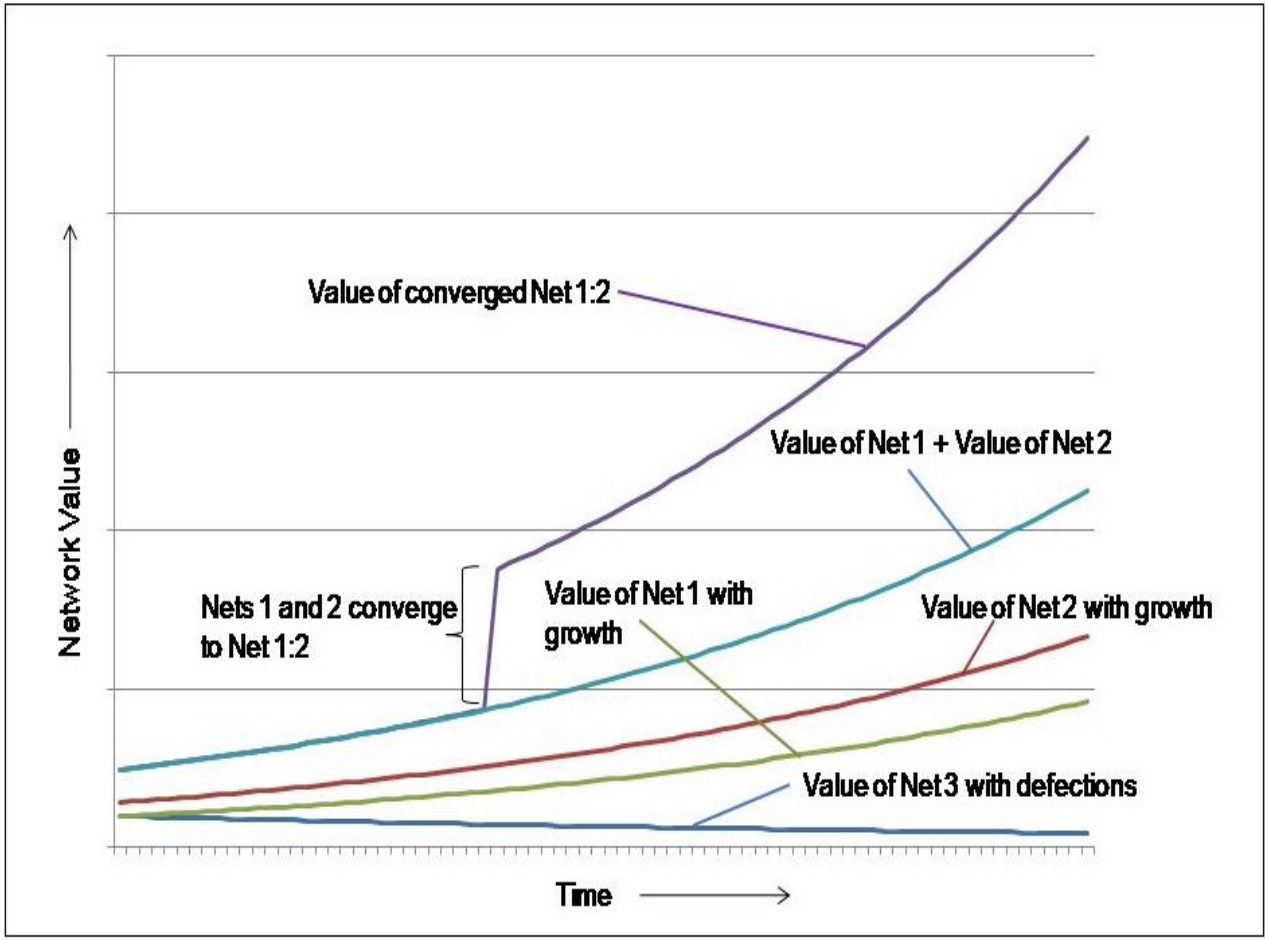


Market and Control Interaction Regimes

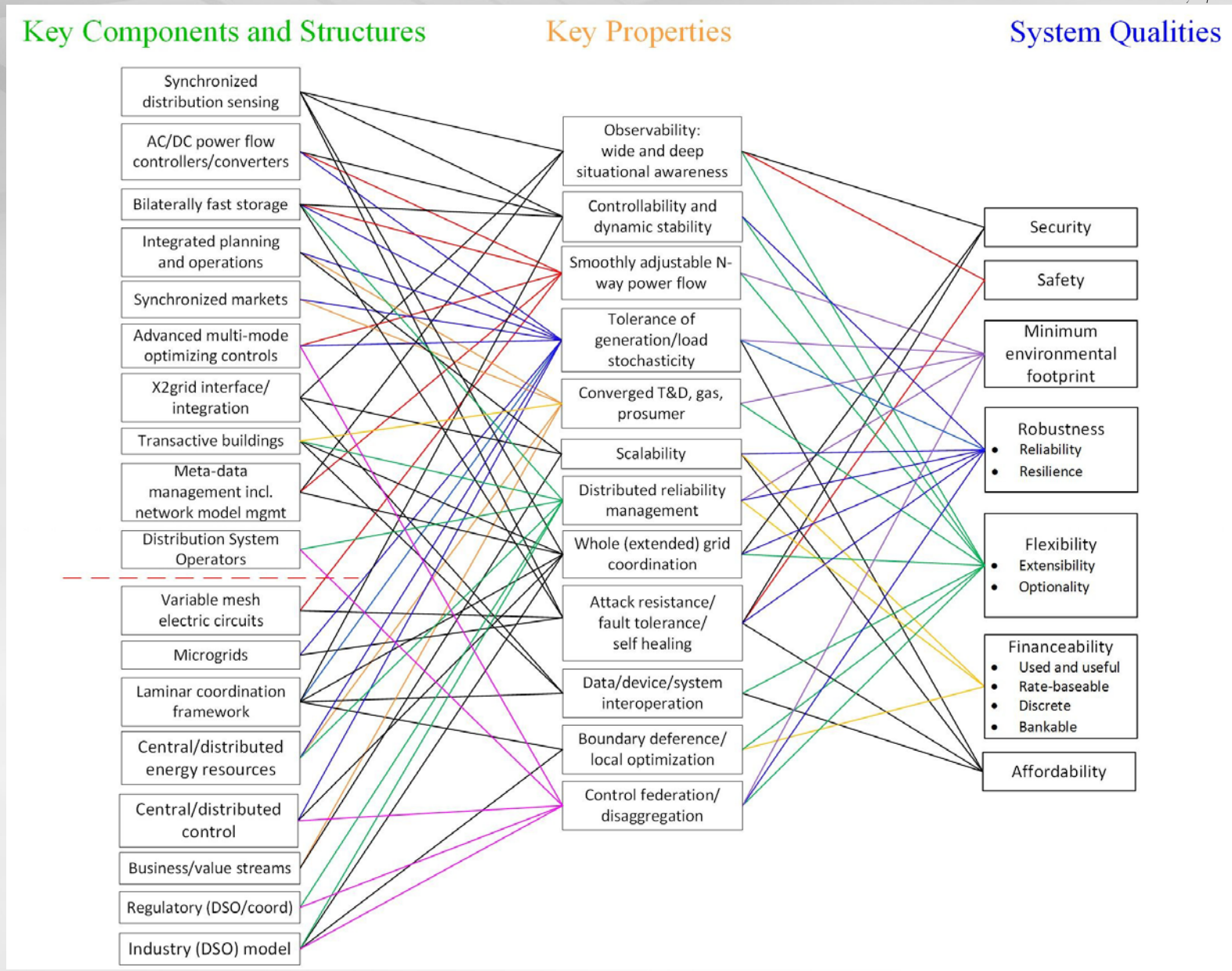


Network Convergence and Platforms

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.



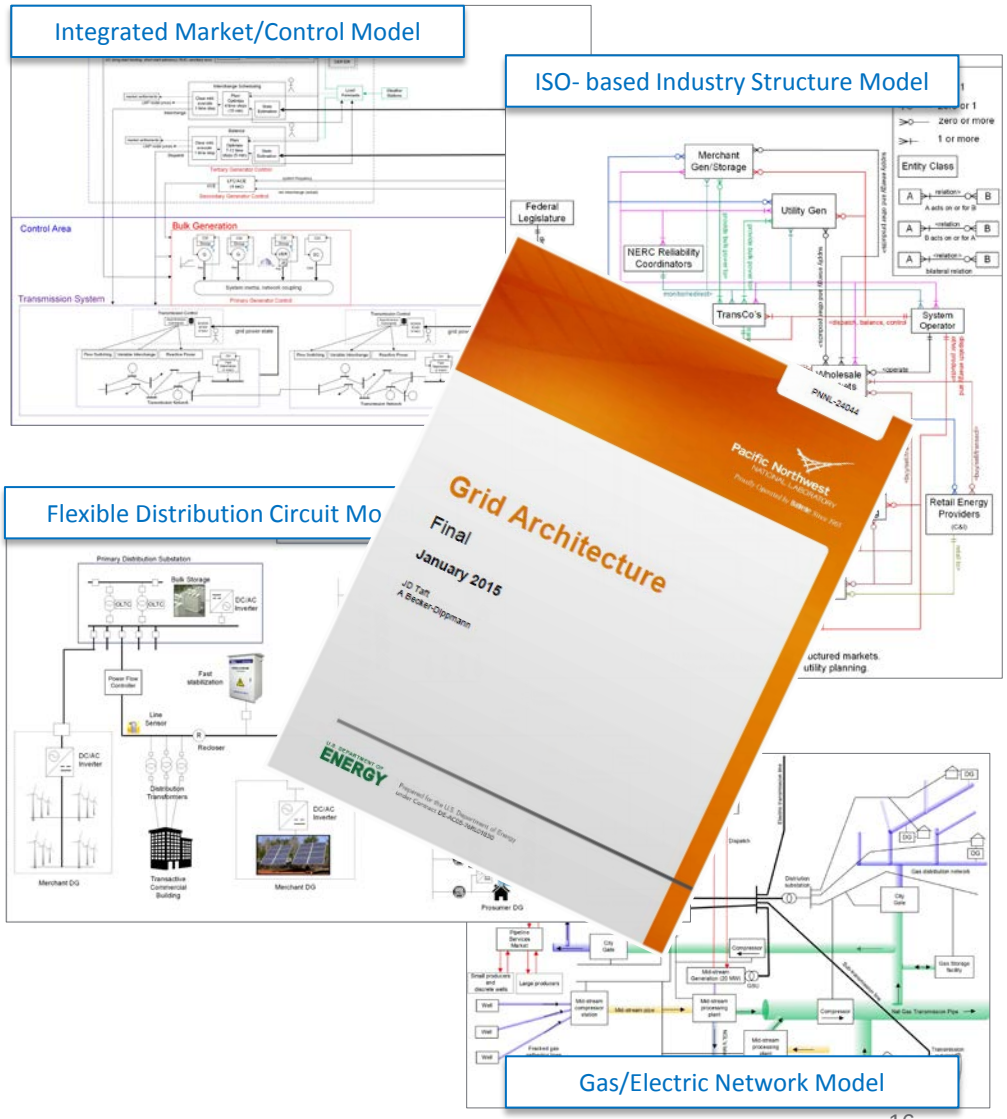
Architectural Quantification



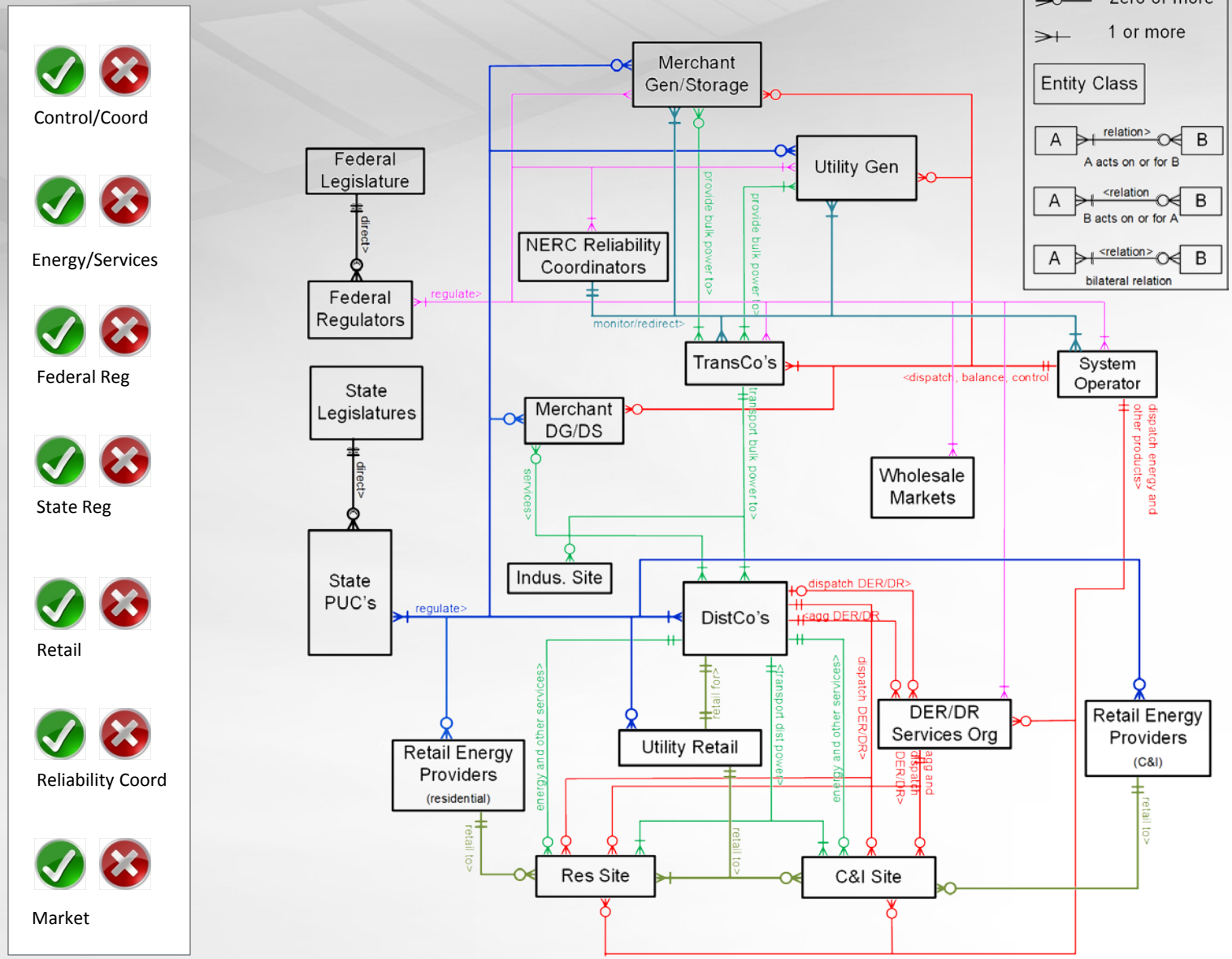
recent work

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

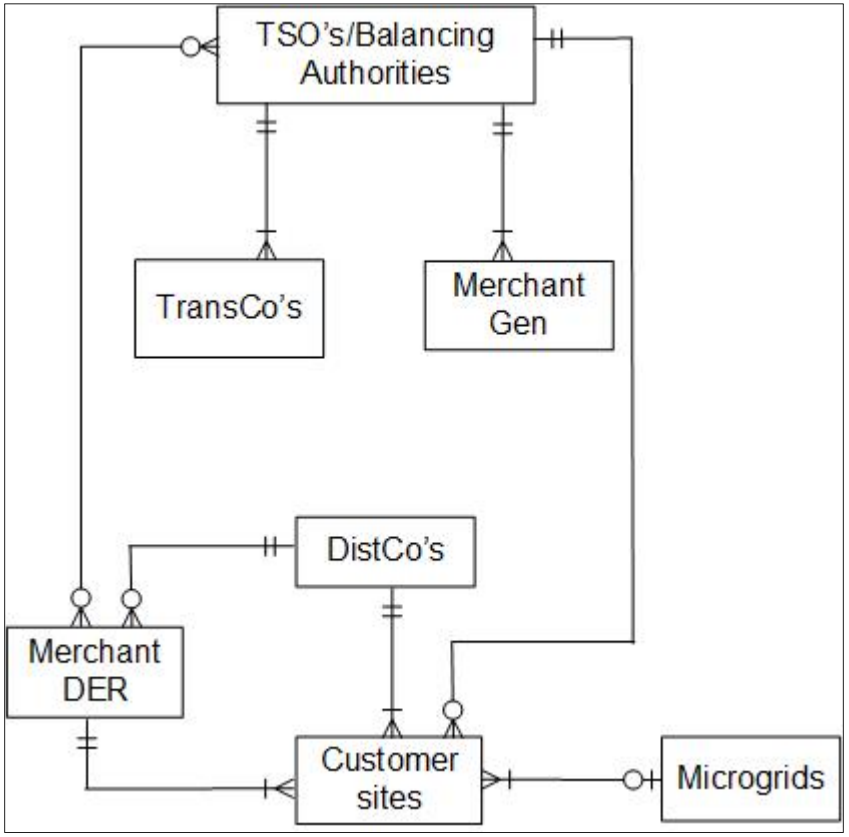


Disaggregated U.S. Utility Industry Operational Structure (Post 2000)



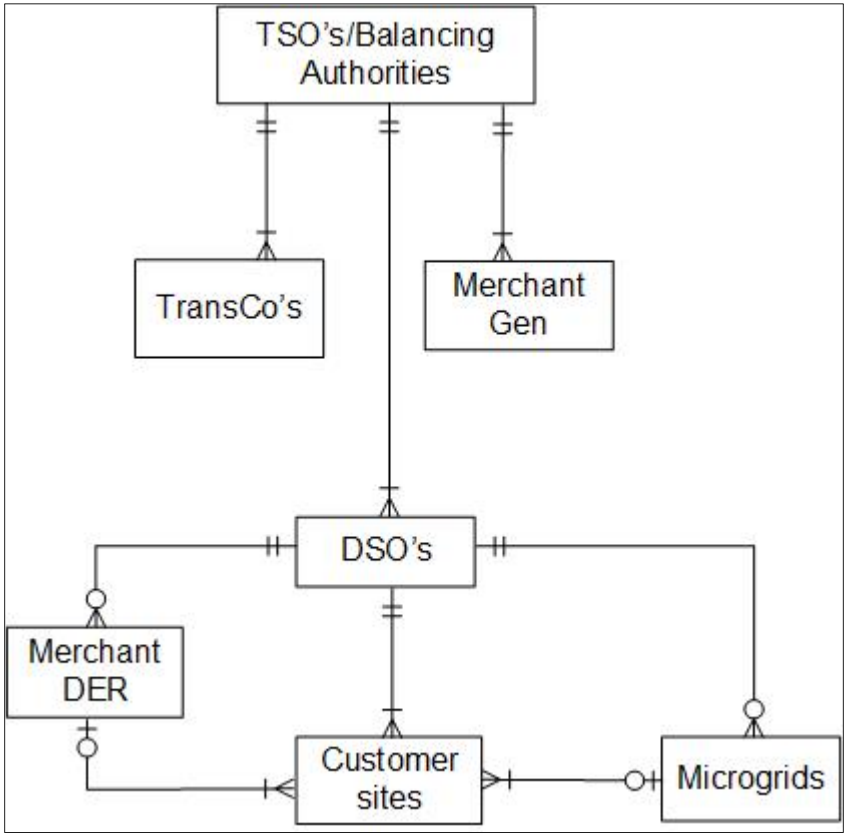
Notes: 1) Markets incl. bilateral and structured markets.
2) Other relationships exist for utility planning.

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

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thank you

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