Delivering grid modernization value by design

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for New England Conference of Public Utilities Commissioners
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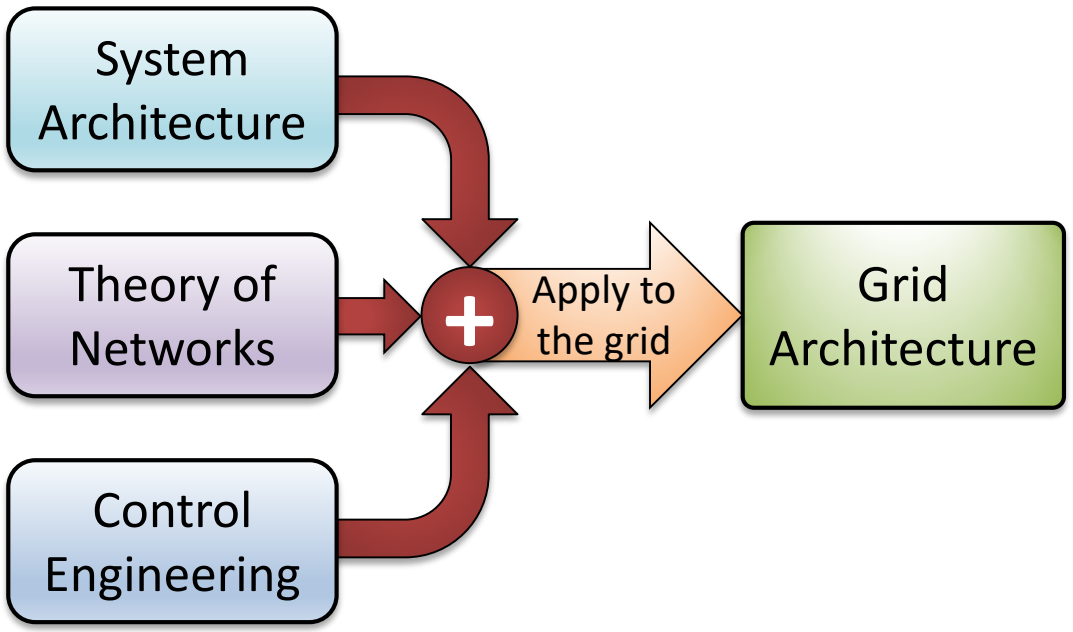
Outline

- Overview of Grid Architecture as applied to grid planning
- Common Grid Architecture structures
- Examples to show how Grid Architecture concepts have been used
- Questions commissions can ask
- Takeaways

Overview of Grid Architecture as Applied to Grid Planning

Grid Architecture

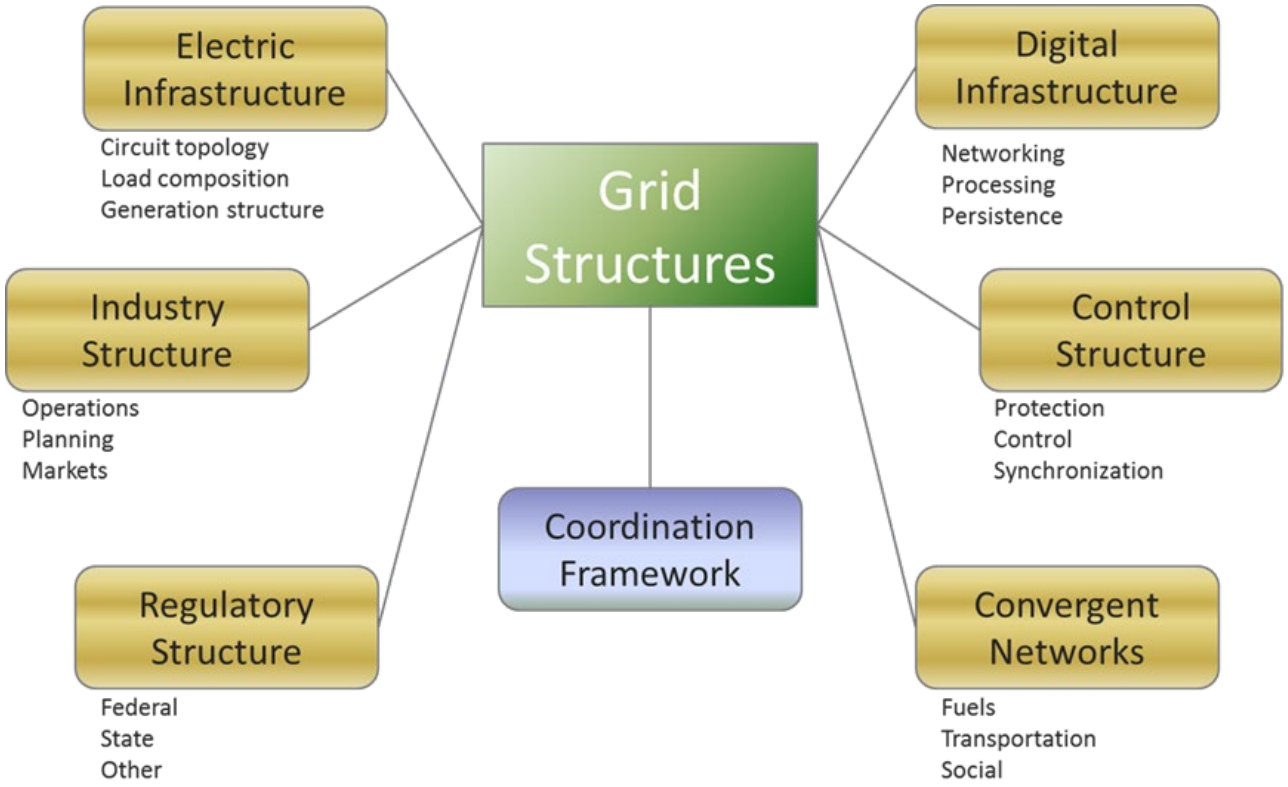
- An architecture is an abstract depiction of a system, consisting of black box components, structure, and externally visible characteristics.
- Grid Architecture is the highest-level representation of the electric grid with ultra-large-scale complexity.
- It enables reasoning about the grid's properties, behavior, and performance.



https://gridarchitecture.pnnl.gov/

Grid Architecture Is about Structures

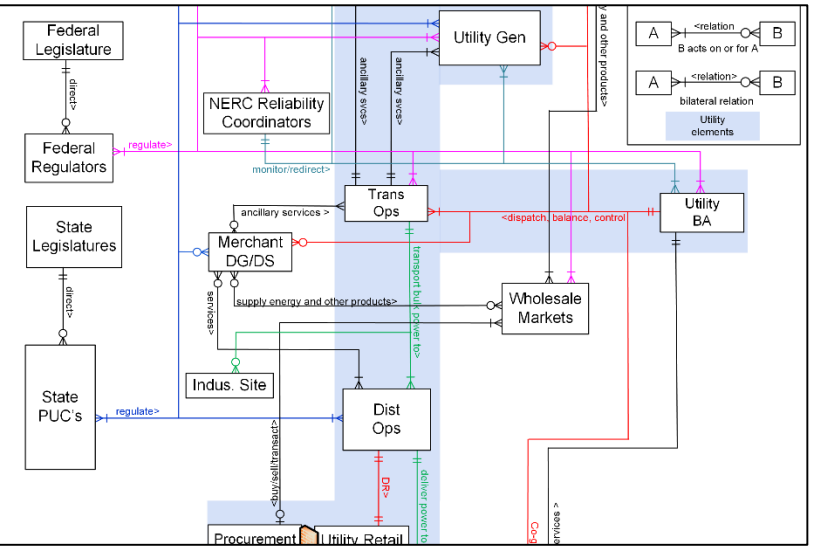
- Grid is viewed as a network of highly interconnected structures
- Planning must account for multiple grid structures simultaneously, so it should incorporate knowledge of grid architecture concepts.



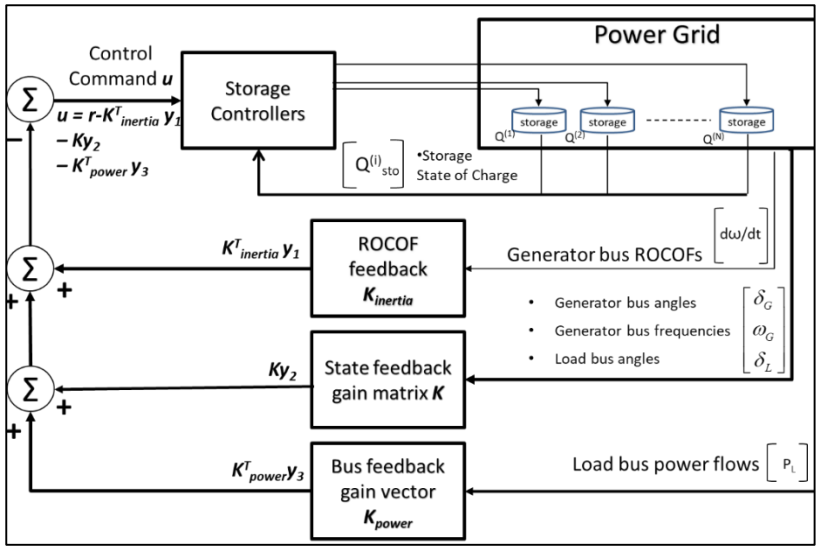
Grid Architecture is about ***structure.*** Structure sets the essential limits on what complex systems like the grid can and cannot do.

Grid Architecture Levels of Abstraction

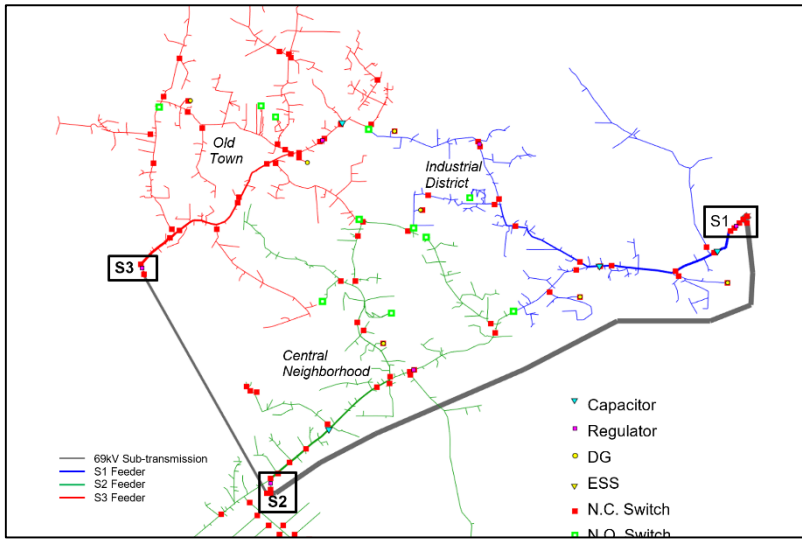
- Conceptual – structure, connectivity, classes of entities, “black boxes,” technology agnostic, starting point for logical / functional design
- Logical / Functional – structure, connectivity, input / output relationships, functional behaviors, technology independent, starting point for physical design
- Physical – structure, connectivity, physical system components



Conceptual



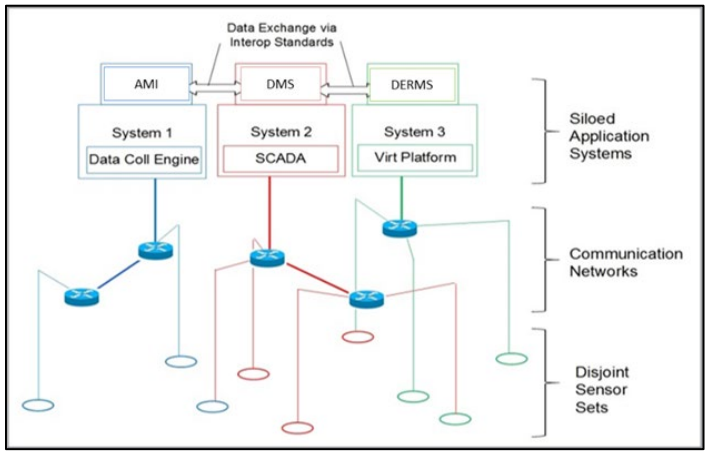
Logical / Functional

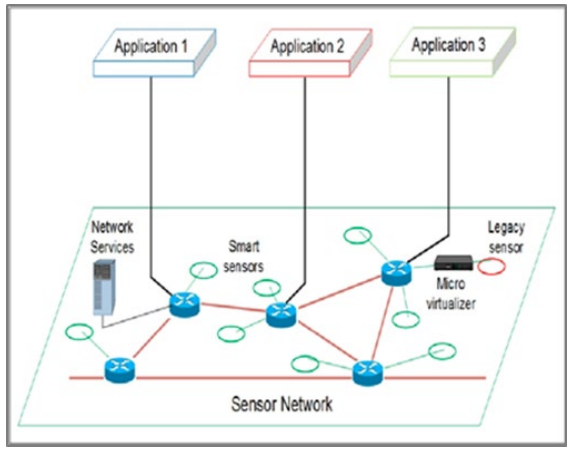


Physical

Planning Structure Transformation for Grid Modernization

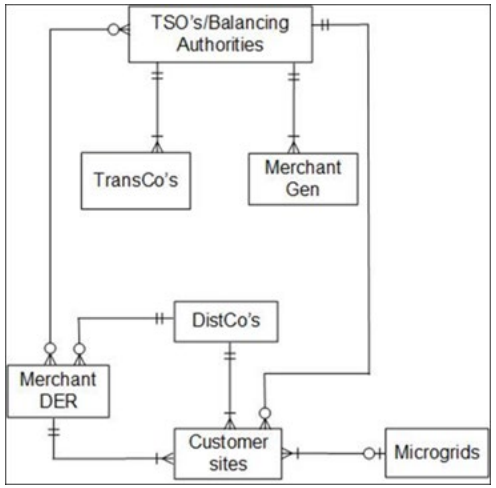
- Obtain holistic view of the existing system
- Assess gaps in the current structure
- Perform structure transformation to achieve grid modernization goals

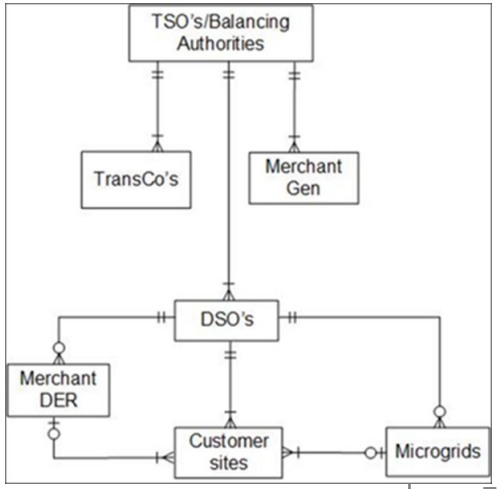




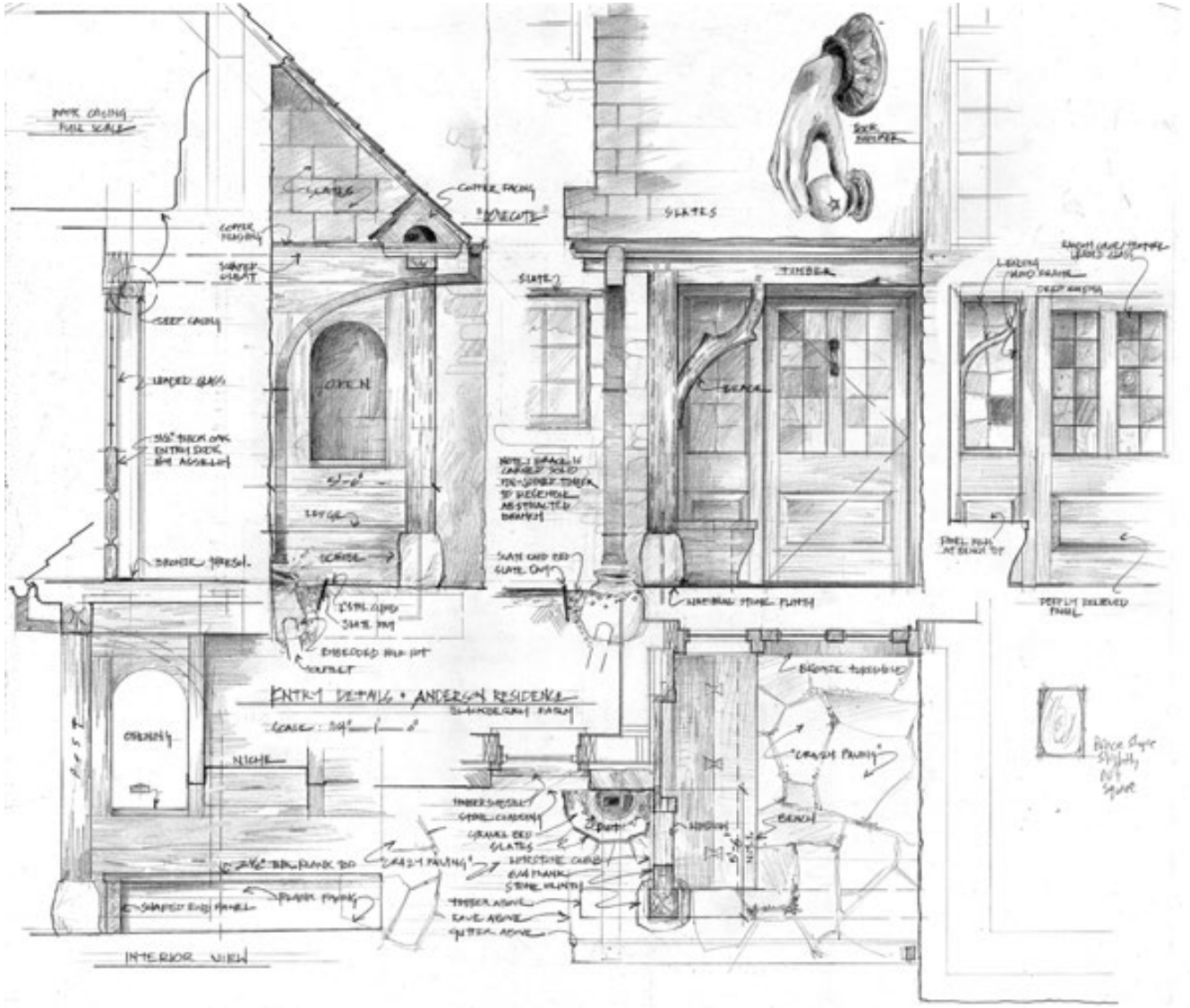
- Get the structure right and all the pieces fit into place neatly, all the downstream decisions are simplified, and investments are future-proofed.
- Get the structure wrong and integration is costly and inefficient, investments are stranded, and benefits realization is limited.

Structure Transformation



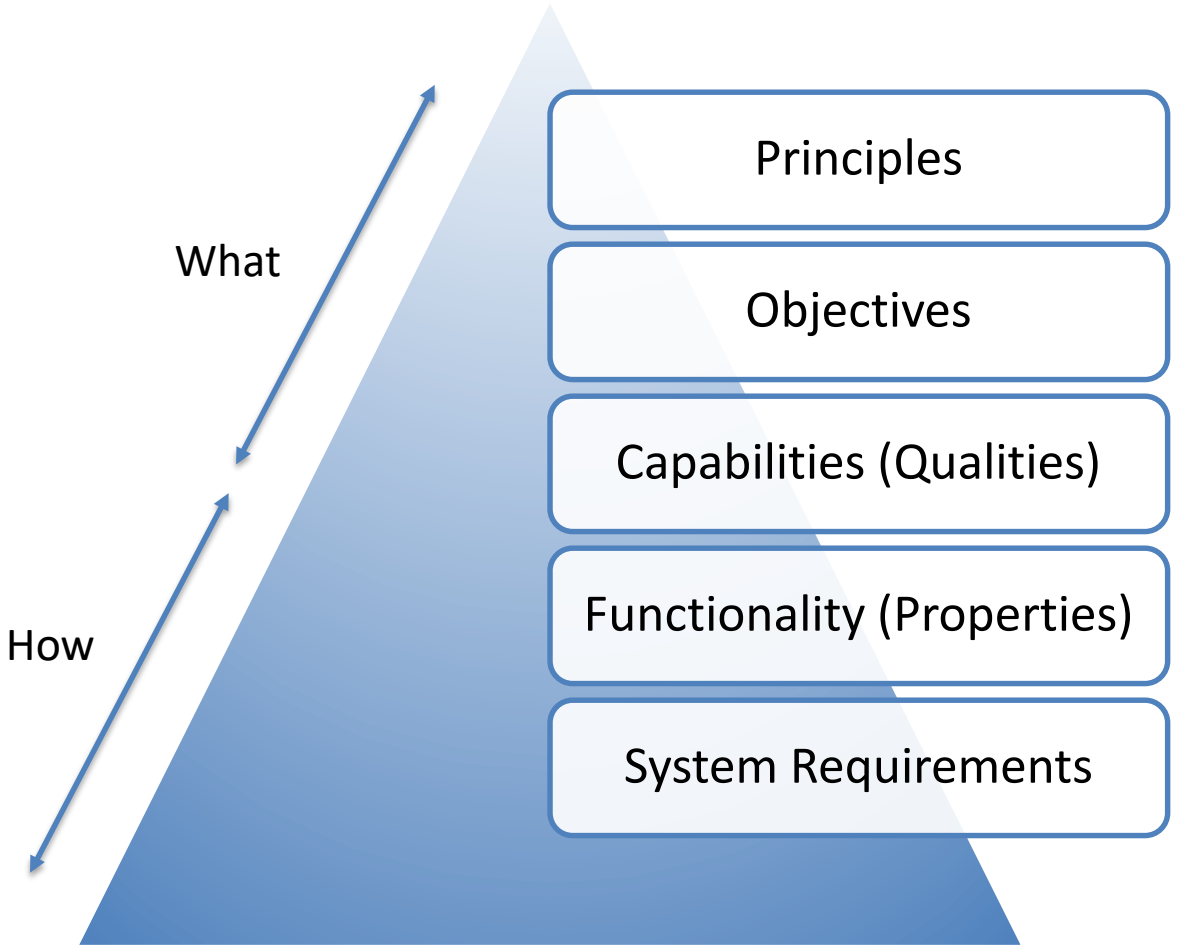


Plan Out the System Before Starting to Build



Grid Architecture Approach

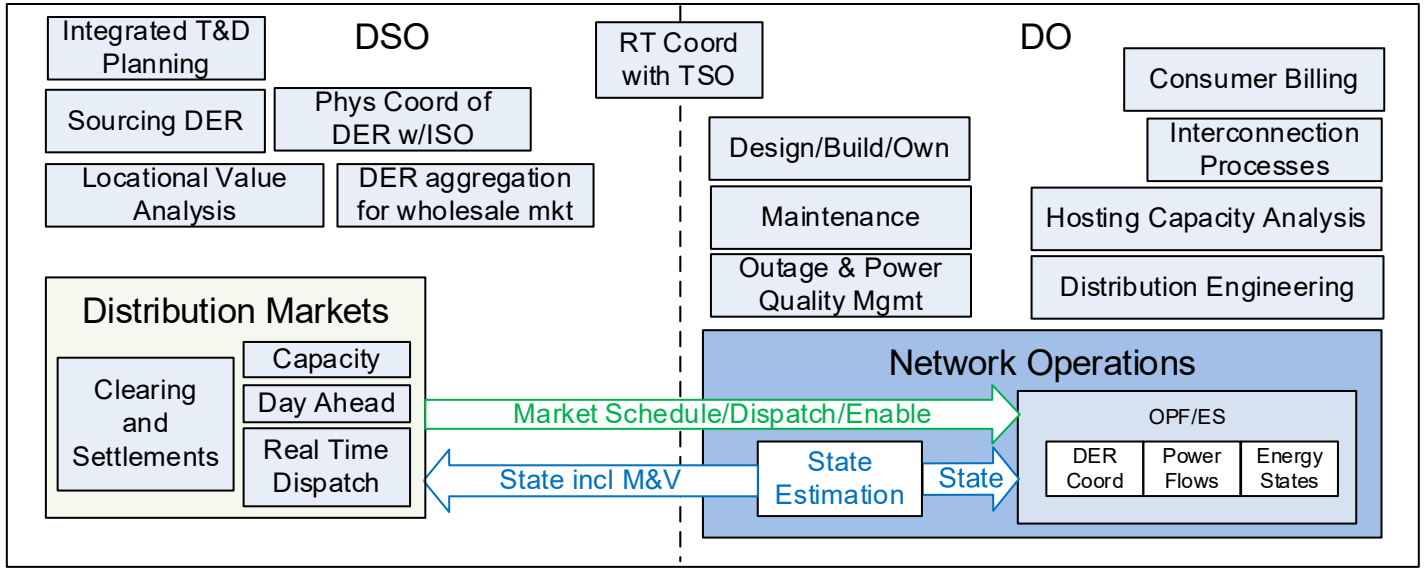
- Grid modernization planning starts with stating desired objectives and capabilities.
- Expressing the scale and scope of needs requires a holistic architectural approach – structure and function.
- Resist the temptation to start with technology choices!



Grid Architecture and Planning

- Planning is inherently about the future and change.
- Grid Architecture provides a variety of techniques for:
  - Establishing a common vision of the future grid
  - Representing the proposed changes
  - Appreciating interactions and consequences of potential changes
  - Determining impact of changes on overall system behavior

Consider introducing a Distribution System Operator (DSO) into a Distribution Operator (DO) construct



How Can Different Stakeholders Benefit?

- Help manage system complexity (and therefore risk)
- Enable reasoning about a system's structure and behavior
- Enable prediction of system qualities
- Facilitate communication among stakeholders (internal and external)
- Manifest earliest design decisions/constraints
- Enable prediction of system characteristics
- Identify gaps in theory, technology, organization, regulation…
- Identify/define interfaces and platforms

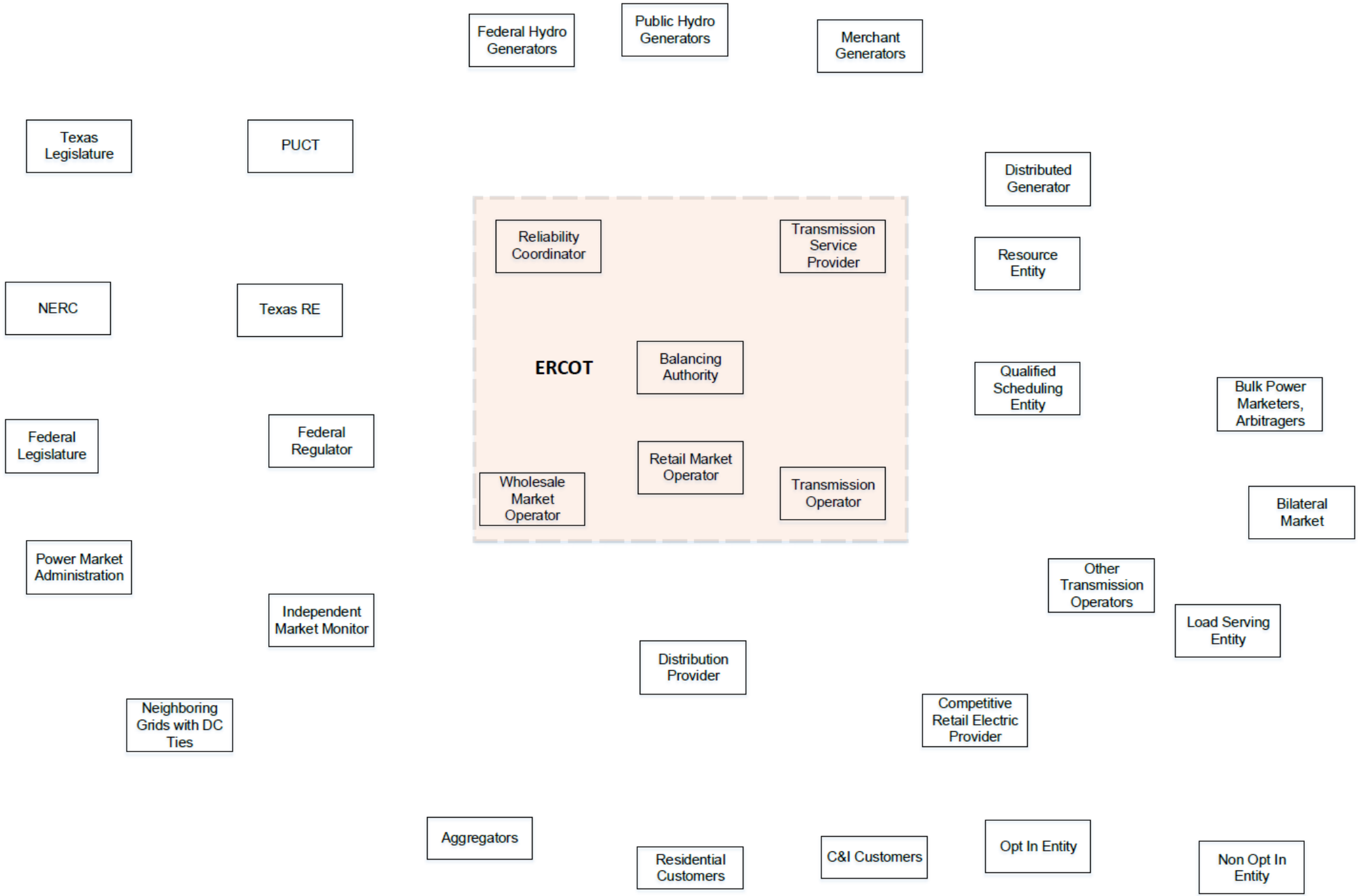
https://gridarchitecture.pnnl.gov/

Commonly Used Grid Architecture Structures

Industry Structure Diagram

- One diagram visualization of present regional grid which assists in:
  - Managing complexity
    - Identifying stakeholders
    - Determining the different entity classes involved
    - Determining the interactions between any pairs of entity classes
    - Understanding the many complex interactions between entity classes in different functional groups
  - Helps stakeholders understand the complete picture
  - Tools for grid modernization

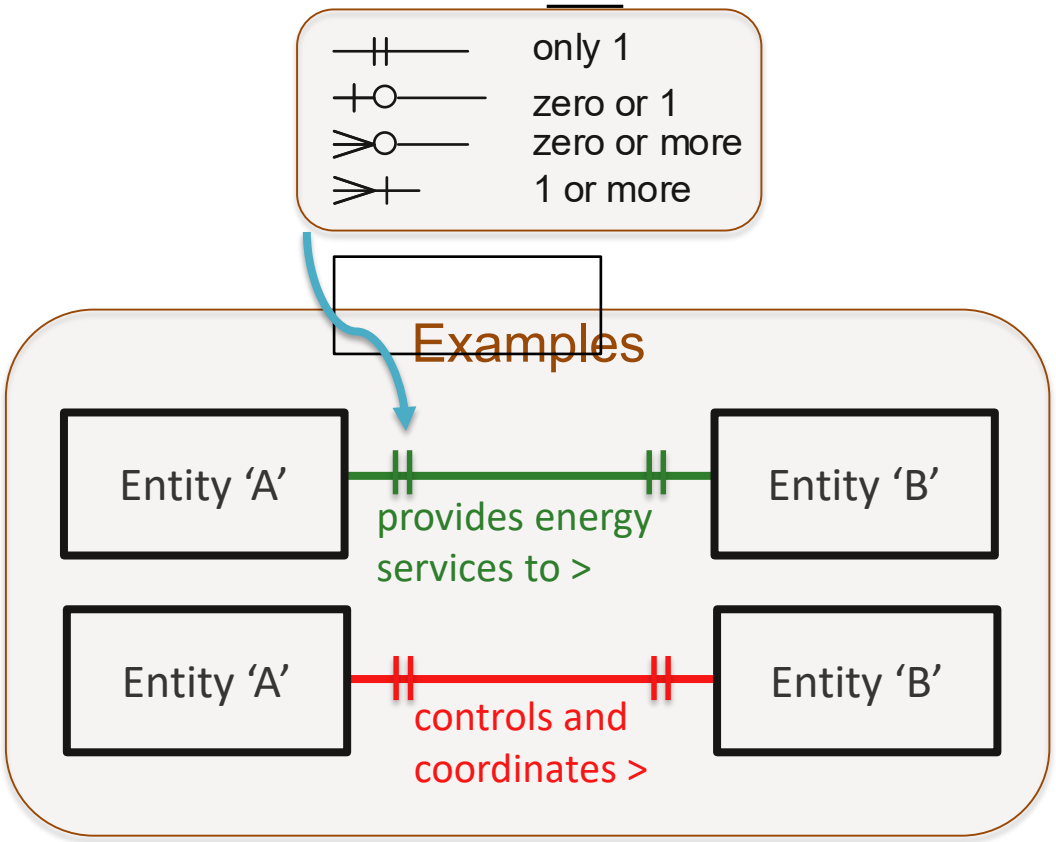
Key tool for understanding the present grid and planning for the future


Federal Hydro Generators
Public Hydro Generators
Merchant Generators
Texas Legislature
PUCT
Distributed Generator
Reliability Coordinator
Transmission Service Provider
Resource Entity
NERC
Texas RE
ERCOT
Balancing Authority
Qualified Scheduling Entity
Bulk Power Marketers, Arbitragers
Federal Legislature
Federal Regulator
Retail Market Operator
Wholesale Market Operator
Transmission Operator
Bilateral Market
Power Market Administration
Other Transmission Operators
Independent Market Monitor
Load Serving Entity
Distribution Provider
Neighboring Grids with DC Ties
Competitive Retail Electric Provider
Aggregators
Residential Customers
C&I Customers
Opt In Entity
Non Opt In Entity

Entity Relationship Diagrams

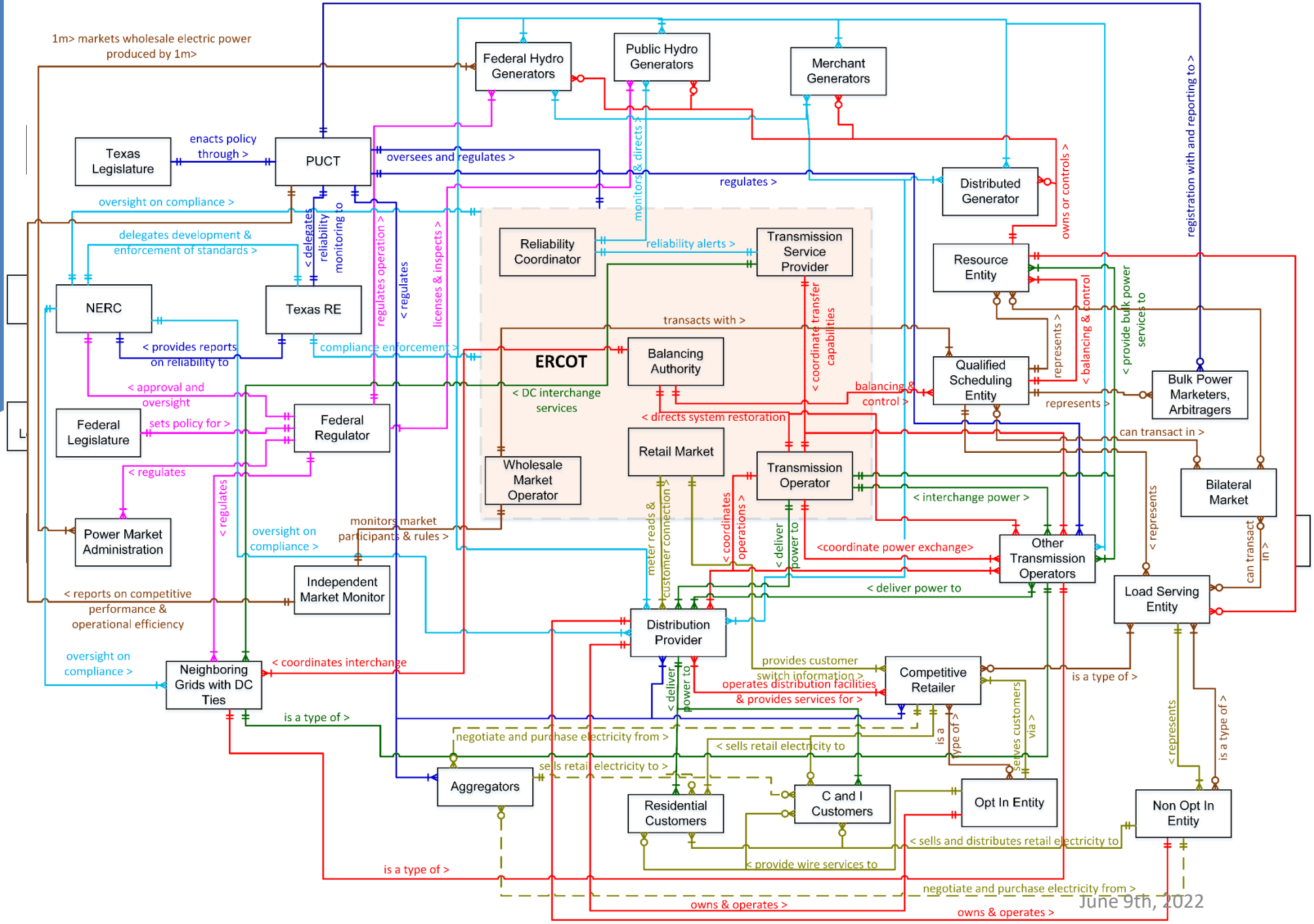
Entity classes are representative of entire group

Relationships represent group of behaviors between two entity classes

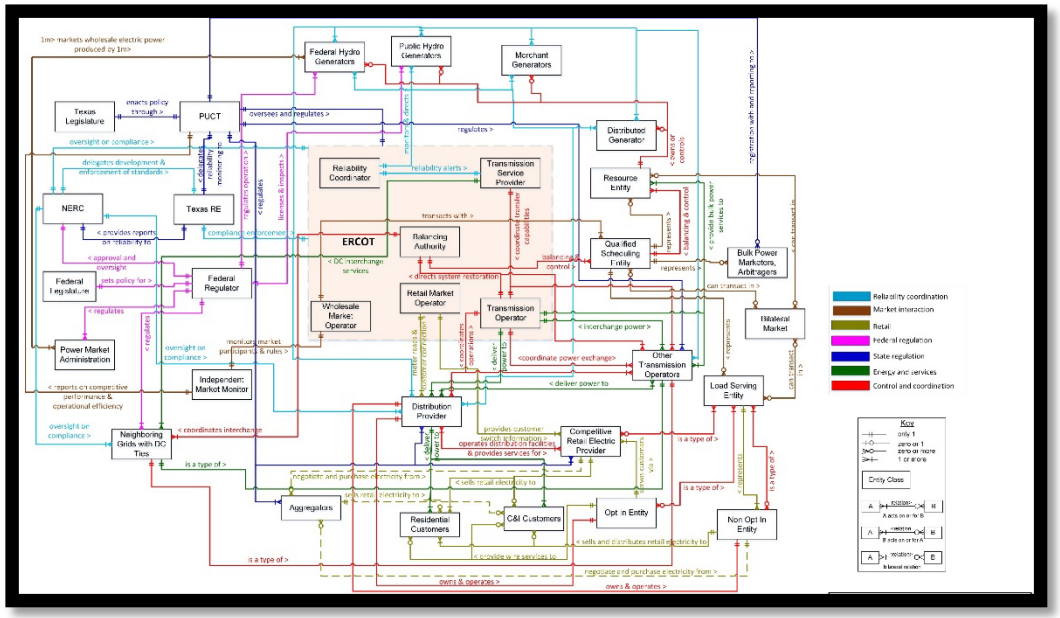


Colors	Layers
(turquoise)	Reliability coordination
(brown)	Market interaction
(olive)	Retail
(purple)	Federal regulation
(blue)	State regulation
(green)	Energy and services
(red)	Control and coordination

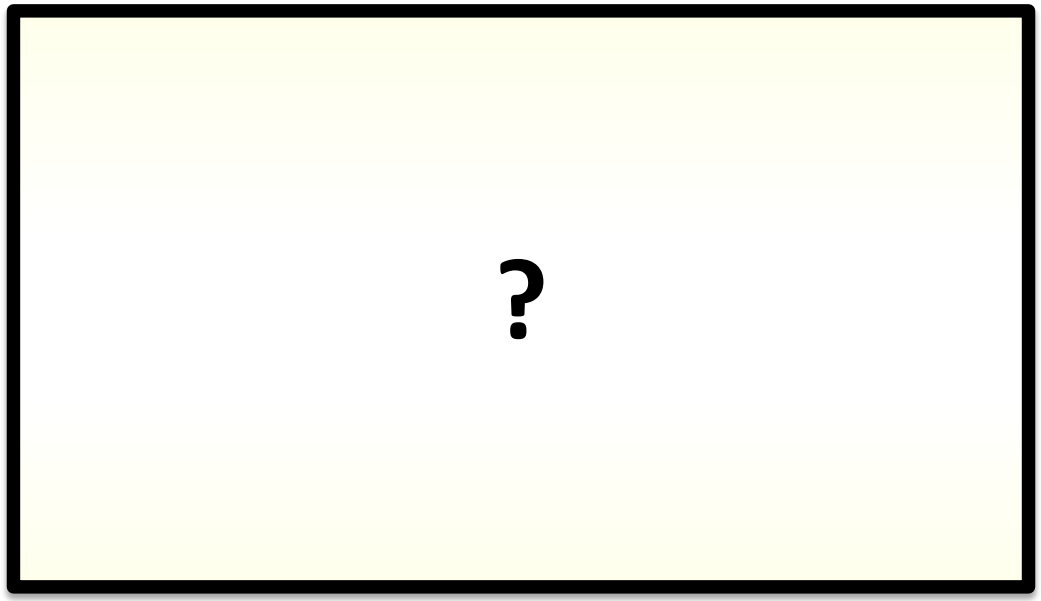
Example: ERCOT's Industry Structure Diagram



ERCOT's Industry Structure Diagram



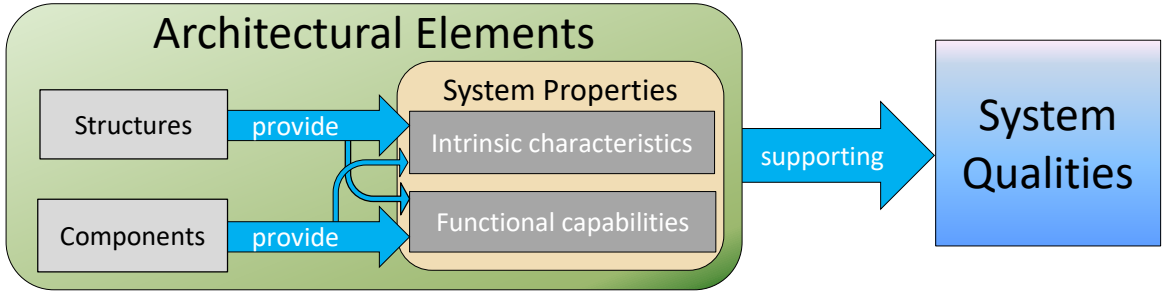
As-Built Model



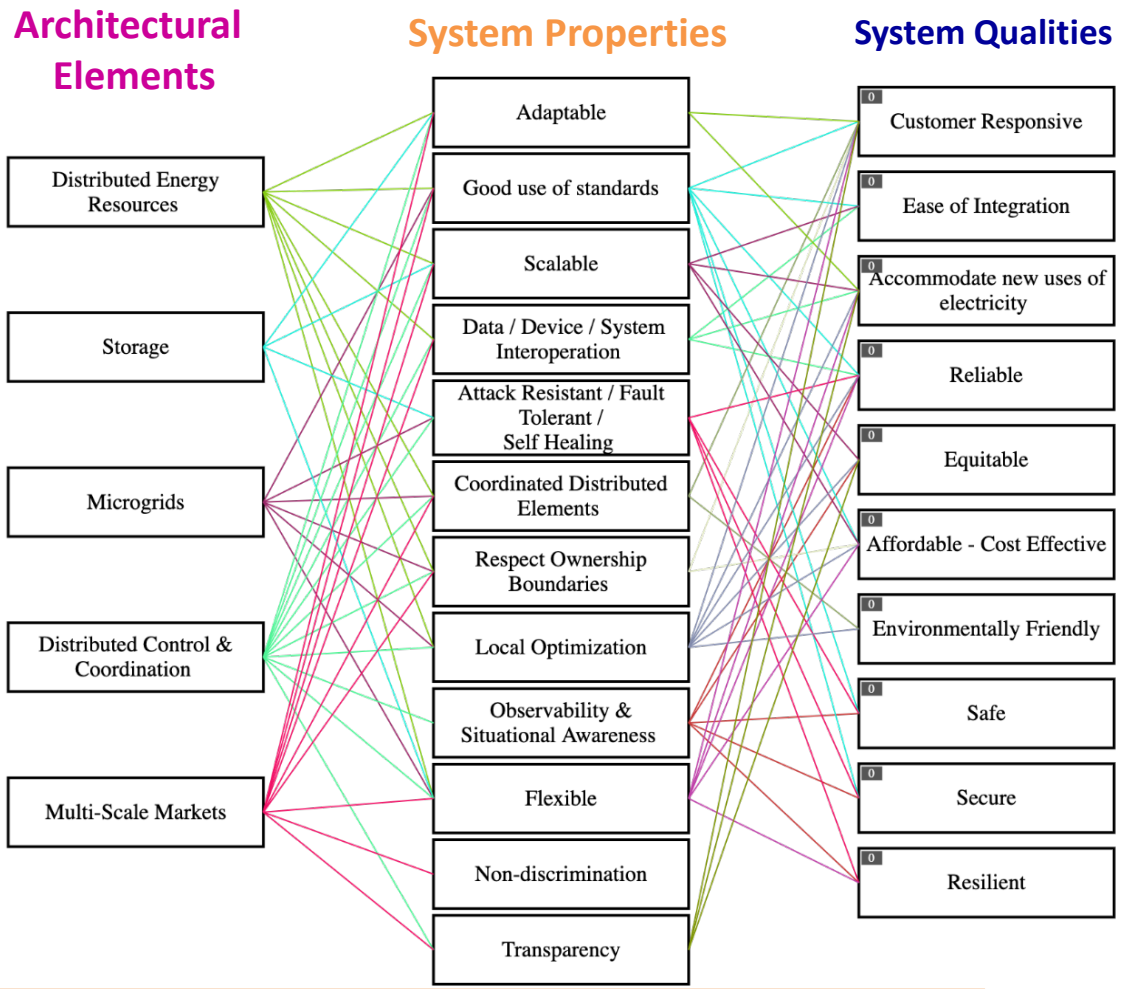
Future State Reference Architecture

Utilities and regulators need to understand current systems and relationships in order to understand the potential impacts of proposed changes.

Framework for Mapping from Components to Qualities



- ***System Qualities:*** *desired characteristics of the system (high-level requirements expressed from "users" view)*
- ***System Properties:*** *enable System Qualities to be manifested and comprised of intrinsic characteristics and functional capabilities*
  - System intrinsic characteristics mostly associated with structure
  - System functional capabilities mostly associated with components

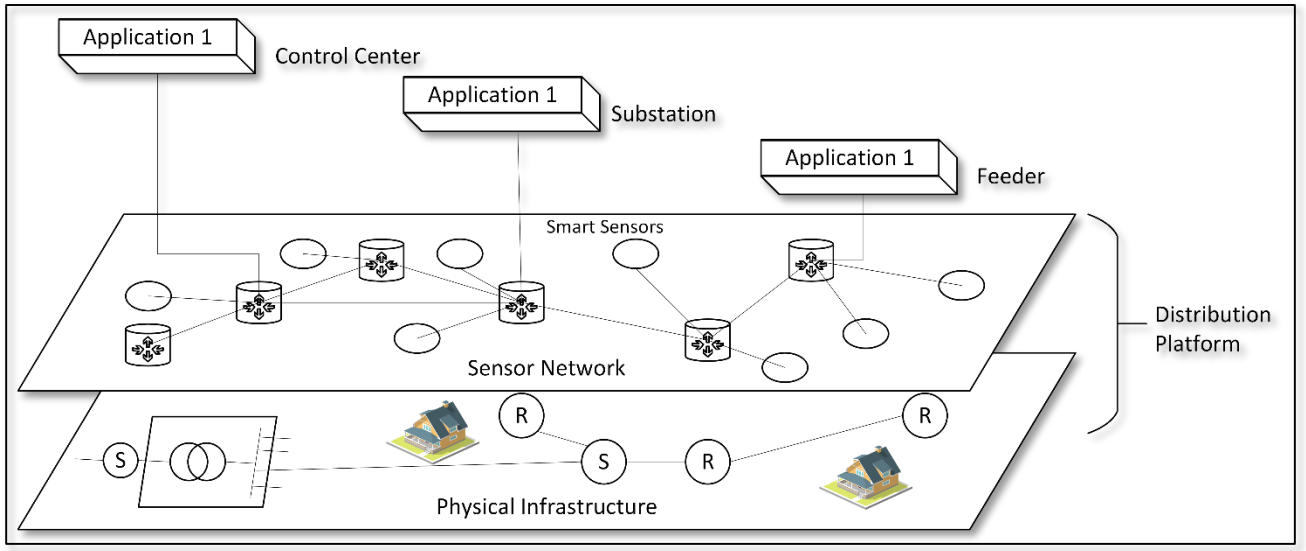


Determine key architectural elements for understanding what policy changes would be most effective.

Platform Concept

- Separates foundation functions from end uses (“applications”) via layering
- Provides a set of services and capabilities that are useful to many applications
- Platform is stable over time, while applications may change frequently
- Provides decoupling of changes between applications and underlying infrastructure
- May scale (adjust resources) to support variable demands from applications

A platform is a stable collection of components that provide fundamental or commonly-needed capabilities and services to a variable set of uses or applications through well-defined interoperable interfaces.



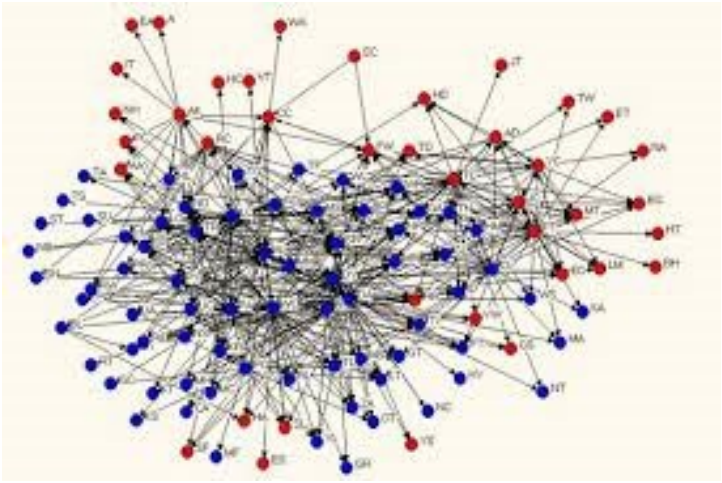
Examples of How Grid Architecture Concepts Have Been Applied

Application by PUCs and Utilities

- Hawaii: By Order No. 34281, filed in Docket No. 2016-0087, PUC encouraged stakeholders to provide their views on grid architecture and interoperability and how these concepts may be integrated into the Companies' grid modernization efforts.
- New York: Grid Architecture concepts helped Public Service Commission with review of utility's proposed changes to business models and metrics that support Reforming the Energy Vision and require improvements.
- Ohio: PowerForward initiative layers cyber-physical platform with a markets platform and associated applications.
- See discussion of Grid Architecture concepts in DOE's Modern Distribution Grid (DSPx) guides, including Volume I: Customer and State Policy Driven Functionality.

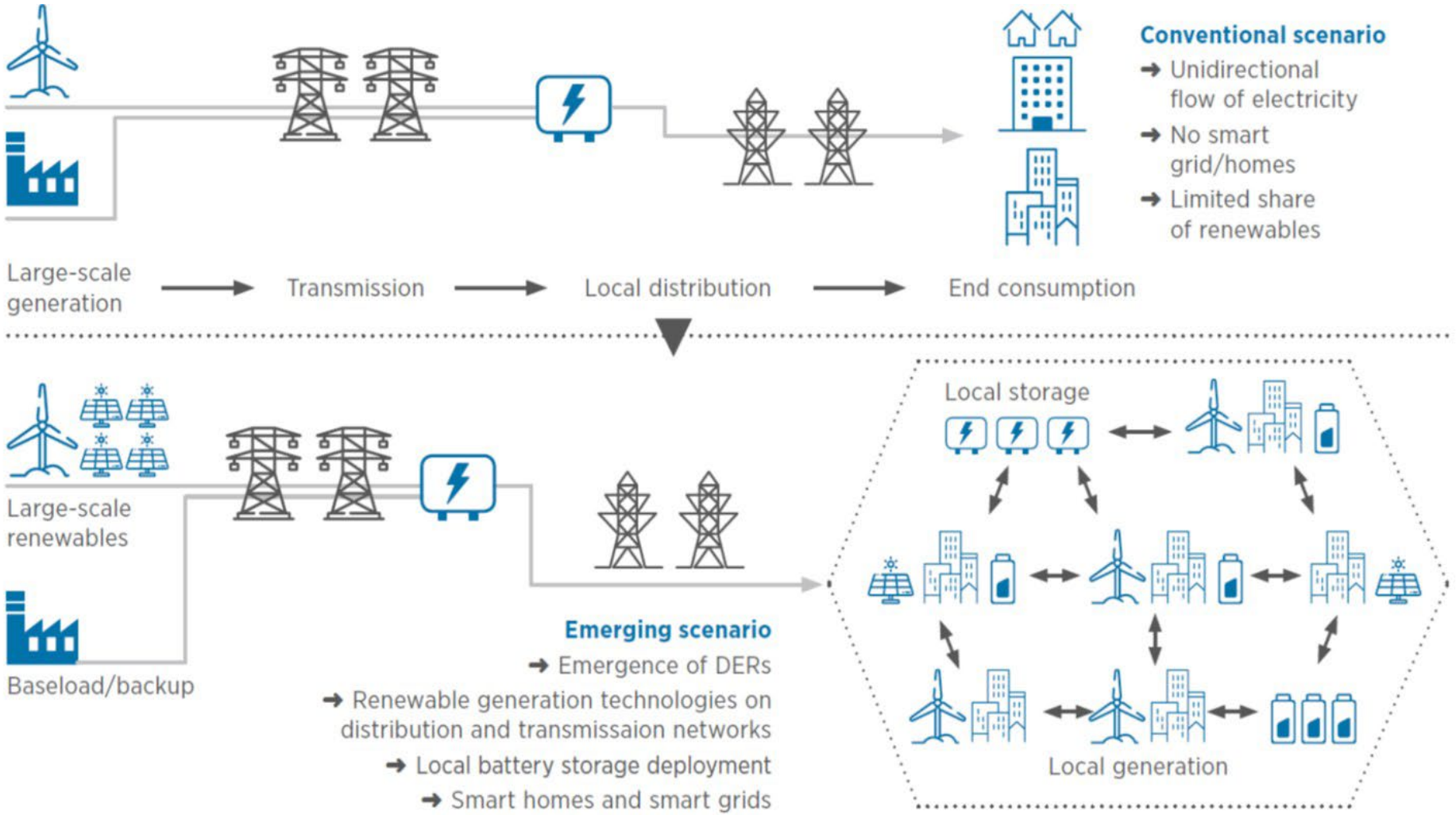
Example: Ohio PowerForward Roadmap

- Reconsider the distribution grid as a platform that creates opportunity for entities to provide innovate products and services to customers
- Network connects all the users of the platform
- View grid as a network that supports the platform concept
  - Grid value is expanded by enabling interconnection of DERs as a grid resource
  - Distribution system platform has an underlying architecture that supports it.
- U.S. Department of Energy's Modern Distribution Grid identifies core components needed for modern grid platform:
  - Physical infrastructure (wires, transformers, switches)
  - Advanced protection and controls
  - Sensing and situational awareness
  - Operational communications
  - Planning tools and models



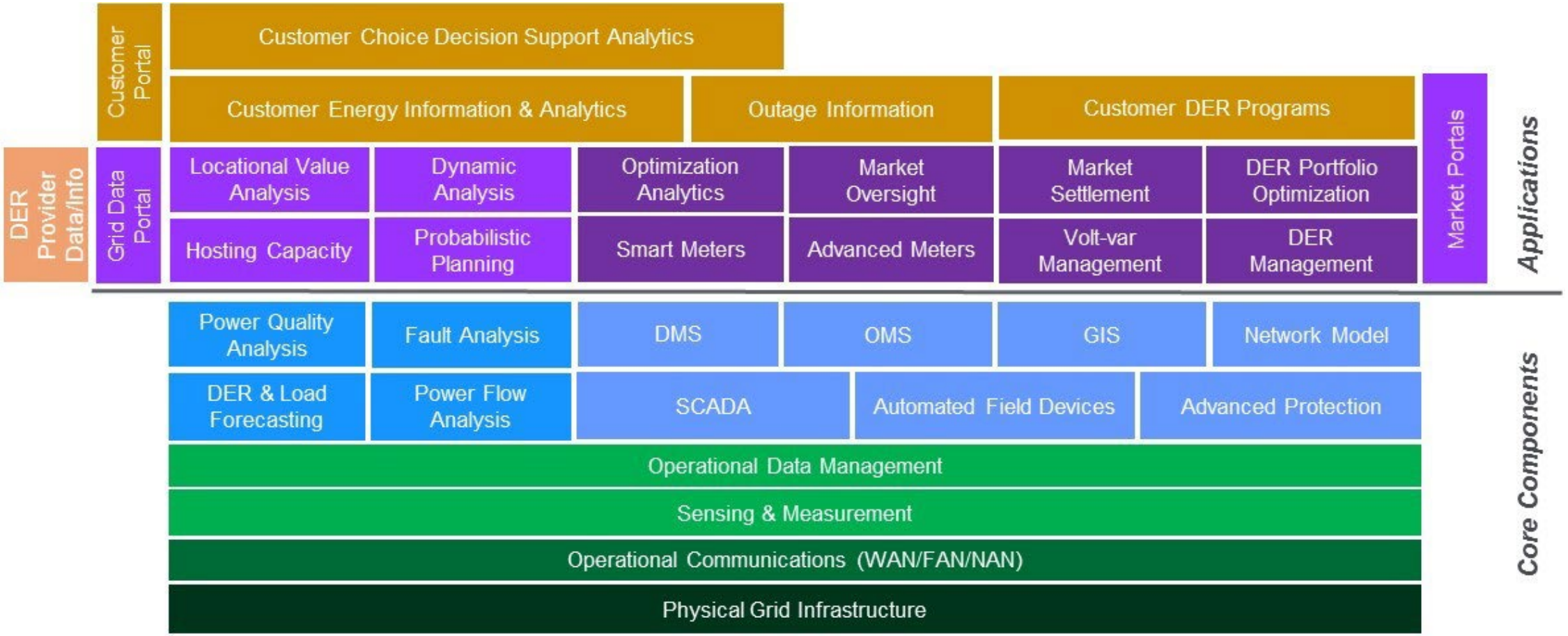
A Structural Change Example from Australia

From “Topic 7 – Power Systems Architecture” prepared by Strategen for CSIRO & AEMO: https://www.strategen.com/s/Strategen-GPST-Topic-7-Power-System-Architecture-Public.pdf



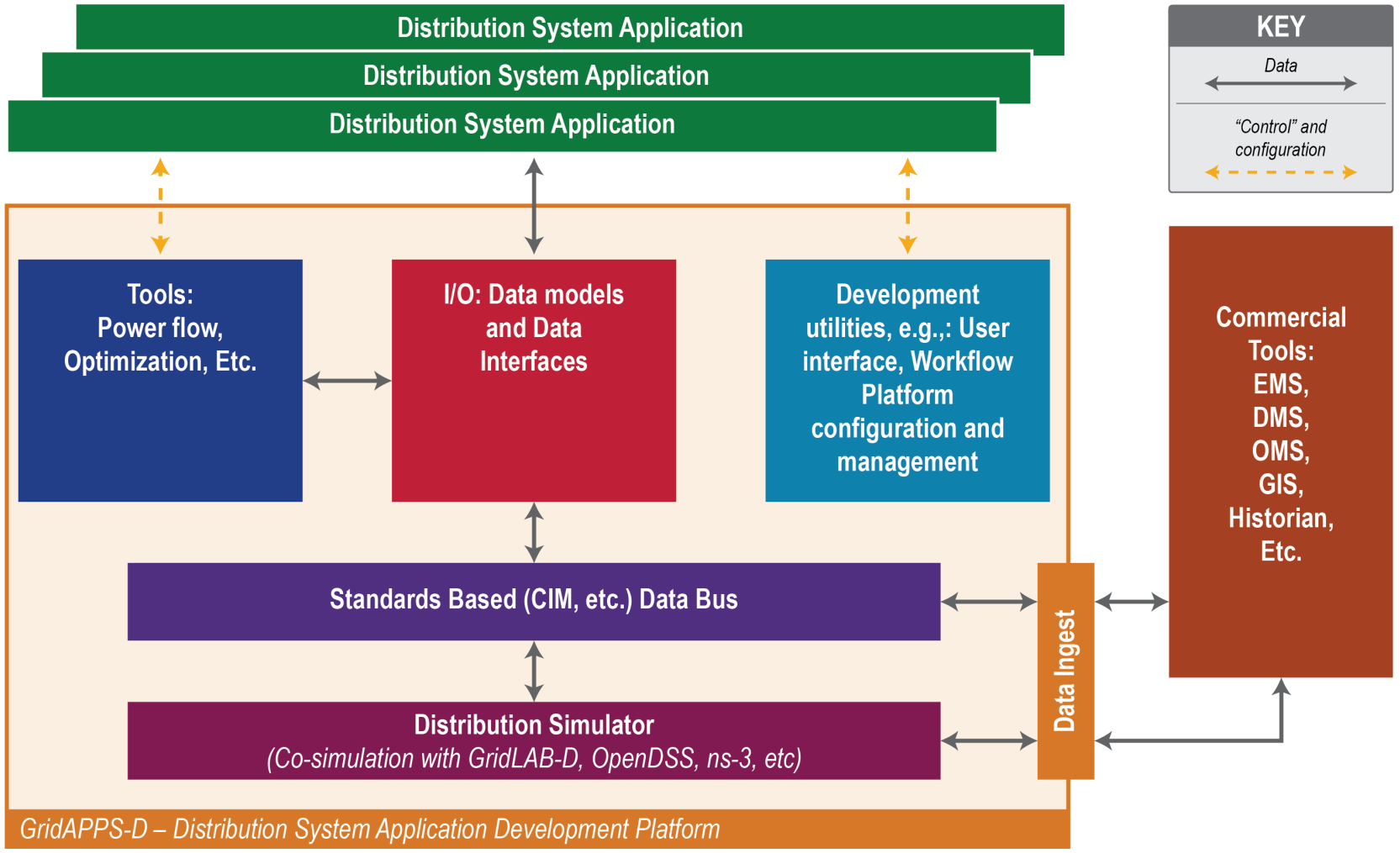
Distribution System Platform – from DSPx

Existing systems organized into a platform view



Source: U.S. Department of Energy, 2017. Modern Distribution Grid, Volume III: Decision Guide.

Software Platform Example: Conceptual View



- Adoption of the platform concept can make integration of different applications easier and more affordable.
- Applications often have common capability needs at the base, but currently vendors may have proprietary platforms and ad-hoc implementations which make integration difficult.

Source: GridAPPS-D

Simple Steps for PUCs to Get Started with Grid Architecture

- PNNL's Grid Architecture website is a rich collection of resources.
  - It is crucial to understand current systems and relationships in order to assess the potential impacts of proposed changes. Review the different structure diagrams (like industry and market structure diagrams) to help build that foundational understanding.
  - Reference architecture packages serve as the starting point for utilities. Each package emphasizes specific architectural concepts. Utilities may adopt or adapt them based on their unique needs.

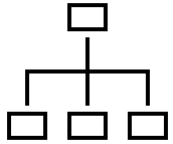
- Encourage utilities to apply Grid Architecture concepts to futureproof investments.
  - Support a set of stakeholder workshops to move from requirements, to qualities to properties to architectural elements for considering large enterprise investments.
  - Determine key architectural elements for understanding what policy changes would be more effective
  - Use the platform concept: Plan core components and applications when planning and proposing an enterprise system to ensure easy integration and support of multiple applications.
  - Develop basic grid architecture diagrams to make visible relationships between utilities, customers, RTO/ISO (if applicable), third-party providers, etc.

Questions Public Utility Commissions Can Ask

- When proposing specific technology investments, has the utility gone through the process of identifying how proposed investments help achieve broader desired objectives, capabilities, and functionalities?
- Has the utility mapped key relationships and processes, and identified how proposed changes will impact other industry actors and systems?
- What time horizon are you planning for and how are you dealing with expected growth of DER to prepare your system for meeting decarbonization goals?
- If distributed architecture is a goal, has consideration been given to preparing for structural change from a centralized system?
- Should distribution operators' roles and responsibilities be changed and, if so, how does this impact grid control, markets, and oversight?
- What steps are being taken to make integration of new applications into the system more cost-effective and less time-intensive?

Takeaways

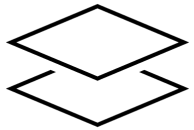
- Grid Architecture is all about structure — get the structure right and all the pieces fit into place neatly, all the downstream decisions are simplified, and investments are future-proofed.



- Knowing current system is critical for planning the system of the future. Industry and market structure diagrams help with understanding the existing complex system and sharing a common vision of the future system.

- Determining the desired qualities of the system helps to identify the enabling intrinsic system properties. Properties assist in identification of the essential architectural elements that should be prioritized for grid modernization investments.

- It is important to decouple the changes between applications and underlying infrastructure to make integration of new applications easy and more cost-effective. Platform concept holds the key to achieving that.



References

- https://gridarchitecture.pnnl.gov/
- R. Melton and S. Pal, “Problem Domain Reference Model”, PNNL-28399, Richland, WA, Jan. 2019.
- J. Taft, “A Mathematical Representation of System Architectures: Application to Grid Architecture”, PNNL-27387, March 2018.
- C. Huang, F. Li, D. Zhou, J. Guo, Z. Pan, Y. Liu and Y. Liu, “Data Quality Issues for Synchrophasor Applications Part I; A Review”, Journal of Modern Power Systems and Clean Energy, July, 2016, pg. 342-352, https://doi.org/10.1007/s40565-016-0217-4
- N. Wang, “Transactive control for connected homes and neighbourhoods”, Nature Energy, pg. 907-909, 2018, Available at: https://www.nature.com/articles/s41560-018-0257-2
- https://www.powerworld.com/WebHelp/Content/MainDocumentation_HTML/Available_Generation_Control_Modeling.htm
- https://meme.xyz/meme/28230/why-is-the-electric-bill-so-high.html

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Questions?

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