Identifying Architectural Modularity in the Smart Grid
An Application of the Design Structure Matrix Methodology
Architecture Track – Innovative Architectural Models Session

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Simple Answer:

An **umbrella term** for the enhancement of the traditional electricity infrastructure that uses computer technology and **two-way digital communications** networking to improve and expand the capabilities of the grid.
Smart grid promises to transform the electric industry yielding many benefits, such as:

- A more stable and **reliable** electric supply
- Increased utilization of the immense investment in our electric infrastructure
- Increased capability to integrate **renewable** resources
- More **customer choice** and improved cost structures
This isn’t incremental change.

- But smart grid is currently a vision that can only be realized if the diverse elements of the grid can work together as a system.

- **Interoperability** is the lynchpin of smart grid success.

  Interoperability refers to the ability of diverse systems and organizations to work together (inter-operate). In the context of the electric system, interoperability refers to the seamless, end-to-end connectivity of hardware and software from end-use devices through the T&D system to the power source, enhancing the coordination of energy flows with real-time information and analysis.
Today interoperability is dismal.

US ‘smart’ grid more Flintstones than Jetsons
- Smart Grid Today Headline (8/8/2011)
Realizing the vision requires interoperability.

Rich & Vibrant Market Ecosystem
- Delivers full potential of smart grid benefits
- Fosters open markets and innovation
- Evolution of industry business models

Paths to Interoperability
- Low Interoperability
- Limited Interoperability
- High Interoperability

Adoption of Appropriate Standards, Best Practices, and Policies

Current State of Electricity Delivery System

Future State of Electricity Delivery System

Incremental Improvement
- Delivers some of the promised smart grid benefits
- Incumbents maintain market share and power
- Incremental advancement of the industry
The grid has an ‘Accidental Architecture’

An *accidental architecture*¹ is the organization of a system resulting from numerous **point-to-point** integrations between various applications to achieve **near-term** objectives.

Point-to-point integrations are **not scalable** and often create unintended **ripple effects** on downstream applications.

The result is a unique and customized system that becomes increasingly **difficult** to maintain and update.


*(klōoj)* **n. Slang**
A clumsy or inelegant solution
What’s Architecture?

If the grid is a patchwork quilt, which quilt do we want?

It’s subjective …right?

Fiberfantasies.wordpress.com

TheStitchersCupboard.com
Why do we need architecture?

Well architected systems integrate easily, evolve flexibly, and operate simply and reliably.¹

¹ Massachusetts Institute of Technology © Ed Crawley 2007
How to approach architecture?

More Specificity

More Degrees of Freedom
How do we get interoperability?

Generally accepted as the sweet spot to addressing interoperability.
In the **Energy Independence and Security Act** of 2007 (EISA), the U.S. Congress established the development of a “smart” electric power grid as a national policy goal.

Essential components of the Smart Grid, as conceived in the EISA legislation, include:

- standards
- an information architecture
- a cyber-security strategy
- a framework for testing and certification

Initiated by the National Institute of Standards and Technology (**NIST**), the **Smart Grid Interoperability Panel** (SGIP) plays a leadership role in facilitating and developing these components and in realizing the national policy for the transformation of the power system to the Smart Grid.
SGIP created the Conceptual Model
...and added some detail.
A Brief Moment of Zen.

This next transparency is an incomprehensible jumble of complexity and undefined acronyms.

You might wonder why I’m going to show it to you since the only possible result is to lower your opinion of my communication skills.

Frankly, it’s because I like making complex pictures more than I like you.
...and it became a standard organizing principle.

Modularity is a general systems concept, typically defined as a continuum describing the degree to which a system’s components may be separated and recombined. It refers to both the tightness of coupling between components, and the degree to which the “rules” of the system architecture enable the mixing and matching of components.

- Wikipedia article on modularity
12/5/2011

Modularity in systems architecture is the degree to which elements of a system can be grouped with minimal dependency across groups.
What is Design Structure Matrix?

The **design structure matrix** (DSM) is a modeling tool that represents the relationships and dependencies between components of a system, product, or process. The DSM captures **coupling and dependency** relationships between the components of a system in a graphical matrix.

How can DSM help identify modularity?

**Clustering** is a process applied to a DSM by which elements of a system are arranged and grouped in order to **minimize interdependency** across groups.
“Technical skill is mastery of complexity, while creativity is mastery of simplicity.”

- Sir Erik Christopher Zeeman, Mathematician
Let’s take the NISTIR Logical Reference Model

Translate dependencies into a DSM matrix

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Clustering can be more an art than a science.

A clustering algorithm can give a good starting point, but “manual” organization is typically needed.
A pattern emerges in complex systems.

Clustering complex systems frequently results in a **Hub & Spoke** configuration.

- Identifying the appropriate hub elements allows for the creation of modular spokes.
- Without indentifying and grouping the most central, cross-cutting elements...high levels of dependency would exist across the spokes, and little modularization can be achieved.
Varying levels of dependency may be allowed. It’s up to the architect to determine the most appropriate configuration.
DSM can be applied for specific implementations.

This is the planned architecture for a federally funded smart grid demonstration project.

NRECA's Demonstration Architecture: Physical and Logical Architecture for Enterprise Application Integration¹

DSM can be applied for specific implementations.

High densities of dependencies and of whitespace generally indicate a more modular organization.

DSM Representation of NRECA’s Demonstration Architecture
Different organizations may emerge. But you never know what might emerge…such as **two independent hubs** in this case.
Different organizations may emerge. Or a daisy chain of dependency in an alternate configuration.
Conclusions

- Modularization can help combat accidental architectures by isolating groups of dependency allowing them to be treated as an independent sub-system. Modular systems can evolve more elegantly because modular organization is more easily respected.

- Hubs identify the most cross-cutting elements of a system. Prioritizing these elements and acknowledging their centricity will reduce the complexity of the system.

- DSM is a useful approach to visualizing and structuring complex systems, such as those in a smart grid.
Shout-Out to the GWAC Stack

Interoperability Categories:
- Organizational (Pragmatics)
  - 8: Economic/Regulatory Policy
  - 7: Business Objectives
  - 6: Business Procedures
- Informational (Semantics)
  - 5: Business Context
  - 4: Semantic Understanding
- Technical (Syntax)
  - 3: Syntactic Interoperability
  - 2: Network Interoperability
  - 1: Basic Connectivity

Cross-cutting Issues:
- Configuration & Evolution
  - Shared Meaning of Content
    - Resource Identification
    - Discovery & Configuration
    - System Evolution & Scalability
- Operation & Performance
  - Time-Synch & Sequencing
  - Transaction & State Management
  - Quality of Service
- Security & Safety
  - Security & Privacy
  - Logging & Auditing
  - System Preservation
If you work with complex systems, products, processes, or other giant hairballs…
…this is a **MUST READ!**

Design Structure Matrix Methods and Applications

Steven D. Eppinger and Tyson R. Browning

An introduction to a powerful and flexible network modeling tool for developing and understanding complex systems, with many examples from a range of industries.

- 334 pages
- >175 color illustrations
- 44 detailed examples from industry
- 80 contributors
- 12 reviewers

Finally… a comprehensive introduction to DSM methods… all in one place.

Now available from **MIT Press** and other sellers (e.g., **Amazon**).
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For more DSM resources, see:
DSMweb.org

For DSM training, see:
executive.mit.edu
Managing Complex Product Development Projects