Laying the Foundation for Next-Gen Grid Architecture

Utility planning has always been challenging but, driven by growing complexity within electric power systems, it's getting even harder. Complexity is increasing because the use of distributed energy resources is shifting the source of power to include a future with substantial contributions from within distribution systems. Add to that the variability introduced by growth in renewable energy resources, the introduction of "smart" equipment that enables distributed control and we now have a much more complex system. Even though it has adapted to numerous changes in technology, legislation and regulation over the years, it is now facing new challenges that should be analyzed and understood before large investments are made.

Here's the rub: Utility planners are faced with the task of modernizing their grid in the most timely and cost-efficient manner while ensuring that upgrades to the grid can survive a dynamic, uncertain and hard-to-forecast future. This is a very tough job!

Grid architecture is a top-down approach to understanding and documenting the complex structures and interdependencies of electric power systems. A grid architect uses techniques from system engineering, control engineering, and theory of networks to understand the components, structures and relationships within electric power systems. In applying grid architecture tools, the architect manages the complexity of the electric power system enabling stakeholders to identify well-thought-out solutions to pressing problems. Traditional engineering design is driven by use cases that satisfy business requirements. Use cases describe a set of actors and how those actors interact through specific scenarios that model the desired solution. These use cases are used to explore the problem and ferret out system requirements which feed into the RFP/RFQ (Request for Proposal/Request for Quote) process. This has served utilities well as the basic structural shapes of the grid have remained relatively constant.

The electric power grid is a complex, ultra-large-scale system. (See references below) The approach of employing incremental use cases breaks down in dealing with large, dynamic systems with high complexity that must thrive and adapt over extended periods of time. This is because the number of potential use cases that the future system must accommodate grows very large and many are not known in advance due to dynamic changes in conditions, functions, and even base grid structure. As a rule, the structure of a system determines the performance boundaries of the system and so understanding these structures and the consequent constraints can help avoid the time and costs associated with large unexpected fork-lift revamps. From a grid manager or regulator perspective, it’s important to avoid falling into a pattern of incremental-only growth of modern technologies (solar, storage, EV) with the right intentions, but not knowing when a tipping point will be reached in the system when structural changes will need to be made to enable future growth and maintain reliability.

The architecture of a complex, large-scale-system must first be considered logically and conceptually to provide a solid foundation for subsequent engineering design. As one moves from system architecture into design of components and sub-systems, use cases can be developed and then used to test the architecture and to drive the physical design processes. This top-down analytical approach for visualizing and thinking about the impact of change on the grid is core to grid architecture. Applying grid architecture enables the understanding needed to effectively modify the basic shapes of the grid (the structures) in accordance with the changing broad issues of grid modernization.

What are the Benefits of Developing Grid Architectures?

By providing high-level views, grid architecture is a tool to help understand the grid's structure and reason about the grid's properties, behaviours and performance. The importance of structure is fundamental: 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, risk of stranded investments is high, and benefits realization may be limited.

Why is Grid Architecture Needed?

Historically the grid changes slowly and was built from components with service lives of 50 years or more. It was based on one-way power flows from the bulk power system to loads. Now we see a system in flux with the introduction of information and communications technology with much shorter life cycles, renewable resources introducing variability in supply, and distributed energy resources introducing two-way power flows in some parts of the grid. How do we successfully manage this change?

Grid architecture provides us the tools to better understand the impacts of these changes. Every system has an inherent architecture. It's the way the system is structured and how the parts and pieces fit together and interact with each other within that structure. Some systems are small, some are large. Some have few parts and others many. Some have simple structures and others have complex structures. Why is "structure" a key focus of system architecture? Because the structure of a system determines, to a large part, the properties of that system. These properties translate into what the system is capable of doing, easily and cost effectively, and what inherent constraints the system has that represent speedbumps to change. Without a focus on system architecture, sustainability becomes harder and harder as the system grows and evolves until it is no longer cost effective and reaches end of life.

Structures, Structures and More Structures

The grid is far more than central stations and wires. It's a network of seven interacting, interdependent structures. Each of these structures is complex unto itself but they interact in subtle, and not so subtle, ways. Investigating and understanding these interactions takes effort but the payoff is well worth the effort.

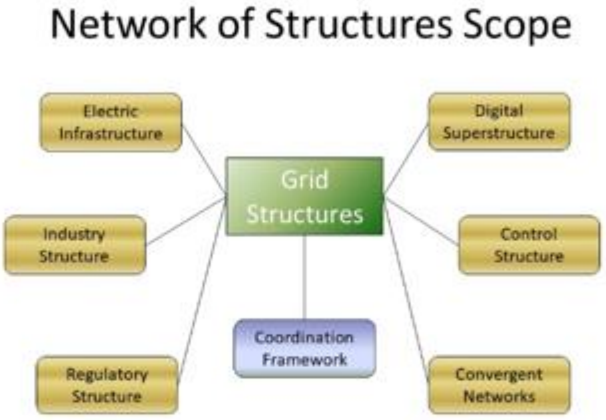

Diagram 1 - Network of Structures (Jeffrey Taft)

Electric Infrastructure

The electric infrastructure is an obvious one. Wires from generators to customers running through transformers, switches and protection circuits of all shapes and sizes. What is the impact of electrical circuit topology on change and resilience? What's the load composition and generation structure?
A few quick examples; 1) radial feeders of progressively reduced capacity can impede distributed generation import to the grid, 2) mesh feeders provide high resilience but are often protected against reverse power flows which constrain feed in, and 3) feeder transformer location and characteristics along with protection circuits and power quality compensators can either enable or disable efficient power flows between DER sources and sinks.

Industry Structure

The power industry has evolved over time into a diverse landscape of 3000+ utilities and organizations that interact with each other through operations, planning and markets. The structure of the markets is described by the market entities and their relationships which differ from region to region. Some regions have wholesale markets, others don't. Some are investor-owned, others are not. Each organization has characteristics that impact its desire and ability to change that range from the availability of capital and resources to internal business models and incentives.

Control Structure

The grid control structure consists of all the protection circuits, control systems and synchronization systems that is critical to safe and efficient operations. From transmission synchrophasors to substation automation and beyond, these control systems react to changing conditions and events on the grid. Performance is critical.

Digital Infrastructure

The digital infrastructure includes the information and communication systems (ICT) that provide visibility into the electrical system and the ability to monitor and control devices and systems throughout the grid. These systems are critical for all business processes including planning, operations and maintenance but are increasing in importance as more and smarter devices become integrated into the grid.

Regulatory Structure

The power industry is a mostly regulated industry. The regulatory framework includes the federal, state and other jurisdictions that provide oversite through policy and regulations. Regulatory structure describes the entities and their relationships. For example, there is a regulatory relationship between the Federal Energy Regulatory Commission and the Independent System

Operators. Similarly, there are regulatory relationships between state utility commissions and investor owned utilities.

Convergent Networks

Several non-electricity networks are interrelated to the grid even though at first glance they appear separate. Hydrocarbon fuels and natural gas pipelines are critical for power generation. Critical transportation systems and other utilities such as water are highly dependent upon the electrical system. The systems management and operations of these networks share a lot in common and as cities and regions modernize to achieve a more efficient infrastructure, they are starting to converge as redundancies are identified and systems management and operations technology continues to improve.

Coordination Framework

Implicit in the operation of the grid is a framework for control and coordination of all the different structures and assets that make up the system, including increasingly many that are not owned by the electric utilities. This framework needs to be explicitly identified so that the impact of any proposed changes can be analysed and understood, and in some cases modified to eliminate structural barriers or enable new functions and capabilities in a modernized grid.

An Example: Moving Beyond Siloes

Many utilities have evolved their information technology systems through an incremental process that involves specifying, purchasing and deploying self-contained systems that manage specific aspects of the business. These typically are supplied by third-party providers and represent a set of related functionalities. Examples include outage management systems (OMS), distribution management systems (DMS), customer information systems (CIS), advanced meter infrastructure (AMI), meter data management systems (MDM), demand response management system (DRMS), distributed energy resource management system (DERMS) and the list goes on. Each of these typically includes networking and communications with field and back office systems using their own set of protocols forming vertical siloes. As the business requires new informational views across these systems, IT (information technology) devotes time and effort to extracting, transforming and aggregating the data to meet the requirements.

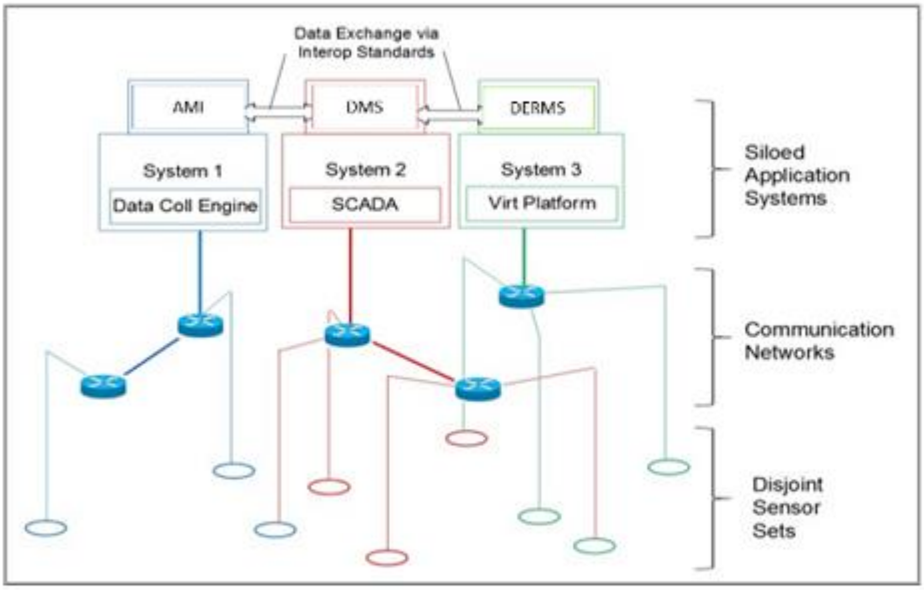

Diagram 2 – Vertically Integrated Siloed Systems (Jeffrey Taft)

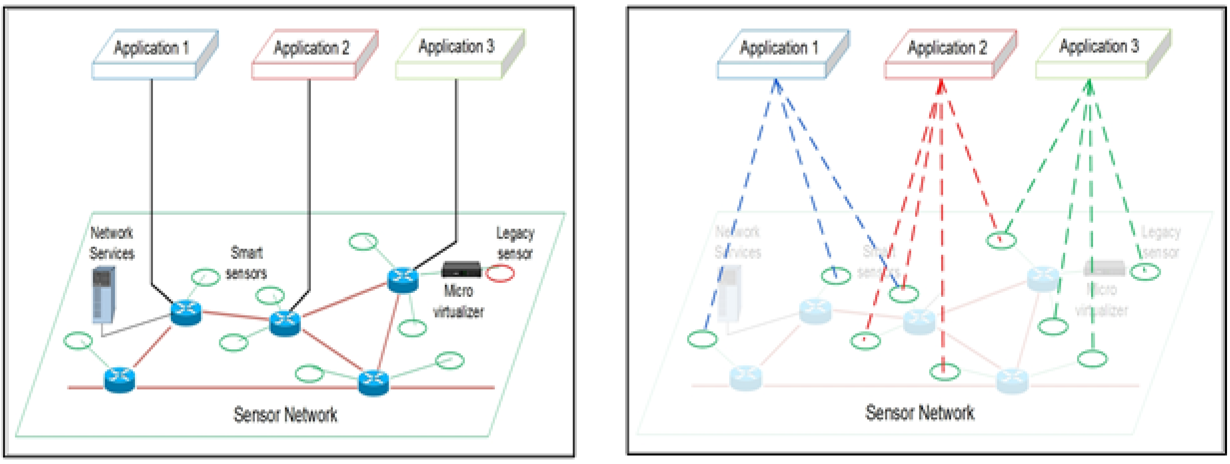

Diagram 3 – Layered Application-Independent Communications (Jeffrey Taft)

What are some of the properties and characteristics of this vertical structure? Applications are dependent on their closed networks so if an application needs data from another application it must take the high-latency path through IT. This places limits on data access performance and increases the risk of failure due to the increased number of dependent devices and systems.

The limitations of siloed systems are resulting in a growing migration toward application-independent, layered networks. Early adopters are considering the network as a shared resource that is managed separately from the applications, enabling applications to directly access the data they need without the middleman. Device data can be easily and securely used by applications without extensive and brittle back-end integration. By decoupling the applications from the network, data access throughput is increased, latency is decreased, flexibility and resiliency are improved, and new open applications that can leverage the network are more cost-effective. In the initial phases of this migration, grid architecture provides key insights into how to get maximum benefit from the new layered approaches.

In addition, the costs associated with wide-area communications networking in a utility are very non-trivial. Converting from a vertical to a layered structure requires an in-depth analysis to determine if, when and how a migration makes sense, but as network technology continues to improve and standards continue to evolve, it could be a very wise investment for the future. But…

Change and the Future

No one can predict the future. That shouldn't stop us from thinking about the future and paving the way forward. We can ask some very important questions. What technical and societal drivers and trends are at work? What current constraints do we now have that should be addressed? What are our short-term and long-term business objectives? What is our long-term vision for the future? What type of future do we want to enable in 5-years? 10-years? 15-years? These are very difficult questions in today's quarter-by-quarter business world but they, and many more, help to set the stage for reasoning about the flexibility and tradeoffs between different alternatives. A well-thought-out grid architecture enables use cases that emerge over time to be implemented within the scope of normal day-to-day operations and support. A huge win in an age of never ending change!

The Road to Success

While each utility is different and needs to wrestle with their own issues, utility planners and architects don't need to start from scratch. DOE's GMLC Grid Architecture program is developing a set of reference grid architectures along with training materials that can be leveraged by utilities. They are not intended to be "shovel ready" but will provide a sturdy foundation upon which to adapt and build.

Now is the time to get involved. Join SEPA's Grid Architecture Working Group and begin the journey.