What Kind of Lens Do You Use to Look at the Grid?

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25 February 2016

PNNL-SA-116473

Our power grids are massively complex and are rapidly becoming more so; consequently the use of architecture to help understand and manage that complexity is a necessity. But the term "architecture" is used in many ways with respect to the grid - how to know what is most useful? Let's look at two flavors (Enterprise IT[1] Architecture and Grid Architecture) and see how they stack up.

Differences in Purpose and Scope

Enterprise IT Architecture was the essential basis for Smart Grid Architecture, which makes some amount of sense if we think of Smart Grid as the convergence of Information and Communication Technology (ICT) with the power grid. The scope of Enterprise IT Architecture is information exchange and processing and the focus is what is known in the discipline as "the enterprise." PC Magazine defines the enterprise as an "entire organization, including all of its subsidiaries. It implies a large corporation or government agency, but it may also refer to a company of any size with many systems and users to manage."[2]

The purpose of Enterprise IT Architecture is to be the precursor to detailed design and implementation of specific information systems that automate business processes for an enterprise. As shown in Figure 1, the scope of such architectures is often represented as a stack, with business processes at the top, software applications next, followed by data, and finally the IT infrastructure (computing, data storage, and networking) needed to support the information systems being developed. It is worth noting the similarity between this and the GridWise® Architecture Council's GWAC Stack.[3,4]

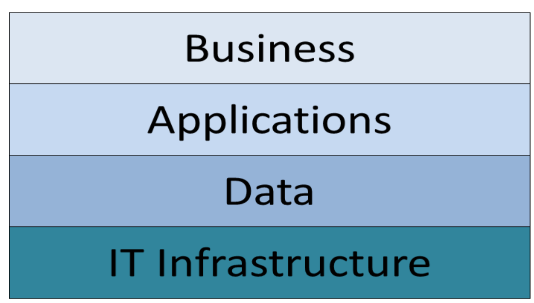

Figure 1 Enterprise IT Architecture Scope

The relevant disciplines underlying Enterprise IT Architecture are computer science and networking as it applies to data centers and business offices. The main consumers of Enterprise IT Architecture are IT architects and IT system integrators. Various stakeholders may encounter work products of Enterprise IT

[1] Information Technology
[2] http://www.pcmag.com/encyclopedia/term/42637/enterprise
[3] http://www.sgip.org/Interoperability-and-the-GWAC-Stack
[4] http://www.gridwiseac.org/about/imm.aspx

Architecture but its purpose is largely to inform the next level of stepwise refinement toward detailed design. The focus on information exchange drives enterprise IT architecture development and leads naturally to an intersection with Interoperability standards.

Grid Architecture is defined as the highest level description of the complete grid, organized in a way that supports reasoning about the whole grid. It defines the components, structure, behavior, qualities, properties, interfaces, and essential limits of the entire power delivery system. The focus of Grid Architecture is grid structure and structural properties; the scope is the entire set of entities, components, processes, and structures associated with the grid.[5]

The purpose of Grid Architecture is to help stakeholders think about the overall shape of the grid, its attributes and limits, and how the parts interact, in order to help manage complexity (and therefore risk), to assist communication among stakeholders around a shared vision of the future grid, to identify and remove barriers and define essential limits, to identify gaps in theory, technology, organization, regulation, and to provide a framework for complex grid-related development activities. As shown in Figure 2, structure includes not just the physical grid but also industry structure (including business and market structure), regulatory structure, sensing and measurement, protection and control networks and coordination frameworks, communications, and convergent systems such as water, natural gas, transportation, and social networks.

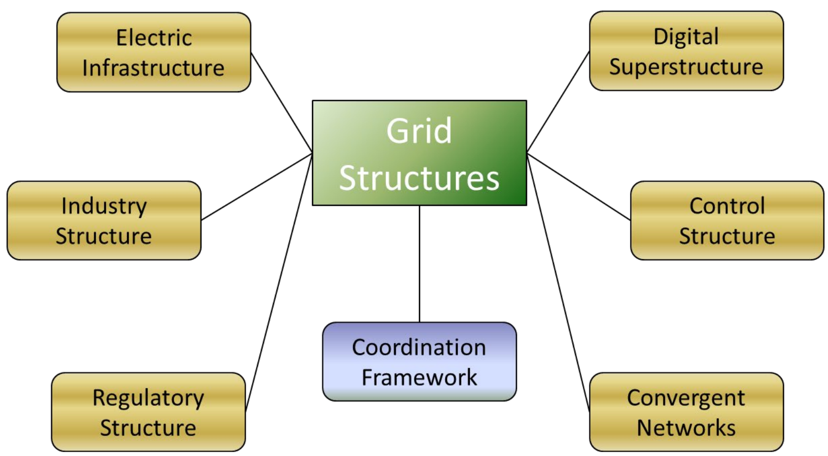

Figure 2 Grid Architecture Scope

The relevant underlying disciplines are system and software architecture, network theory, and control engineering. It serves a wide range of stakeholders, including consumers and prosumers, public policy makers and regulators, utility executives, engineers and grid operators, third party energy services organizations, grid researchers, IT architects, system integrators, and product development organizations. This scope naturally intersects with a variety of standards efforts, including Interoperability standards. Grid Architecture uses emerging trends, public policy, and stakeholder requirements and preferences as primary drivers of the architecture development process.

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[5] http://gridarchitecture.pnnl.gov

Based on these scope and focus descriptions, it may be tempting to think of Grid Architecture as a 30,000 foot level representation of the grid and Enterprise IT Architecture as a more nearly ground level view, but is not really the case. Each approach supports both high level abstractions and drilldown detail depictions. A better analogy is that Enterprise IT Architecture is a keyhole view of utility data management, while Grid Architecture provides a high definition 360 degree panoramic view of the entire grid, its systems, and its processes.

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Differences in Methods and Paradigms

Enterprise IT Architecture uses a set of paradigms, methods, and tools that concentrate on information flows and information processing components. Four of the main elements of this approach are shown in Figure 3. We will examine each of these briefly.

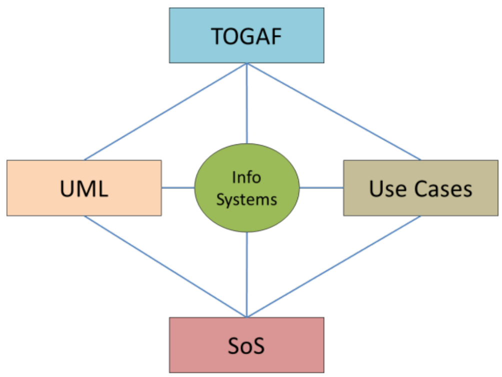

Figure 3 Enterprise IT Architecture Foundation

TOGAF – The Open Group Architecture Framework[6] is widely used as the primary methodology for developing enterprise IT architectures. It treats architecture development as a stepwise design refinement process, with different names for each stage (conceptual, logical, physical, etc.) and having a degree of formalism in the architecture development process, but without much underlying rigor.[7] It should be noted that there are a great many enterprise architecture frameworks and methodologies (TAFIM, ADM, DODAF, MODAF, FSAM, BEAM, SEAM, ABACUS, EBA, GERAM, Zachman Framework, ATAM, SAAM…) but TOGAF is most widely cited.

UML – Unified Modeling Language[8] is a key tool used in enterprise IT architecture development. It is a graphical language (meaning it represents architectures in diagram form with text annotation) and focuses on the four layer stack shown in Figure 1 above. Various software tools are available to create and manage the UML descriptions.

[6] http://pubs.opengroup.org/architecture/togaf8-doc/arch/
[7] http://www.forbes.com/sites/jasonbloomberg/2014/08/07/enterprise-architecture-dont-be-a-fool-with-a-tool/#599bbb0c45f1
[8] http://www.uml.org/

Use Cases – The primary input to enterprise IT architecture development is a set of use cases. Use cases are defined as a list of actions or event steps, typically defining the interactions between a role (known in the Unified Modeling Language as an actor) and a system, to achieve a goal.[9] Due to the limitations of UML, use cases are often used to document various kinds of requirements, even when they are not well supported in the UML tools. Enterprise IT architecture projects typically include the creation of a library of use cases and a list of requirements as inputs to the process. UML itself is somewhat weak in terms of representing performance requirements, especially for real time systems.

SoS – System of Systems[10] is a paradigm often mentioned in enterprise IT architecture work as the means to handle large scale complexity. It is essentially the translation of the 1970's software engineering concepts of program module strength (now often called cohesion) and module coupling applied to whole IT systems. This is the largest scale concept employed in Enterprise IT Architecture, but it is mostly component-based rather than structure-based.

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Grid Architecture focuses on grid structure to consider essential limits and the structure changes that may be necessary to enable new grid capabilities and energy value streams to be implemented. It also reveals couplings, gaps, and potential unintended consequences that can result from a change in the grid rippling through its various structures. A number of key elements are shown in Figure 4 below; we will take a brief look at each.

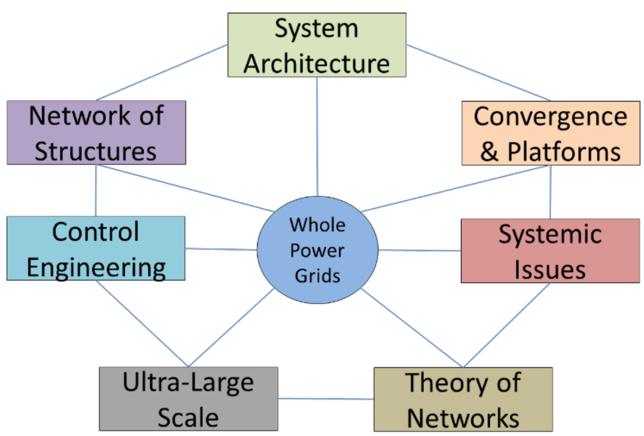

Figure 4 Grid Architecture Foundation

System Architecture – The basic underlying principles and methodology come from the discipline of system architecture (which includes concepts from software engineering). System architecture is not as

[9] https://en.wikipedia.org/wiki/Use_case
[10] US Department of Defense, Systems Engineering Guide for Systems of Systems, available online at: http://www.acq.osd.mil/se/docs/SE-Guide-for-SoS.pdf

well-known as enterprise IT architecture but is used widely in the development of real time systems that include diverse hardware (not just computing systems) as well as software of various kinds, including embedded software. It can employ tools like SysML[11] (in place of UML) but for Grid Architecture work such tools are too esoteric for most stakeholders to use. Instead, a variety of more easily digested illustrations and descriptions are used to communicate system structural concepts. A proper system architecture is not a design; it specifies the minimum number of constraints necessary to free up design choices, and admits many possible implementations, whereas any specific design allows only one.

Network of Structures – As shown in Figure 2 above, the grid is treated as a network of interconnected structures of various kinds. Not all are physical, and not all are electrical, but all are crucial to understanding how the grid operates and how changes must be developed.

Control Engineering – Since control is central to grid operation, concepts from control engineering are important elements of Grid Architecture. This does not mean that a grid architecture specifies control algorithms, but rather that control *structure* is used as part of the whole grid architecture.

Ultra-Large Scale – The complexity of the grid vastly exceeds that of ordinary systems. In the Grid Architecture discipline, the precepts of Ultra-Large Scale Systems[12] are used to develop architectural views that account for the properties that accompany such complexity.

Theory of Networks – The focus on structure and the network of structures paradigm naturally lead to the use of network theory to provide underlying rigor for the development of new structural views of the grid.

Systemic Issues – Grid Architecture is concerned with large scale structure and so is driven by in large part by systemic issues (also sometimes called cross-cutting issues). Use cases are employed, but more for validation purposes than as primary inputs to the architectural synthesis process.

Convergence and Platforms – In many architecture approaches, systems or devices may be related either by dependence or integration. In Grid Architecture, the network of structures focus leads to another concept – the convergence of networks and resultant formation of platforms.[13] This concept is very useful in dealing with market-control mechanisms for DER penetration, for example.

Another way to compare these two approaches is to consider the difference in paradigms between Enterprise IT Architecture and Grid Architecture. Figure 5 lists seven important paradigm differences, with Enterprise IT paradigms on the left and Grid Architecture paradigms on the right. Among the distinctions are how Grid Architecture focuses on structure, the use of market-control models, the change from integration to network convergence as a key concept, and the emphasis on using formalism for structure and evaluation of architectures.

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[11] http://www.omgsysml.org

[12] Linda Northrup, et. al., Ultra Large Scale Systems, Carnegie Mellon University, June 2006, available online at www.sei.cmu.edu/library/assets/uls_book20062.pdf

[13] http://smart.caltech.edu/papers/ElectricNetworksConvergence_final_022315.pdf

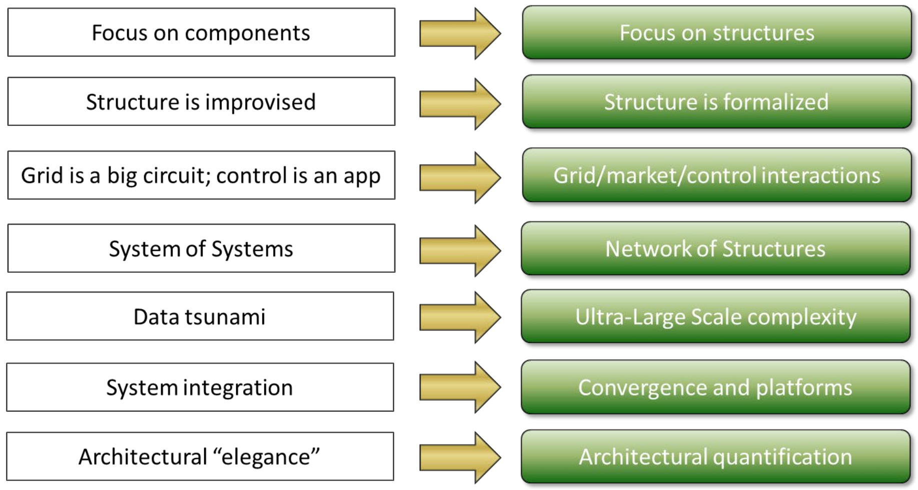

Figure 5 IT Architecture Paradigms vs. Grid Architecture Paradigms

This last point is significant. Enterprise IT Architecture does not provide rigorous methods by which to compare architectural alternatives, whereas Grid Architecture is able to do so through its use of Quality/Property/Element mappings to provide an open and rational basis for performing architecture tradeoff analysis.

An Example Result Comparison

Consider the problem of collecting and sharing data from a heterogeneous set of grid sensing and measurement devices across a set of real time and non-real time applications. In the Enterprise IT Architecture approach, the set of siloed sensors, data collection head ends, and applications systems are taken as givens; the focus is on defining information flows via use cases and this results in a selection of back end interoperability standards and specification of data flow models, data representation schema, and databases to be implemented/integrated as a solution design. Some of the consequences of such an approach are the need to interconnect application systems (read: cross- couple, creating dependencies) and to exchange information on the back ends of these systems as shown in Figure 6 below, thus incurring both massive system integration costs and high latency that limits real time performance.

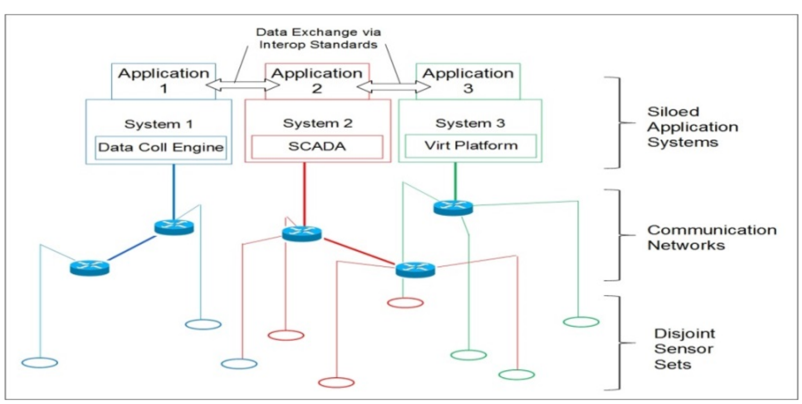

Figure 6 Siloed IT Approach

By contrast, in the Grid Architecture approach, the silos are *restructured* such that the sensors and communication network form an infrastructure layer, with supporting network-attached services. The result is low latency to all applications, future-proofing of the communications network investment, decoupling of the applications, significant reduction of integration costs, simplification of the interoperability issues, and separation of infrastructure costs from application costs (a benefit to rate cases). Figure 7 below illustrates the structural approach to grid sensing and measurement.

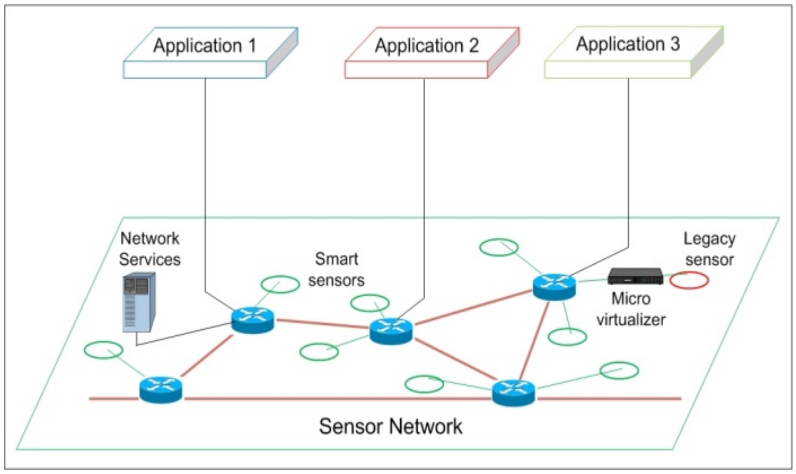

Figure 7 Restructured Grid Sensor Network Approach

Enterprise IT Architecture fits best in situations where a specific IT solution is being developed for a particular organization. Grid Architecture fits best when considering grid modernization at any scale from a single utility to a community, an entire industry segment, or a whole interconnection.

Summary

The discipline of Grid Architecture delivers new and useful results for electric grid modernization - results that have not been previously available from past approaches to smart grid architecture. In this article we explored the reasons for this by looking at the root differences between Grid Architecture and Enterprise IT Architecture to develop an understanding of their relative strengths and how they may complement each other.

Grid Architecture provides a stronger and more focused set of paradigms, methods, and tools for supporting grid modernization than does Enterprise IT Architecture. At the same time, it uses a wider and more comprehensive view of the grid problem domain than just information exchange and processing. Enterprise IT Architecture will continue to have an important place in utility information system solution development and should be viewed as a primary tool for developing business software solutions for any particular utility. Grid Architecture provides a larger framework to manage the complexity of grid transformation and to determine the structural changes that enable new grid capabilities and new energy value stream realizations.

Grid Architecture provides a comprehensive framework to manage the complexity of grid transformation.