WHITE PAPER

Grid Architecture: Crossing the Chasm Between Concept and Implementation

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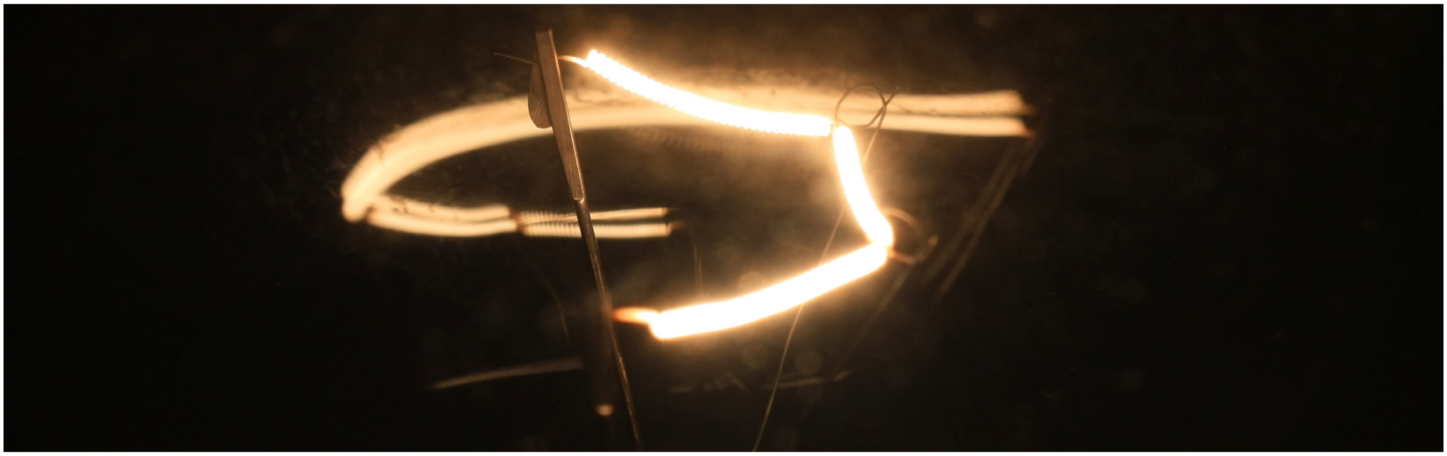
Today's technology is disrupting the edge of the grid. As the flow of power moves in multiple directions and the edge of the grid blurs, it becomes apparent that grid design will need to change to meet future needs.



The State of the Grid

Significant transformations are occurring in the electric power system. The challenges and risks associated with managing these complex changes must be understood to reduce unintended consequences. According to the 2019 GridWise Transactive Energy Framework, these include the growing use of renewable energy resources in the bulk power system; proliferation of distributed energy resources of various capacities in both the transmission and distribution systems; an increasing number of installations of local renewable resources at end-use points; and load growth through electrification of transportation and other end uses.

Technology — in terms of generating capability, inverters and communications — is more advanced and cheaper than ever before. This reality is accelerating the deployment of renewables and distributed energy resources, resulting in an evolving grid with greater intelligence, increased sensors and more monitors at lower voltages. Other industries are also deploying these new technologies, often outside a utility's control or visibility.

Investing in the Grid

To develop integrated resource plans and encourage investment in the grid, utilities need to be able to associate grid architecture investments with tangible customer benefits. Increasingly rapid evolution of grid technology and customer behavior means these investments need to be carefully designed.

Planning for the future in the face of constant change is a challenge. It requires refined monitoring and control capabilities that include interaction with customer resources. Increased visibility, coordination and flexibility will all become more crucial.

As interaction at the edge of the grid increases, customers become more involved in the grid. This makes their loads less passive and predictable, yet most are not involved with or aware of the complexities of grid operation beyond their own electricity usage. This means that customers and utilities have very different perspectives of the grid.

Addressing these differences — and understanding the need for new grid management systems — is one of the industry's biggest challenges. Fortunately, a solution has been encapsulated in work sponsored by the U.S. Department of Energy (DOE) in 2015 and conducted by the Pacific Northwest National Laboratory (PNNL). The work addresses a set of emerging trends in the utility industry for developing forward-looking architecture views in a concept referred to as grid architecture.

Grid Architecture

By viewing the grid as a network of structures, it becomes easier to understand the strengths and constraints inherent in legacy infrastructure. Dealing with all these structures simultaneously helps determine the necessary minimal required changes to existing structures, relieving those constraints and enabling new capabilities. Designers and engineers benefit from the knowledge that hidden constraints in the structure will not make it difficult to carry out the implementations of new systems.

The PNNL work describes grid architecture using qualities and properties. System qualities are desired characteristics of the system as seen by end users and other stakeholders with outsider perspectives. These can be thought of as high-level requirements, which may be expressed qualitatively or quantitatively. Generally, the number of qualities selected for a system is small, and one of the challenges is to choose a set that is comprehensive in nature despite the limited number.

System properties are characteristics of the system as seen by insiders that come together to provide the system qualities or enable them. System properties result from system components and structures, each of which has its own set of properties. In practice, a complex system will have a large number of desired properties, according to the Grid Modernization Laboratory Consortium.

Why did the DOE sponsor this work? In reality, the industry needs to rethink its architecture. The DOE has sponsored various projects in this field but real-world complexities, imperfect data, difficulty in assigning value to benefits and changing priorities based on operational necessities challenge effective decision-making. For investor-owned utilities, these decisions also need to be linked to regulatory directions.

The drivers for utilities and properties may not align with customer desires and qualities. Yet, aligning the two is the real goal. Utilities care about performance and cost recovery. This means prioritizing reliability, security, quality of service, adequacy, sustainability and other factors. Unfortunately, customers typically only care about affordability and reliability.

What about regulators? Their role is to formulate decisions and policies that influence utility investments and operations. This prominent role in establishing regulations and policies supports the establishment and implementation of a broad range of utility-sector programs.

From Theory to Policy

Public utility commissions are starting to recognize and reference grid architecture work, as it allows them to more accurately lay out their qualities in a way that is logically consistent and provides actionable direction. With investment needed in systems to coordinate activities and power system management at the edge, commissions need to have confidence that the investments are aligned with the requirements of an evolving grid and are commercially prudent.

Price cap regulation as employed in utility regulation is one mechanism that provides good incentives to reduce costs. But when increasing profits are realized, it ends up creating pressure to tighten price regulation, which then in turn increases regulatory risk and raises the cost of investment. The major challenge in designing regulation for a restructured industry is to provide adequate assurances of investor protection. This will safeguard that the necessary investments will be made.

Historically, our system of regulation has:

- Provided an advocate/single voice for customers.
- Eliminated barriers to entry.
- Acted as consumer educator.
- Enabled a utility to raise financing for investment at acceptable cost.
- Provided incentives for efficiency in operation, pricing, investment and innovation.

Retaining affordability will be difficult as more regulatory changes are required, driven by social factors and customer economics outside of utility control. These regulations are subject to rapid changes and are harder to predict. Thus, a structured approach to grid architecture makes a lot of sense; however, it still leaves a gap between what the customer wants to see and how utilities deliver it. Given the coming changes, regulators are encouraging customers and distribution utilities to work together to solve issues alongside a wide array of third parties, aggregators and additional support groups. Getting this new ecosystem to work will be a major hurdle going forward, given the divergent goals in the ecosystem and the lack of a single leading entity.

The way we consume electricity is changing, placing demands on the electric distribution grid that its creators never envisioned. To address growing needs, the grid needs transformation. Yesterday's grid planning methods must yield to holistic, data-driven distribution planning to optimize the investments of limited capital resources into grid infrastructure and maximize the effectiveness of transformative technologies.

For example, one question left unanswered is, "What should the design capacity of a circuit be in a distribution system?" And this leads to other questions. Should it be designed to meet the current peak load? Or enough to support one electric vehicle in each garage? Perhaps it should support net-zero housing? Or, skip the grid entirely and move directly to batteries? These fundamental questions must be answered so that 40- to 60-year investments in grid infrastructure can be the most effective.

From Policy to Implementation

How can qualities be mapped to properties in order to close that gap? In doing so, is it possible to provide implementation guidance to utilities that aligns with regulatory directives? Regulatory concepts can be turned into systems requirements that align to DOE and PNNL research guidance, providing a path to achieve the desired properties, avoid building unneeded systems and map the business and operational needs for implemented systems. Specifications are mapped against requirements and regulatory directives to provide an effective executive dialog that addresses all stakeholder needs. These specifications and requirements must be driven by qualities to arrive at the desired properties.

Thus, well-formulated requirements are a necessary component for implementing grid architecture. Requirements are what drive design and implementation and, like any implementation project with a life cycle, the requirements should be mapped to results and benefits derived from the implemented system. These requirements are a part of the architecture development process.

For system development, grid architecture interacts with enterprise architecture through these requirements. The Open Group Architecture Framework's Architecture Definition Document provides a qualitative view of the solution and aims to communicate the intent of the architects whereas the Architecture Requirements Specification provides a quantitative view of the solution, stating measurable criteria that must be met during the implementation of the architecture. This is comparable to the relationship between system qualities and system properties that needs to be expressed in terms of requirements.

But requirements are not static. Dealing with changes in requirements is crucial. Architecture deals with uncertainty and change — the gray area between what stakeholders expect and what is possible. Architecture requirements are therefore invariably subject to change, and requirements will also therefore depend on regulatory drivers as well as customer and utility drivers.

A superset of requirements can be used to create high-level systems requirements based on a combination of factors. For utilities this means creating requirements for new and upgraded systems to deal with grid evolution and which can be integrated with commission guidelines so that the final requirements will vary for each utility and state as appropriate. For multistate utilities this can be used to create a set of requirements that will specify single solution implementations that meet different criteria in different regions.

Conclusion

As renewable energy resources, distributed energy resources and electrification technologies continue to alter the grid, the design principles utilized to meet challenges must shift. The grid of the future will contain new technologies that offer greater visibility and flexibility, requiring that utilities make plans now to meet the ever-changing needs of consumers.

Grid architecture, as a concept, is poised to provide the solution. Through an understanding of the qualities desired by the consumers and the regulators — and the properties required by utilities — the grid architecture approach offers a comprehensive look at how to effectively invest in grid infrastructure to make the most impact.

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