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MODERN DISTRIBUTION GRID

Volume I: Customer and State Policy Driven Functionality

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DISCLAIMER

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GLOSSARY

A glossary is provided below for industry and technology terms as referenced in the DSPx effort.[1]

INDUSTRY DEFINITIONS

Balancing Authority (BA) is the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within an electrically-defined Balancing Authority Area (BAA), and supports interconnection frequency in real time. A utility TSO or an ISO/RTO may be a balancing authority for an area.

Distributed Energy Resources (DERs) include distributed generation resources, distributed energy storage, demand response, energy efficiency and electric vehicles that are connected to the electric distribution power grid.

Distribution System is the portion of the electric system that is composed of medium voltage (69 kV to 4 kV) sub-transmission lines, substations, feeders, and related equipment that transport the electricity commodity to and from customer homes and businesses and that link customers to the high-voltage transmission system. The distribution system includes all the components of the cyber-physical distribution grid as represented by the information, telecommunication and operational technologies needed to support reliable operation (collectively the “cyber” component) integrated with the physical infrastructure comprised of transformers, wires, switches and other apparatus (the “physical” component).

Distribution Grids today are largely radial, with sectionalizing and tie switches to enable shifting portions of one circuit to another for maintenance and outage restoration. Some cities have “network” type distribution systems with multiple feeders linked together to provide higher reliability.

Distribution Utility or Distribution Owner (DO) is a state-regulated private entity, locally regulated municipal entity, or cooperative that owns an electric distribution grid in a defined franchise service area, typically responsible under state or federal law for the safe and reliable operation of its system. In the case of a vertically integrated utility, the distribution function would be a component of the utility. This definition excludes the other functions that an electric utility may perform. This is done in order to concentrate on the distribution wires service without confounding it with other functions such as retail electricity commodity sales, ownership of generation, or other products or services, which a vertically integrated utility may also provide.

Integrated Grid is an electric grid with interconnected DERs that are actively integrated into distribution and bulk power system planning and operations to realize net customer and societal benefits.

Independent System Operator (ISO) or Regional Transmission Organization (RTO) is an independent, federally regulated entity that is a Transmission System Operator (TSO), a wholesale market operator, a Balancing Authority (BA) and a Planning Authority.

Internet of Things (IOT) is the network of physical objects (or "things") embedded with electronics, software, sensors, and connectivity that enables the object to achieve greater value and service by exchanging data with operators, aggregators and/or other connected devices. Each object has a unique identifier in its embedded computing system but can interoperate within the existing Internet infrastructure.[2]

Local Distribution Area (LDA) consists of all the distribution facilities and connected DERs and customers below a single transmission-distribution (T-D) interface on the transmission grid. Each LDA is not normally electrically connected to the facilities below another T-D interface except through the transmission grid. However, to improve reliability, open ties between substations at the distribution level exist.

Markets as referred to generically in this report include any of three types of energy markets: wholesale power supply (including demand response), distribution services, and retail customer energy services. Markets for sourcing non-wires alternatives for distribution may employ one of three general structures: prices (e.g., spot market prices based on bid-based auctions, or tariffs with time-differentiated prices including dynamic prices); programs (e.g., for energy efficiency and demand response) or procurements (e.g., request for proposals/offers, bilateral contracts such as power purchase agreements).

Microgrid is a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes.

Net Load is the load measured at a point on the electric system resulting from gross energy consumption and production (i.e., energy generation and storage discharge). Net load is often measured at a T-D interface and at customer connections.

Regulator is the entity responsible for oversight of the essential functions of the electric utility, including funding authorizations for power procurements, investments and operational expenses. This oversight extends to rate design, planning, scope of services and competitive market interaction. Throughout this report we use the term regulator in the most general sense to include state public utility commissions, governing boards for publicly owned utilities and rural electric cooperatives, and the Federal Energy Regulatory Commission (FERC).

Scheduling Coordinator/Entity is a certified entity that schedules wholesale energy and transmission services on behalf of an eligible customer, load-serving entity, generator, aggregator or other wholesale market participant. This role is necessary to provide coordination between energy suppliers, load-serving entities and the transmission and wholesale market systems. This entity may also be a wholesale market participant.

Structures is an architectural structure created by configuration of functional partition in relation to actors, institutions and/or components and their relationships. Related structures include industry, market, operations, electric system, control, coordination and communications.

Transactive Energy is defined by techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market-based constructs while considering grid reliability constraints. Transactive energy refers to the use of a combination of economic and control techniques to manage grid reliability and efficiency.[3]

Transmission-Distribution interface (T-D interface) is the physical point at which the transmission system and distribution system interconnect. This point is often the demarcation between federal and state regulatory jurisdiction. It is also a reference point for electric system planning, scheduling of power and, in ISO and RTO markets, the reference point for determining Locational Marginal Prices (LMP) of wholesale energy.

Transmission System Operator (TSO) is an entity responsible for the safe and reliable operation of a transmission system. For example, a TSO may be an ISO or RTO or a functional division within a vertically integrated utility, or a federal entity such as the Bonneville Power Administration or Tennessee Valley Authority.

TECHNOLOGY DEFINITIONS

Advanced Distribution Management Systems (ADMS) are software platforms that integrate numerous utility systems and provide automated outage restoration and optimization of distribution grid performance. ADMS functions can include automated fault location, isolation, and service restoration (FLISR); conservation voltage reduction; peak demand management; and volt/volt-ampere reactive (Volt-var) optimization. In effect, ADMS transitions utilities from paperwork, manual processes, and siloed software systems to systems with real-time and near-real-time data, automated processes, and integrated systems.[4]

Advanced Metering Infrastructure (AMI) typically refers to the full measurement and collection system that includes meters at the customer site, communication networks between the customer and a service provider, such as an electric, gas, or water utility, and data reception and management systems that make the information available to the service provider and the customer.[5]

Customer Information System (CIS) is used to maintain customer data, which is available to a grid operator's or utility's customer service representatives so that they may answer inquiries from customers.[6]

Customer Relationship Management (CRM) system allows a utility to track and adjust marketing campaigns, forecast participation rates, and move customers from potential participants to fully engaged customers.[7]

Distribution Management System (DMS) is a utility operating system capable of collecting, organizing, displaying and analyzing real-time or near real-time electric distribution system information. A DMS can also allow operators to plan and execute complex distribution system operations in order to increase system efficiency and prevent overloads. A DMS can interface with other operations applications such as geographic information systems (GIS), outage management systems (OMS), and customer information systems (CIS) to create an integrated view of distribution operations.[8]

Distributed Energy Resource Management System (DERMS) is a software-based solution that increases an operator's real-time visibility into the status of distributed energy resources and allows distribution utilities to have the heightened level of control and flexibility necessary to more effectively manage the technical challenges posed by an increasingly distributed grid.[9]

Meter Data Management System (MDMS) is a software platform that receives meter data from one or multiple smart meter technologies, verifies and stores the data, and delivers data subsets to the utility operations' applications such as billing and outage management.[10]

Outage Management System (OMS) is a computer-aided system used by operators of electric utilities to better manage their response to power outages.[11]

Supervisory Control and Data Acquisition (SCADA) systems operate with coded signals over communications channels to provide control of remote equipment of assets.[12]

Var is the standard abbreviation for volt-ampere-reactive, written "var,"[13] which results when electric power is delivered to an inductive load such as a motor.[14]

INTRODUCTION

PURPOSE

The U.S. Department of Energy is working with state regulators, the utility industry, energy services companies and technology developers to determine the functional requirements for a modern distribution grid that are needed to enhance reliability and operational efficiency, and integrate and utilize distributed energy resources. The objective is to develop a consistent understanding of requirements to inform investments in grid modernization. The requirements include those needed to support grid planning, operations and markets.

This report represents Volume I of a three-volume set that is intended to support additional discussions on evolving grid structure and function. Volume I, "Customer and State Driven Functionality," provides a taxonomy of functional requirements derived from state policy objectives, and includes a discussion of grid architecture. Volume II, "Advanced Technology Maturity Assessment," examines the maturity of technology needed to enable the functions presented in Volume I. Volume III, "Decision Guide," presents considerations for the rational implementation of advanced distribution system functionality.

This volume defines the functional scope for a modern grid platform**.** This functional articulation employs a taxonomy framework to logically organize the required capabilities and functions based on states' grid modernization policy objectives and related system attributes based on policy papers and sponsoring commissions' input. This volume also includes grid architecture context, comparative assessment of industry architectural applications and priority use case scenarios identified by the sponsoring state commissions.

INITIATIVE SCOPE

The initial scope of this effort addresses the need for an open, innovative approach that engages regulators, utilities, energy services firms, researchers and commercial technology developers to support commercial development and adoption of enhanced functionality as defined by individual states. It is recognized that each state has a unique set of customer drivers and policy objectives that will shape the evolution of their respective distributions systems. This effort identifies a unified palette of common functions and technologies that may be uniquely applied for each state/utility situation. It is also expected distribution grids will continue to evolve over time to address changing customer needs and uses of the system at the pace of value for all customers.

Phase I of this initiative includes:

- Translate the sponsoring regulatory commissions' policy objectives and attributes for a modern grid employing the grid architecture methodology;

- Standardize functional requirements with input from industry experts and commercial technology developers and drawing on prior and current Department of Energy and industry documents;
- Identify relevant commercial technology gaps in relation to sponsoring states' objectives including related technical standards and protocols;
- Facilitate knowledge sharing among states, utilities, commercial technology developers national labs and a broader set of industry stakeholders toward commercial development of key tools and technologies; and
- Develop of a reference decision maker guide highlighting key considerations regarding the relationship between objectives-functions-technologies, timing, and system versus locational investments.

PHASE I REPORT STRUCTURE

Volume I: Customer and State Policy Driven Functionality

Volume I defines the functional scope for a modern grid platform**.** This functional articulation employs a taxonomy framework to logically organize the required capabilities and functions based on states' grid modernization policy objectives and related system attributes based on policy papers and sponsoring commissions' input. This volume also includes grid architecture context, comparative assessment of industry architectural applications and priority use case scenarios identified by the sponsoring state commissions. Volume I extensively uses existing industry references and has undergone industry peer review from a representative group of utilities, DER service providers, technology firms and research organizations.

Volume II: Advanced Technology Maturity Assessment

Volume II consists of a taxonomy of technologies in relation to functions and elements identified in Volume I. This provides the basis for a survey of current commercial technology availability and development. The market assessment identifies the gaps between existing commercial technologies and the needed grid functions and elements to implement specific aspects of a modern grid. This volume also identifies functionality gaps regarding related technical standards and protocols.

Volume III: Decision Guide

Volume III aims to provide a user guide for the application of the Volume I taxonomy in support of decisions related to the implementation of modern grid functionality. This guide reflects key practical implementation considerations, such as drivers, timing, pre-requisite technologies, legacy transitions, technology adoption and deployment approaches. Volume III also provides example applications based on the state commissions' scenarios identified in Volume I.

Volume I Approach and Organization

The approach to Volume I development involved extensive use of existing reference material and a collaborative and iterative engagement with representative industry experts including state regulators, electric utilities, independent system operators (ISOs), and energy services and technology providers. The DOE hosted a series of interactive webinars with these experts to share working draft materials and elicit feedback. The annual More Than Smart National Distributed Energy Future conference in November 2016 engaged a wider audience of relevant stakeholders.[15] Comments and revisions were compiled into a comprehensive matrix and reviewed for changes reflected in this published version.

Volume I provides an overview of the functional scope for a next generation system platform and outlines key assumptions guiding the scope of this effort:

- **Five-year implementation time horizon**: This initiative focuses on the initial set of functions and related technologies needed to begin implementation within five years to support the sponsoring commissions' objectives.

- **Technology neutrality**: This initiative is avoiding preference of one type of technology over another, and is thus taking a technology neutral approach. This effort is also not focused on design-level solutions.

- **Industry structure neutrality**: This initiative is neutral on roles, industry structures and business models. However, the sponsoring commissions sought guidance on the development of distribution platforms in relation to potential regulated utility investment, and consequently there may be aspects of this report that imply certain utility functions.

Volume I includes five chapters following a taxonomy, described in Chapter 2. The taxonomy structure includes the following levels: L1) state policy objectives, L2) state defined grid attributes, L3) grid capabilities, L4) business functions, and L5) functional elements. Existing regulatory documents, industry references and review provide the basis for definitions used in this volume. Definitions that do not contain industry references reflect industry engagement and review through this effort.

Chapter 1 – State Policy Objectives and Attributes: Examines a cross-section of U.S. states' legislative and regulatory documents to extract objectives and attributes with respect to a future grid. Chapter 1 provides a summary of this analysis across states and draws out a set of key objectives and attributes for a modern grid.

Chapter 2 – Grid Architecture: Summarizes the general architecture view informing modern grid development and this initiative, assessment of key industry grid architecture applications, the taxonomy framework guiding the effort, and sponsoring state commissions' priority scenarios requiring grid modernization.

Chapter 3 – Capabilities: Identifies grid capabilities in relation to the policy objectives and grid attributes analysis in Chapter 1.

Chapter 4 – Reference Business Functions: Identifies and defines reference business functions in relation to the identified grid capabilities in Chapter 3.

Chapter 5 – Reference Business Functional Elements: Identifies and provides detailed descriptions of the functional elements that enable grid functions outlined in Chapter 4.

Chapters 3-5 in Volume I are organized into three general categories to orient the more detailed capability and function definitions stemming from the taxonomy outlined above: Distribution System Planning, Distribution Grid Operations and Distribution Market Operations. This follows a similar organizational structure used in the New York Public Service Commission's Distributed System Implementation Plan (DSIP) guidance and other industry characterizations.[16]

These general categories may be defined as follows:

- Distribution System Planning: An integrated planning approach that assesses physical and operational changes to the electric grid necessary to enable safe, reliable and affordable service that satisfies customers' changing expectations and use of DERs, including the provision of DER services to operate the distribution system.
- Distribution Grid Operations: Safe and reliable operation of a distribution system (including non-Federal Energy Regulatory Commission (FERC) jurisdictional sub-transmission facilities). This involves regular reconfiguration or switching of circuits and substation loading for scheduled maintenance, isolating faults, and restoring electric service, as well as active management of voltage and reactive power. This includes physical coordination of DER and microgrid operation and interconnections to ensure safety and reliability as well as physical coordination of DER services, and scheduled and real-time power flows between the distribution and transmission systems.
- Distribution Market Operations: Several states are developing operational markets for DER-provided grid services. Examples of such grid services include providing alternatives to distribution infrastructure upgrades and supporting operational requirements to manage voltage and reliability. These are described as non-wires alternatives in New York[17] and grid services in California.[18] More information on grid services can be found in Appendix B.

1. STATE POLICY OBJECTIVES AND ATTRIBUTES FOR A MODERN GRID

1.1 STATE OBJECTIVES AND ATTRIBUTES

1.1.1. Overview and Purpose

Many parts of the country are experiencing fundamental changes in customer expectations for distribution grid performance, with large numbers of customers utilizing the grid to integrate DER and connect other new technologies or seeking a platform for market transactions. Even in areas in which such demands are muted, the grid faces new challenges while seeking to fulfill its role of delivering reliable, affordable power as it has for decades. These challenges include more demanding customer expectations and requirements to support new technologies, some of which have low tolerances for disturbances or require two-way communication and energy flow; increased threats to the system from environmental, electro-magnetic, physical and cyber events; the need to integrate power from intermittent resources and deploy advanced technologies that can improve system efficiencies, reduce outage durations and truck rolls, or otherwise enhance customer satisfaction and reduce costs; and the ability of the distribution platform to interact with a more complex transmission system. This initiative seeks to work with regulatory commissions to develop a common framework for grid modernization that represents the objectives of all states and serves as a guide for the industry.

A modernized grid likely possesses attributes and delivers services that have a net positive value to customers, and avoids imposing on customers the cost of attributes and capabilities that are neither desired nor valued. This may seem self-evident, but it is important to expressly incorporate customer expectations, including as articulated in state policy objectives, into the foundation of the DSPx initiative. The degree to which the grid architectural blueprint informs and guides states when they develop their distribution grid modernization plans will determine the success of this initiative. Since the cost of the grid is typically socialized over a broad customer pool, including customers with varying needs and tolerances for rate increases, regulators and customers may seek to clearly identify the value proposition of any proposed changes in the grid in order to justify rate recovery. Regulators are unlikely to adopt grid modernization investments perceived as "gold-plating" or providing limited benefits for customers and relative to a state's priorities. Therefore, the analytical starting point for development of a modern grid includes customer needs and state policy goals and objectives.

Assessment of costs and benefits is beyond the scope of this initiative. Such determinations are application specific, and would be made by states in the future, upon implementation of their grid modernization plans. Rather, at this early stage of development, policy goals and objectives are used as a proxy for understanding what customers are likely to consider valuable. Development of a common architecture would be expected to create efficiencies that would be reflected in the future cost of implementation.

Observers typically focus on states' structural differences, but both restructured states and traditional vertically integrated states, states with an Independent System Operator (ISO) or part of Regional Transmission Organizations (RTO) and those outside of ISO/RTOs, have strongly similar operational needs. As discussed below, this can be seen by looking at states such as California, New York, the District of Columbia, Minnesota, and Hawaii, all of which have already commenced grid modernization proceedings, and others, including non-ISO/RTO states such as Oregon, Florida, and North Carolina (only part of which is in an RTO). Examining each state's objectives for a future grid reveals an emerging consensus around certain key concerns, such as reliability, resiliency, integration of newer technologies, environmental responsibility, and response to more complex customer demands, including for distributed generation and "smart" services. While different states might rank such concerns differently, and have different timelines over which these policy objectives will be addressed, when looking at the distribution system platform, similar technical issues and functionality will need to be addressed across all states, albeit at differing paces and scope.

For the purposes of this initiative, an "objective" is an envisioned or desired outcome. Objectives are high-level goals for the modernized grid, such as providing reliability or enabling the integration of DER. States, utilities, and other stakeholders also often reference other qualities or properties that they hope will be inherent characteristics of the modernized grid, such as resiliency or flexibility, which for the purposes of this initiative are "attributes." In this initiative, an attribute is a lower tier characterization of the grid compared to an objective and the first step, below objectives, for drilling down to the identification of the grid "capabilities" desired, the "functions" it may perform, and the "elements" that can be incorporated. More definitions and an explanation of this hierarchy relative to the work being done here are outlined in Chapter 2.

The key grid modernization objectives utilized in this initiative are distilled from documents setting forth states' visions for the objectives, attributes and desired capabilities of the future distribution system. This chapter explains the methodology for identifying and synthesizing information about those visions. By comparing key states' policy agendas, we draw commonalities that will serve as a foundation to develop the grid capabilities, functions, elements, and ultimately system requirements.

1.1.2. Methodology

<u>Selected States</u>

A sample of ten states and the District of Columbia were selected for analysis. The sample consisted of California, Florida, Hawaii, Illinois, Massachusetts, Minnesota, New York, North Carolina, Oregon, and Texas to reflect regional diversity and regulatory environments across the country. This state-by-state analysis provided a broader view of grid modernization definitions by comparing commonalities and contrasts among states.

Literature Sources

To capture each state's vision for grid modernization, relevant legislative and regulatory documents governing electric utilities were examined. The literature sources are publicly available documents, selected because they present policy-driven objectives and grid attributes. For most of the states, the objectives and attributes for grid modernization were drawn directly from legislative or regulatory documents in the belief that these types of documents would speak most broadly to the concerns of multiple stakeholders. The exceptions to this are North Carolina and Florida, where grid modernization legislation or regulation leaves the definition of objectives and attributes open to utilities. For this reason, literature sources in these two states also include utility filings related to grid modernization technology deployment. Table 1details the resources used to extract objectives and attributes of each state.

Table 1: State Policy Literature Review

	Literature Source
California	❖ CA Ruling on Guidance for DRP filings, February 6, 2015.
New York	❖ Track 1 Order NY PSC, Order Adopting Regulatory Policy Framework and Implementation Plan, NY REV 14-M-010, February 26, 2015.
District of Columbia	❖ PSC DC Formal Case No, 1130 in the Matter of the Investigation into Modernizing the Energy Delivery System for Increased Sustainability (MESIS), June 12, 2015.
Minnesota	❖ MN PUC Staff Report on Grid Modernization, March 2016.
Hawaii	❖ Commission's Inclinations on the Future of Hawaii's Electric Utilities – White Paper Exhibit A, 2014.
Massachusetts	❖ Investigation by the DPU on its own Motion into Modernization of the Electric Grid, June 12, 2014.
Illinois	❖ SB 1652 - Sec. 16-108.5, Infrastructure investment and modernization; regulatory reform, 2011.
Oregon	❖ Staff Recommendation to Use Oregon Electricity Regulators Assistance Project Funds from the American Recovery and Reinvestment Act of 2009 to Develop Commission Smart Grid Objectives for 2010-2014, 2012. ❖ Oregon 10-Year Energy Action Plan, 2012.
North Carolina	❖ Docket E-100, SUB 123, 2009. ❖ Duke NC Smart Grid Technology Plan, 2014.
Florida	❖ Florida Energy Efficiency and Conservation Act (FEECA) Report, 2006. ❖ Docket No. 150002-EG-Smart Meter Progress Report, FPL. 2014, 2015.

Texas	❖ HB 2129-Relating to Energy-Saving Measures that Reduce the Emissions of Air Contaminants. ❖ Rule 25.130 Advanced Metering. ❖ Title 2 Public Utility Regulatory Act, Subtitle B, Electric Utilities, Chapter 39: Restructuring of Electric Utility Industry.

Because the states surveyed for this policy analysis are in varying stages of grid modernization, the documentation available varies both in its thoroughness and degree of authority. For example, because the District of Columbia is still in an information-gathering stage, the source used was a DC Public Service Commission order opening an investigation and setting forth the Commission's goals. The document is authoritative, but information gathered during the proceeding may result in a more robust statement of objectives.[19] In contrast, the objectives for Minnesota were drawn from an MPUC staff report, which was based upon a robust inquiry. The staff report outlines five recommended principles for the MPUC to consider based on 2015 stakeholder engagement discussions and written comments.[20] Accordingly, the objectives should be read as collectively indicative of states' interests, with the understanding that any particular state's objectives may be developed and refined over time.

Normalized State Objectives and Attributes Definitions

A normalized set of definitions was developed for the identified state objectives and attributes, using common language to express similar concepts, for ease of comparison and interpretation. Figure 1 illustrates the result from this analysis in a matrix identifying the normalized objectives and attributes in relation to a respective state's current policies. State regulatory participants and industry experts reviewed and validated these materials throughout an engagement process.

Objectives

Adopt Clean Technologies: Enable customer adoption of new and clean technologies (e.g., energy storage, DER, electric vehicles, microgrids, etc.) to facilitate greater customer choice, reduce emissions, improve reliability and resource diversity, and enhance customer experience.[21]

Affordability: Provide efficient, cost-effective, and accessible grid platforms for new products, new services, and opportunities for adoption of new distributed technologies.[22]

Customer Enablement: Support greater empowerment, engagement, technology options and information for customers to manage their energy bills including related infrastructure investment to accommodate two-way flows of energy.[23]

Enable DER Integration: Ensure that the grid can integrate or host DER with the necessary communication and cyber and physical security protocols, in order for DER to be dispatched and controlled, while providing engineering and economic benefits.[24]

Operational Market Animation: Monetize DER services, reduce barriers for DER integration, and provide greater opportunities for realizing benefits of distributed energy resources through the provision of grid services (see Appendix B).[25]

Optimal Asset Utilization: Ensure optimized utilization of electrical grid assets and distributed resources to minimize total system costs.[26]

Reduce Carbon Emissions: Reduce carbon dioxide emissions emitted from the electricity sector. For example, this may result from: meeting new generation needs with renewable or other clean sources of energy; displacing fossil fuel use in generation with renewable power or other clean sources of energy; making more efficient use of fossil-fuels; increasing building efficiency and taking other conservation or energy efficiency measures; and increasing electrification of the transportation sector.[27]

Reliability: Maintain and enhance the safety, security, reliability, and resiliency of the electrical grid at fair and reasonable costs, within accepted standards and consistent with the state's energy policies.[28]

System Efficiency: Enhance the operation of the physically connected generation, transmission, and distribution facilities, which are operated as an integrated unit typically under one central management or operating supervision.[29,30]

Attributes

Cyber-physical Security: Application of cyber and physical security requirements commensurate with the adverse impact that loss, compromise, or misuse of systems, physical and resource assets could have on the reliable operation of the distribution grid.[31]

Flexibility: Operation and design of the electric grid to allow multi-directional flows of energy and enable all types of DER technologies to interconnect and participate in market opportunities.[32]

Operational Excellence: Enhanced customer service and optimized utilization of electricity grid assets and resources to minimize total system costs. [33,34]

Resiliency: Preparation for and adaption to changing conditions and the ability to withstand and recover rapidly from disruptions. Disruptions can be caused by deliberate attacks, accidents, or naturally occurring threats or incidents.[35]

Safety: Operation of the distribution grid in a manner that ensures public and workforce safety, operational risk management, and appropriate fail safe modes.[36]

Transparency: Visibility and accountability into the market design, planning, and operation of the distribution grid through greater access to data, integrated planning procedures, and competitive processes. [37,38]

1.1.3. Key Findings

Figure 1 below is a summary of the comparative assessment reflecting normalized labels for each objective and attribute based on the respective states' descriptions. Affordability, reliability, customer enablement, system efficiency, adoption of clean technologies, operational market animation, reducing carbon emissions, and DER integration are all identified as objectives. While there is relatively common interest in cleaner distributed technologies, interest in the use of DER as non-wires alternative is fairly nascent.

Resiliency, safety, security, and operational excellence are corresponding attributes identified by all the states. States have also identified the need for flexibility as the changes underway in the customer expectations and the adoption of DER create uncertainty regarding the timing and scope of distribution enhancements that may be required. Additionally, transparency is explicitly or implicitly discussed by half of the surveyed states that are seeking to enable customer choice and DER integration. To date this has focused on increasing stakeholder visibility into the distribution planning processes (e.g., assumptions, methods, etc.).

Figure 1: Normalized State Objectives and Attributes

Objectives	CA	DC	FL	HI	IL	MA	MN	NC	NY	OR	TX
Affordability	●	●	●	●	●	●	●	●	●	●	●
Reliability	●	●	●	●	●	●	●	●	●	●	●
Customer Enablement	●	●	●	●	●	●	●	●	●	●	●
System Efficiency	●	●	●	●	●	●	●	●	●	●	●
Enable DER Integration	●	●	●	●	●	●	●	●	●	●	●
Adopt Clean Technologies	●	●	●	●	●	●		●	●	●	●
Reduce Carbon Emissions	●	●	●	●				●	●	●	●
Operational Market Animation	●	●		●		●	●		●		

Attributes	CA	DC	FL	HI	IL	MA	MN	NC	NY	OR	TX
Safety	●	●	●	●	●	●	●	●	●	●	●
Cyber-physical Security	●	●	●	●	●	●	●	●	●	●	●
Operational Excellence	●	●	●	●	●	●	●	●	●	●	●
Resiliency	●	●	●	●	●	●	●	●	●	●	●
Flexibility	●	●	●	●	●	●	●	●	●	●	●
Transparency	●			●	●		●		●		

In sum, the industry's long-term goals of delivering reliable and affordable energy and achieving a high degree of customer satisfaction are reflected in these prioritized objectives. The objectives that are explicitly linked to new challenges build upon and support these priority areas. For example, the strong interest in integrating DERs supports reliability, customer satisfaction, and sustainability as the grid will need to be able to interconnect customer-selected new technologies without a loss of reliability and because more states are looking at microgrids and local generation to facilitate resiliency. The interest in efficiency reflects a continuing concern with cost containment and affordability, as well as conservation of resources. Similarly, the interest in animating markets is directly related to seeking lower cost alternatives to traditional grid investments to address affordability of electric service. Additionally, attention to enabling customer choices and opportunities for customers to participate in operational markets are elements of customer satisfaction. Overall, the key objectives reinforce one another to advance traditional goals, through a modern grid tailored to meet 21st century challenges and customer demands.

2. GRID ARCHITECTURE

2.1 ARCHITECTURAL PERSPECTIVE

It is a fundamental premise of this report that the functional operation of the distribution grid will change as customer expectations for reliability and DER adoption increase. These and other key factors are changing the use of the distribution system beyond traditional uses of the grid and related operations. The use of DER-provided grid services, for example, is a fundamental driver for enhanced distribution operational functions, such as schedule coordination, DER portfolio dispatch, aggregation and settlements. Without high levels of DER on a distribution system, these functions would not be necessary. By extension, these issues and questions also arise in considering the evolution of a distribution system platform (DSP) structure. This is why the timing, pace, and locational diffusion of DER on a distribution system matter with respect to decisions about DSP functional evolution and structures.

However, it is clear that foundational modern grid capabilities, including suitably robust sensing and measurement, information management, and communications networking capabilities, are required for reliability, resilience and security irrespective of DER adoption. These foundational investments are analogous to the physical hardware and operating system that comprise smart phone platforms that enable a variety of applications that expand the capabilities of the system overall. In the grid modernization context, the foundational investments similarly support current and future applications in a modular fashion, if properly architected.

For this reason, this effort is grounded in the basic principles and methods of Grid Architecture as developed for the Department of Energy.[39] As context, key emergent trends and issues, beyond the adoption of DER, that influence the architecture and design of complex systems, and electric grids in particular are described below.

2.1.1. Relevant Emerging Trends

Consumer/Local choice – Consumers are increasingly looking to have more choice over options to manage their energy bills. Likewise, communities and cities have increasingly sought energy options to address economic development and environmental and resiliency objectives. One example is the rise of Consumer Choice Aggregators (CCAs) in several states, which are non-profit default retail energy suppliers for a designated local area. CCAs often seek to develop local DERs to manage their energy supply portfolio. Additionally, smart city efforts are often linked with urban development related infrastructure including microgrids. Increasingly, multi-user microgrids that involve peer-to-peer energy transactions across the distribution system are being considered. Lastly, social network interactions may also play a role as groups of end users, consumers, and prosumers self-organize.

Information and communication technologies (ICT)/grid convergence – Information and communication systems will continue to converge with power grids, resulting in both new capabilities and new inter dependencies. Decreasing cost of both computing and networking, plus the synergy of combined computing and networking, and the prevalence of embedded computing in a wide variety of grid and edge devices impacts all levels of the grid, its users, and utilities. Convergence implies common architecture for synergy, and development of new value streams, both of which are emerging for the utility worlds. Examples include the gradual move toward using communication and edge devices such as network routers, meters, and grid device controllers as application platforms for the grid.

Faster grid dynamics – In the last century, aside from protection, distribution grid control processes operated on time scale stretching from minutes and longer as human decision making within the process is common. With the increasing presence of technologies such as solar PV and power electronics for inverters and flow controllers, active time scales are moving down to sub-seconds and even to milliseconds. Consequently, automatic control is necessary and this brings with it the need to obtain data on the same times scales as the control must operate. As a result, there are not only many more new devices to control, but also much faster dynamics for each device. This leads to vast new data streams and increasing dependence on ICT for data acquisition and transport, analysis, and automated decision and control.

Reduction/loss of system inertia – The replacement of nuclear and fossil fueled generating steam turbines with their high rotational inertia is causing an overall system level decrease in inertia. System and individual generator turbine inertias play a role in transient stability and in the dynamics of load sharing; loss of rotating masses on the grid gradually decreases system inertia and thus reduces system stability and increases "hunting" of the remaining generators. The significance of this at the distribution level is that DERs may be valuable in countering this trend if controlled properly to do so.

Evolving control system structure – Utility controls systems have traditionally been centralized, with hub and spoke communication to remote subsystems and equipment as needed. As the various trends cited here have emerged, the need for changes in control system structure has become apparent. While the industry generally recognizes the need for a transition to more distributed forms of control, this cannot happen without vendor-developed products. The vendors see thin markets and are slow to commit to new product development investment until they are reasonably assured of a market; the utilities are reluctant to commit to buying until they can see how new controls would work for them and what support they would see from regulators for new expenditures on controls and communications.

Focus on resilience and cyber-physical security – The ability of the grid to resist degradation and to recover quickly in the face of extreme events, whether they are natural or human-caused, is of increasing importance. In addition, the connection of increasing numbers of smart devices (devices capable of both computation and communication) is enlarging the opportunity for malicious activity by a number of actors. Finally, the desire or need to share certain information raises increasingly complicated issues of data privacy and confidentiality. These issues are not peripheral and must be considered early and continually throughout the development processes and operational lifetimes for modernized grids.

2.1.2. Key Systemic Issues and Constraints for Grid Platforms

Centralized vs. distributed control – One of the key decisions about management of modernized grids is the issue of how control is performed. The traditional model is centralized. In the context of DERs this expands greatly to what is sometimes called "grand centralized optimization." In the model, massive amounts of data must flow to a central location; massive amounts of computation must be done to determine everything from voltage regulator set-points to DER dispatches and then the commands must be distributed back to the grid and edge devices. In the more distributed approaches, data flows are more local and decentralized computing operating under a coordination framework solves the control problems in a distributed fashion, with each part acting as a team member rather than as a slave to a central master. The centralized approaches are traditional, but the distributed approaches offer better potential for resilience and scalability in the face of growing numbers of interactive edge-connected devices. The choice between these approaches is structural (architectural) and has a massive impact on many other downstream design decisions.

Market vs. control mechanisms – As with the centralized vs. distributed issue, there are two extreme views about grid and DER management: one says that a well-designed market with the "right rules" will provide prices that make everything work. The other says that a proper optimal control formulation will make everything work. Both views have limitations and in fact, both mechanisms are needed for modern grids. The key issue is to understand where each mechanism fits and how they work together.

Interoperability – Since there is no single system or application for operating a distribution grid, multiple systems must be used and often must interchange information to do so. Integration of such systems is expensive and time consuming, but this problem can be mitigated somewhat by the use of open international standards for information exchange. Such interoperability standards and the processes, systems, and devices that go with them must be integral to a grid modernization strategy.

Increasing number of distribution level functions – New functions are increasingly connected through the grid, adding complexity as well as hidden control coupling through grid electrical physics even when they appear on the surface to be independent (e.g., interaction between Volt-var control and demand response). This type of coupling may not be recognized until a penetration tipping point has been passed (i.e., may not show in demonstrations and pilots). This can lead to a multiple controller/multiple objective situation where applications want to make use of the same control element or infrastructure element for differing purposes.

Growing number of interconnected endpoints to be managed, sensed, and/or controlled – Large numbers of devices with embedded processing and communication capabilities are increasing the potential efficiency of the grid. However, these intelligent devices must be managed in terms of provisioning, accounting, security, and function to achieve the benefits and mitigate potential operational risks. For example, devices that have sensing and measurement capabilities should be read; those that have control capabilities may be commanded or otherwise directed to action. It is important to consider that legacy control systems and network management systems were typically designed for sense/control endpoints numbering in the thousands. New systems will increasingly be required to integrate several million devices (e.g., smart meters, other sensors, grid devices and DERs).

Poor distribution grid observability and connectivity models – Distribution grids have low levels of sensing and measurement, which are generally not adequate for advanced grid functions and devices to meet certain policy objectives and DER adoption. Little knowledge is available to provide guidelines for distribution grid observability strategy or design. In a larger sense, grid state may be extended to cover T&D, but not just electrically. It would include electrical, thermal, stress, risk, financial, utilization, and security states, for example.

2.1.3. Reference Architectural Views for a Modern Grid

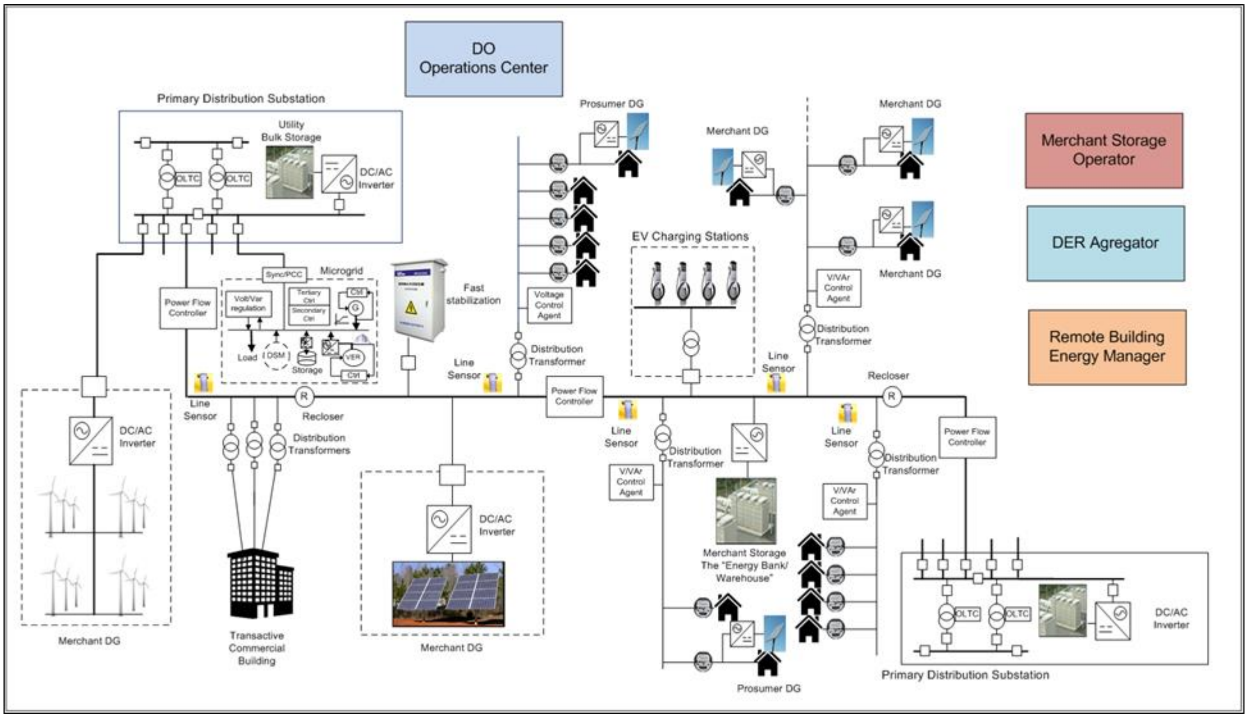
This section contains several architectural views related to distribution platforms. This is not intended to be a complete architecture, and certainly not a design; rather these views are intended to illuminate specific key issues that affect early decisions in the grid modernization process. Each utility should develop a grid architecture that meets its particular needs and the requirements as developed in this effort.

Reference Model Views

Figure 2[40] below illustrates a view of a possible future distribution grid. It is not an architecture, but a reference model that depicts the problem domain. It shows a portion of a distribution system in which DERs of various kinds play significant roles. In addition to wind and solar generation sources, the model incorporates responsive loads, transactive buildings and a microgrid. It also contains three levels of storage: substation, neighborhood, and behind-the-meter. Power electronic flow control is depicted via inline flow controllers and solid state transformers but sectionalizing is via standard reclosers. While radial feeders are common, and in some urban areas secondary meshing is present, partial meshing of feeder primaries is depicted with the inter-tie being a power flow controller or a conventional inter-tie switch. The feeder primaries are instrumented with line sensing and Volt-var regulation is done at various feeder locations. Fast voltage stabilization may be provided via power electronics, e.g., S&C's PureWave® DSTATCOM[41] at the feeder level.

A problem domain reference model such as this is a starting point for developing a grid architecture. In practice, the models are more detailed and contain considerable explanation. They are important because stakeholders need to see the elements of concern to them reflected in a comprehensible manner and decision-makers need to understand the full scope of the issues at hand. Such a depiction in graphical and text form is a powerful means to address these needs.

Figure 2: Distribution Problem Domain Reference Model

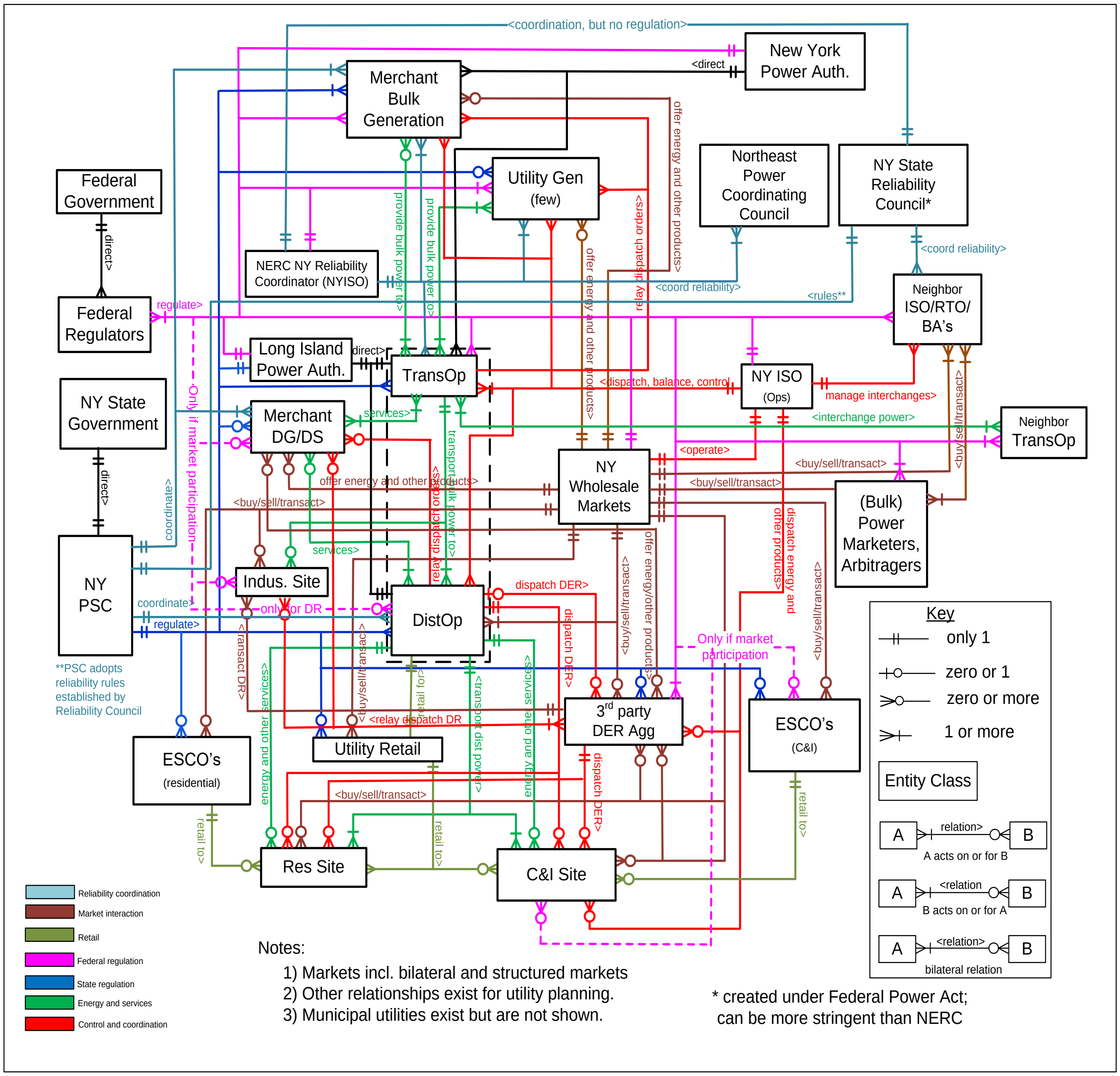


The distribution system is managed by a Distribution System Operator (DSO), which is where the grid operations and sourced DER services are managed. While there are a range of DSO models under consideration in the industry,[42] this reference model presumes that the DSO has substantial responsibility for coordinating DER operation in its service territory and handles the interface to the bulk system Transmission System Operator (TSO) at a locational marginal price (LMP) node or transmission-distribution substation.

Industry Structure Views

Industry structure views provide a means to consider systemic implications of changes to specific grid components and processes. These diagrams and the accompanying explanatory material focus on the various entities involved in the grid, along with their relationships. A complete model is complex, but so is the environment in which changes are being made. Models are useful for understanding the system-wide implications for changes and are crucial for architecture work. Figure 3[43] below illustrates an example of an industry structure model diagram developed for New York. It was used to extract a skeleton coordination framework to assist in working out the proposed relationship between the NYISO wholesale markets and potential distribution level DER markets. These diagrams are multi-layer in form, but here we show all the layers at once. When developing changes, the "as-is" version of industry structure is part of the initial conditions and constraints, and part of the architecture process is to develop a "to-be" version and to understand how proposed changes may ripple through the whole system.

Figure 3: New York Industry Structure Model Constructed by PNNL (2015)



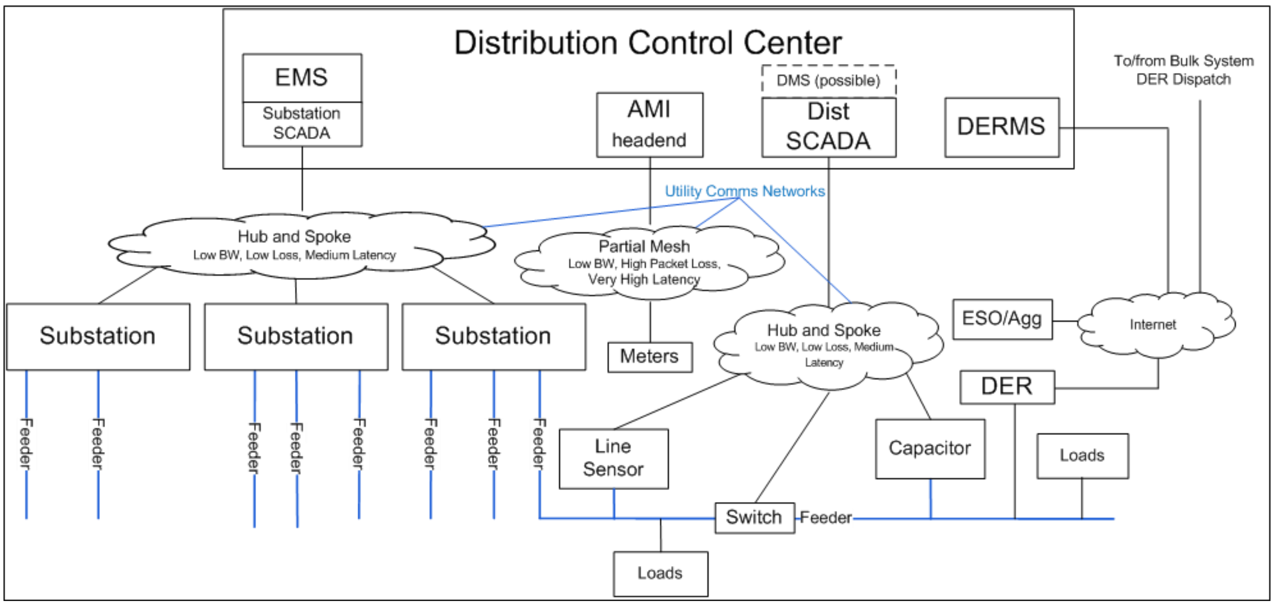
There is no single structure model that fits the entire US electric power industry, so appropriate models must be constructed for each specific case, and will differ for vertically integrated utilities, co-ops with generation and transmission entities, and municipal utilities, as compared to say, investor-owned utilities (IOUs) in a deregulated state.

Distributed, Layered Architecture

One of the uses of an industry structure model is to extract a coordination framework. Coordination is the process of ensuring that distributed elements (i.e., grid components, DERs, organizations) collaborate appropriately to solve a common problem. It can involve direct control, markets, or organizational interaction rules, among other things. Coordination frameworks exist in all grids, but may be incomplete or may not fit well with new grid functions. In the case of DER integration, coordination is an emerging key issue since most DERs are not owned by the utility to which it is connected or to which it provides services.

The structure of the grid control system is a more familiar issue at utilities. The Grid Architecture work treats control and coordination together, since they are closely related. Figure 4 below illustrates the structure of a traditional distribution control system. This is a centralized form with hub-and-spoke communications and has several siloed systems. While it is possible that this can be used as part of a modern grid, it may be that other forms are more appropriate. In any case, if this represents the existing system at a given utility, it must be understood as the legacy starting point.

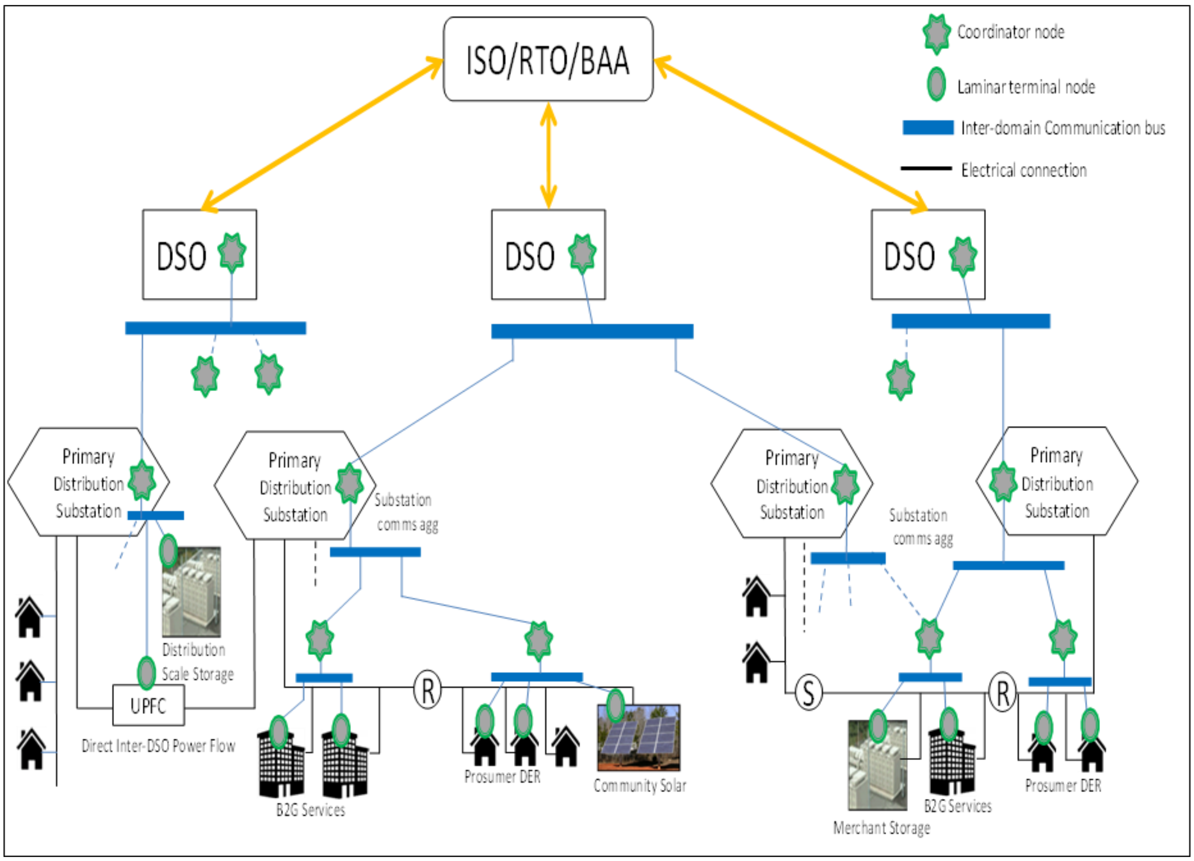
Figure 4: Traditional Centralized Distribution Control



The centralized control structure has the virtue of familiarity and a long history of understood performance, but was not intended to deal with vast numbers of intelligent edge-connected devices and systems. This form was developed in the days before significant DER penetration began to take hold and was appropriate at the time, but it suffers from limitations in its ability to scale up both communications and computation to levels needed to handle large numbers of intelligent interacting edge devices. Such scalability limitations eventually impede the ability of the system to perform at the level needed to support the desired new capabilities for DERs, leading to the need to significantly rework the existing systems. It is also increasingly difficult to integrate new applications and capabilities into this structure. Part of the limitation comes from the communication network arrangements and part from the fact that this structure is mis-matched to the evolving form and structure of the grid.

Figure 5 below illustrates a layered, distributed approach to grid and DER management. This is a newer structure that addresses scalability as well as other issues through a combination of central and distributed structure in a layered hierarchical form. This architecture is quite different from the traditional control model but is consistent with a number of advanced formulations for grid management with DER, including SGIP's OpenFMB™/Distributed Intelligence Platform (DIP) architecture and much of the Southern California Edison (SCE) architecture as described below. The formal basis for this approach has been connected to both distributed control and transactive energy approaches to grid and DER management, which is the essence of the Laminar Coordination framework, as discussed in more detail below. Slightly less obvious is the fact that this approach is also the underlying basis for the structures indicated in the recent work on DSO models.[44]

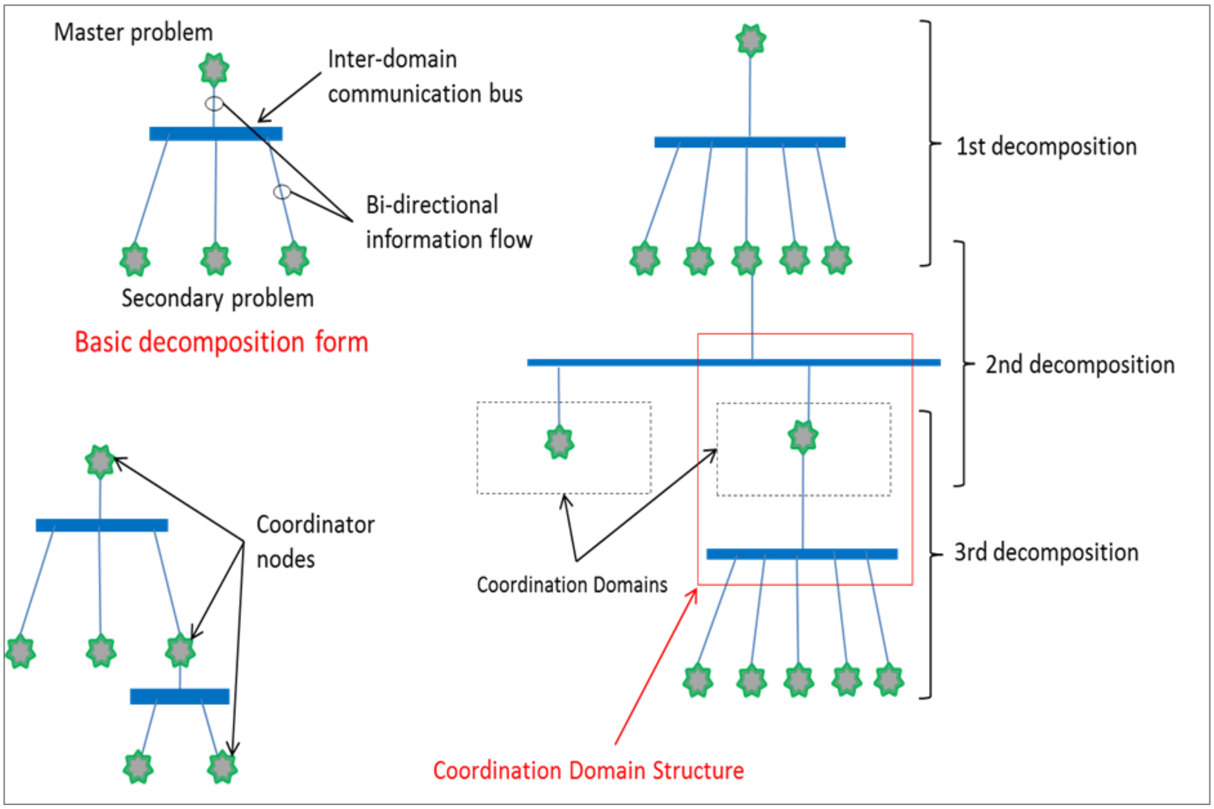
Figure 5: Layered Hierarchical ("Laminar") Control/Coordination Structure



Laminar Coordination Frameworks were developed using the mathematics of network utility maximization via layered decomposition.[45] This method has been used for a variety of purposes, including communication network management,[46] formulation and solution of problems involving control of DER,[47] and coordination of autonomous elements in distributed control systems.[48] In the work on Grid Architecture done for the Department of Energy in 2015, layered decomposition was used to develop a coordination framework for distributed control and coordination of grid elements and DER in a highly distributed manner, including mixed control and transactive (market-like) elements.[49]

In the theory of distributed control, a key issue is the mechanism that keeps decentralized and autonomous elements focused on solving a common problem. One class of methods involves goal modification; the other, of interest here, is the use of structural methods. The latter approach is of interest because the goal is to extract essential structure from the mathematics, so as to have a basis for understanding the properties inherent in the structure. When the structure *induced by the mathematics* of layered decomposition is extracted and examined, a multi-scale form emerges that uses a stacked hub and spoke arrangement (i.e., a Laminar Coordination Framework) to provide pathways for coordination signals (see Figure 6).

Figure 6: Stacked Hub and Spoke Structure and Coordination Domains



In addition to the layered hub and spoke structure, a repetitive cellular form (i.e., the coordination domain) also emerges that becomes a general building block for composing arbitrarily large systems as needed to match underlying infrastructure, namely the electric grid in its various topologies.

Coordinator nodes provide the distributed processing that aligns local elements by exchanging coordination signals in well-defined patterns. The coordinator nodes themselves have core functionality defined by the mathematics, but serve additional purposes as well. Coordinator nodes provide northbound and southbound communications for inter-layer coordination as well as peer-to-peer communications for intra-layer coordination. Discussions underway in several states regarding the respective roles of the transmission operator, distribution operator and DER services provider are following this layered approach. That is, coordination between the transmission operator and distribution operator from their respective responsibilities. Similarly, the distribution operator interfacing with the DER services provider who, in turn, is directly controlling the customers' DER devices. There is an evolution to a fully layered structure in which the current bypass of DER provider to the wholesale market will need to be addressed to reach the scale of participation anticipated in several states. This evolution is also being explored by ISO/RTOs, utility distribution operators, and DER service providers.

To enable such a layered approach, a Laminar Coordination Framework[50] can be used to structure the information flows for a decentralized system or to solve an actual distributed control problem by solving an optimization problem related to the underlying physical system. The mathematics of layered decomposition provide insight into the convergence and, therefore, computational scaling properties of such structures and the Laminar topology can be used to understand communication scaling and cyber security vulnerability issues. Finally, the Laminar structure defines essential aspects of the necessary communication networks.

Some key properties of Laminar Coordination Frameworks are:

- Extensibility – The composable nature of laminar coordination domains means that a framework can be made to fit an existing grid structure, can be built out incrementally, and can be extended incrementally when grid structure changes.

- Boundary deference – The decomposition method and composability of coordination domains enables the creation of an interface wherever one is needed to accommodate a system or organizational boundary.

- Local objective support (selfish optimization) – By introducing additional objective terms at any particular coordinator node, local objectives can be integrated into the overall solution. This is a form of goal decomposition.

- Constraint fusion – By adding in constraints as needed at any coordinator node, local constraints such as thermal or protection limits can be accommodated in a distributed fashion.

- Scalability – Since coordination signals do not need to aggregate up or down the coordination chain, no communication scalability issues arise due to the depth of the coordination chain. Layered decomposition can be used to create new layers as needed if the southbound fan-out for any particular node becomes too large, thus providing structural scalability.

- Securability – The inherent form of the coordination framework and consequent coordination signal flows provides a degree of regularity that supports signature and traffic analytic security measures much more so than arbitrary networking for Transactive Energy nodes and other unstructured coordination schemes.

Laminar Coordination Frameworks provide the basis for understanding and even unifying a number of architectures either in use or proposed for use in electric power systems as discussed below. Most existing and proposed control and coordination structures for modernized grids can be analyzed and understood using this framework as a common basis.

2.1.4. Comparative Analysis of Various Grid Architectures

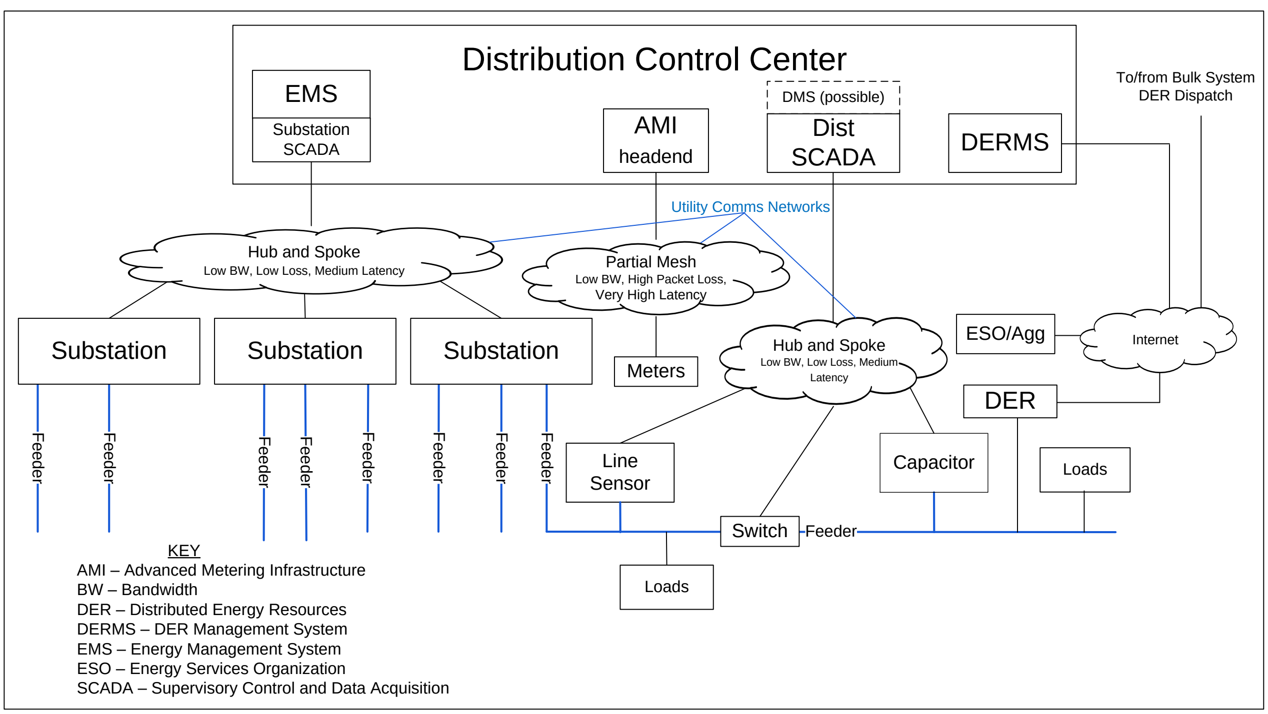
Many architectures for various aspects of electric grids have been proposed over recent years and new ones continue to be suggested. In general, there has been no means except ad hoc analysis by which one can reduce these architectures to some common basis, or extract common elements, until now. This has led to confusion in choosing an architecture for implementation, and has made it difficult to identify core product or platform opportunities with sufficient potential markets to encourage vendors to provide or develop them.

The Laminar Coordination Framework provides a canonical structure onto which many other architectures can be mapped.[51] Doing so shows the common basis for these architectures, and makes it possible to use the properties of Laminar structure to analyze and characterize these architectures, as described above. This material illustrates how such comparisons can be done but is not intended to be an exhaustive analysis of alternatives.

Centralized Control Structure

Traditional centralized grid control has a simple hub-and-spoke logical structure, and when the communication networks are point-to-point, has the same physical structure as well. In a real grid there may be several of these structures operating in parallel (see Figure 7).

Figure 7: Centralized Controls with Multiple Hub-and-Spoke Control Systems

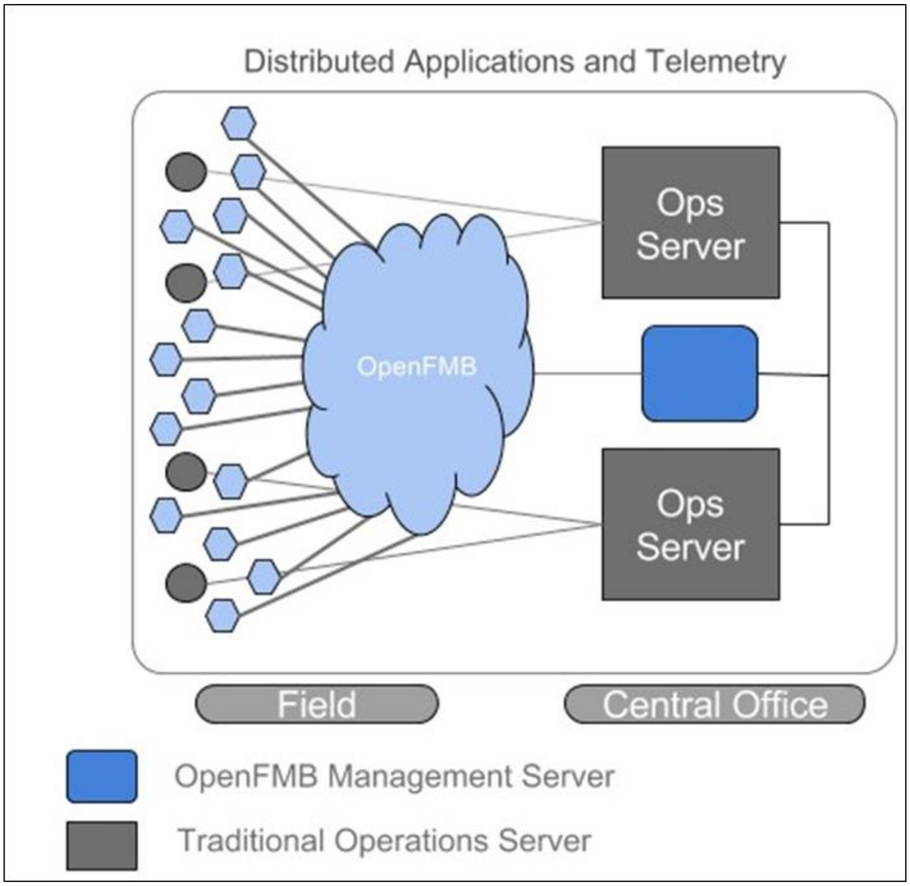


The centralized grid control structure is a simplified version of the Laminar structure, in that there is only one level of decomposition, and for the typical case where the lower layer nodes have no intelligence, all of the coordination is done at the master (i.e., top-level) node. If the field (i.e., lower level) nodes were to have local intelligence, then the coordination/control problem could be distributed incongruent to the layered decomposition approach with no other change in structure required. Therefore, we may view the conventional centralized control model as a degenerate form of the Laminar Coordination Framework. We may also view the centralized control structure as one where the lower layer of intelligence has been virtualized back into the top level node. In this manner, we can analyze the convergence properties of grand central optimization control schemes with the same tools and methods as we use for the distributed structures.

OpenFMB™ and Distributed Intelligence Platform (DIP)

The OpenFMB™ specification and Distributed Intelligence Platform (DIP) architecture,[52] developed by SGIP 2.0, Inc., is intended to support both centralized and distributed analytics and control arrangements. This means that the communication network for electric distribution systems could provide aggregation paths to the distribution substations as well as access to feeder level computational elements used for local coordination and optimization. Consequently, the underlying communication network may support general local connectivity and local peer-to-peer communication as opposed to the more common hub-and-spoke arrangement of standard distribution SCADA. Figure 8 from the OpenFMB™ collaboration site illustrates in high level form the structural concept behind this approach. While it is not depicted in quite the same form as the Laminar Coordination Framework diagrams, it is possible to determine the mapping between these two structures.

Figure 8: OpenFMB™/DIP Structure

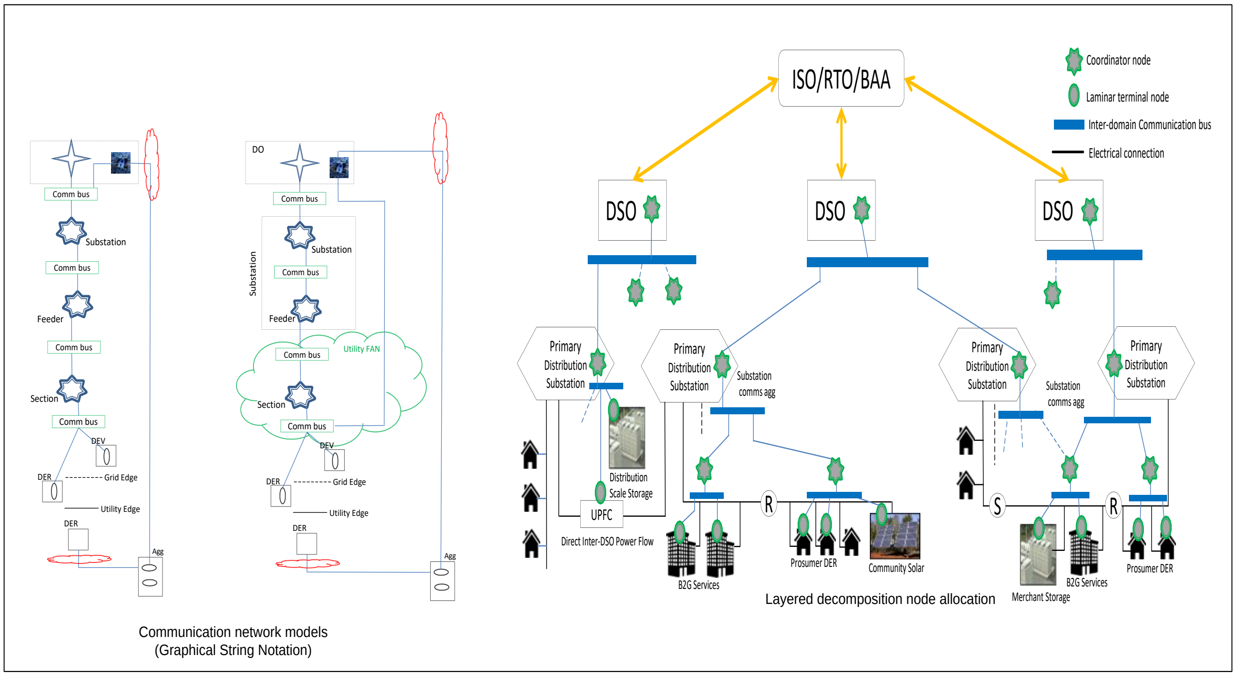


Such a mapping reveals that the model of the OpenFMB™ and its processing nodes are homologous with Laminar structure coordination domains and coordination nodes as shown in Figure 6 above. The Laminar structure provides an architectural context for the DIP nodes and OpenFMB™ itself. The OpenFMB™ /DIP architecture is a proper subset of the Laminar Coordination Framework.

Transactive Energy Systems

Transactive energy systems employ techniques for managing the generation, flow, and consumption of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints.[53] Transactive Energy systems can exist in several forms, but for electric distribution systems and DER, they are envisioned as distributed systems employing a network of transactive "nodes" and intelligent DER endpoints. Several demonstration projects have been built, each with its own design and underlying structure. Recent work has shown how to use the Laminar Coordination Framework as the architectural basis for highly distributed transactive energy systems.[54] Figure 9Figure 7 below illustrates the application of Laminar coordination to Transactive Energy Systems, including communication structure.

Figure 9: Laminar-Structured Transactive Energy System Architecture



The application of the Laminar Framework led to a flexible structure that informs both coordination/control and communication networks for distributed Transactive Energy Systems and provides insight into interoperability requirements, as well as how to include aggregators and ESOs into the coordination framework. In this case the proposed architecture for Transactive Energy Systems is precisely the Laminar Coordination Framework, by design.

Distribution System Operator

The concept of Distribution System Operators (DSOs, also known as Distribution Service Platforms or DSPs) has evolved out of two kinds of concerns: 1) the problem of managing high penetration DER for both bulk system and distribution operations while maintaining distribution reliability; and 2) the emerging problem of tier bypass (passing coordination from one layer to another while skipping a layer in between, leaving the skipped layer unaware of actions that impact its responsibilities) in grid systems due to the same cause. The former led to new models for the roles and responsibilities of distribution operators and system operators[55], while the latter led to new views about multi-scale grid coordination and control.[56] The two views have converged, based on separate paths to similar conclusions about the use of layered decomposition.[57] The Laminar Coordination Framework mode is now used for the industry structure component of emerging DSO models, wherein the relationship between distribution and bulk systems, between DSOs and system operators follows the Laminar framework both electrically, and in terms of coordination, dispatch, and control. The approach to DSO models described in the reference is explicitly the Laminar framework, as applied to industry structure. It connects with the use of Laminar structure for control and coordination at multiple scales.

Fractalgrid[58]/Agile Fractal Grid[59]

These are two closely related concepts for how to connect multiple microgrids into large more or less cellular systems. The term “fractal” is used to reflect multi-scale self-similarity although it might be more appropriately as multi-scale cellular automata with a degree of self-affinity. Nevertheless, each has some notion of multi-scale coordination, although in both cases it seems to be essentially ad hoc in nature, not based on a rigorous foundation. Both have concepts of peer-to-peer interaction and in the case of agile fractal grids, there is recognition of a need for multi-scale coordination. In the case of fractalgrid, there is at least one implementation that uses a two-level structure.[60] It is worth noting the similarity to Balancing Authority Areas at the bulk energy system level.

The agile fractal grid concept is described as follows:[61]

> *Agile control rests on the rapid and accurate collection and sharing of information at all levels of grid operation, and the integration of advanced analytics to manage the data and assess control options. The foundations are a communications network that you can trust (the Industrial internet), and a fractal architecture on which each fragment of the grid operates like a complete grid, using an information and control paradigm that can be shared with other fragments to allow coordinated operation, islanding, and reintegration.*

This implies both electrical structure and control/coordination structure. The “grid fragments” map to coordination domains in the Laminar model.

The following have been listed as fractal grid principles:[62]

1. All segments of the grid operate with the same information and control model – regardless of scale;
2. Every segment of the grid has a decision-making capability;
3. The means for exchange of peer-to-peer information are clearly defined in standards; and
4. The rules for when to divide and when to combine are clearly defined.

While the actual coordination and control structure for agile fractal grids is not detailed, it has been described as “multi-scale” in nature. Note that the Laminar Coordination Framework provides actual mechanisms for the four principles listed above where segments are coordination domains. In fact, one of the presentations on agile fractal grid makes use of a Laminar Coordination Framework diagram.[63]

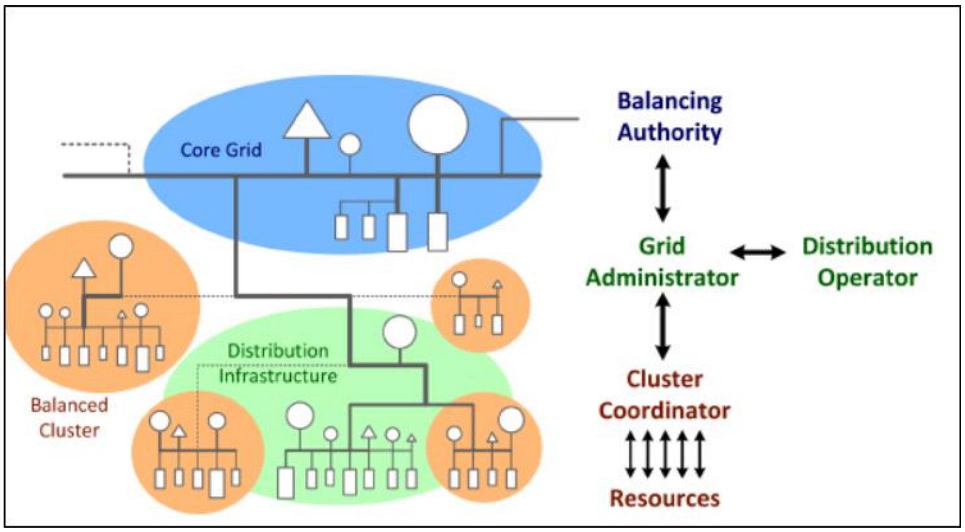
The Laminar Coordination structure could and should be adopted for this purpose in the agile fractal grid paradigm. This would address the apparent gap in how to define a rigorous control schema for such grids.

Grids with Intelligent Periphery (GRIP)

GRIP is a concept developed by researchers at the University of California, Berkeley, the California Institute of Technology, Washington State University, University of Florida, University of Hawaii, and CIEE.[64] It posits a grid structure that clusters resources, with clusters being managed by intelligent "cluster coordinators," while groups of clusters are managed by a "grid administrator" that interfaces with a system operator such as an ISO. Figure 10[65] below illustrates the hierarchical nature of the proposed structure. Clusters can be mapped to Laminar coordination domains and both cluster coordinators and grid administrators can be mapped to Laminar coordinator nodes at different hierarchical levels.

The description is also roughly consistent with the DSO concept and the extension of a coordination framework in a layered fashion down to the device level, but is ad hoc in form.

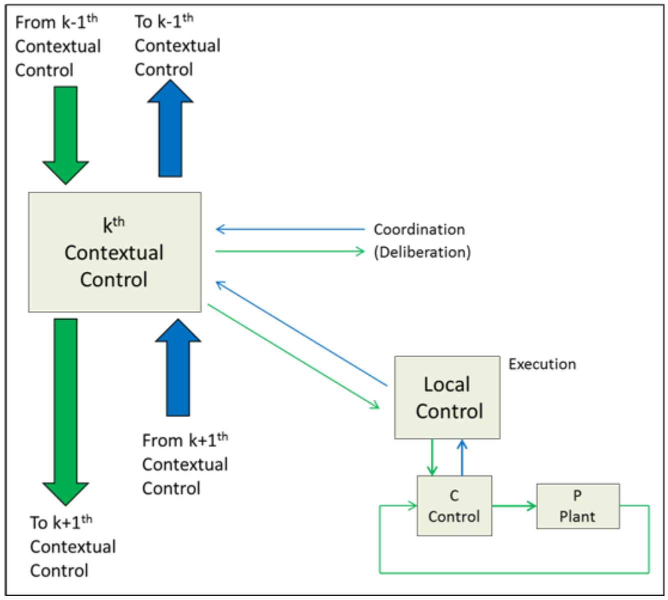
Figure 10: Basic Form for GRIP Architecture



Scalable and Flat Controls for Reliable Power Grid Operation

A multi-university group of researchers has suggested that grid control could be accomplished via a structure they refer to as "scalable and flat."[66] Figure 11 below shows the essential structure for control and coordination described in the cited reference.

Figure 11: "Scalable and Flat" Control Structure



This structure uses the concept of local control supervised by larger scale "contextual control" that selects from among system-level control goals. In this model, local controls map to Laminar coordination domains, and the contextual control chain maps to a chain of coordinator nodes. The approach is limited to two levels at each scale, so the structure has some constraints that are intended to keep the control "flat." These constraints do not exist in the Laminar approach since there is no intent to limit the depth of the layered decomposition.

The "scalable and flat" structure is a delimited version of the laminar structure that employs a supervisor/slave approach to two-level coordination but does not describe how interconnected contextual controls perform coordination. This architecture is only a partial match to the Laminar framework.

Analysis of grid architectures by mapping to Laminar Coordination Frameworks shows commonalities across several apparently disparate approaches including traditional centralized control, OpenFMB™, fractal grids, scalable and flat controls for grids, and DSO models. It also facilitates making conceptual connections between structures used at different levels in the grid (e.g., the connection between Balancing Authority Areas and fractal grids). The ability to perform this type of structural analysis is missing from approaches to compare grid architectures, such as SGAM.

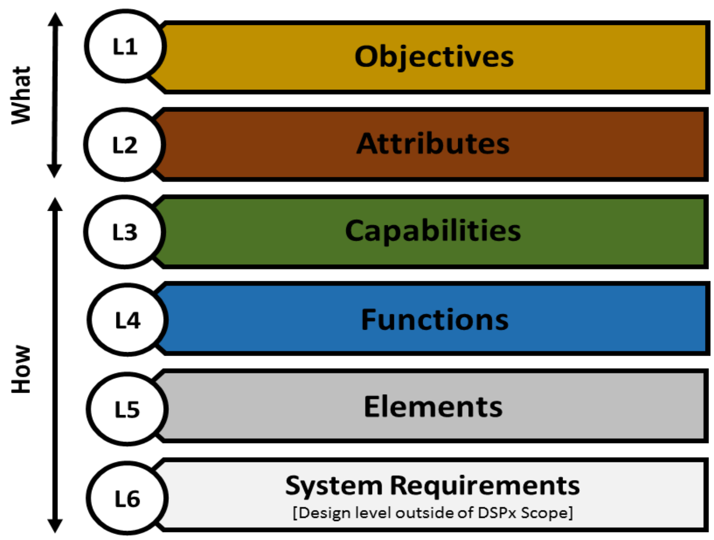
Comparative architecture analysis is important for grid modernization decision makers and stakeholders because architecture represents the earliest and highest level design decisions for complex systems and set the essential limits on what systems (in this case power grids) can and cannot do. Such analysis provides a means to understand what on the surface may appear to be very different approaches to grid modernization. Use of this method (possibly with the assistance of a grid architect) will help clarify decisions about grid investments related to control, coordination, communications, and DER interface.

2.2 METHODOLOGICAL FRAMEWORK

2.2.1. Analytic Taxonomy Framework

Developing a full grid architecture starts with enumeration of various drivers including emerging trends, systemic issues, and also including definitions of user needs and public policies. Such definitions must be not only collected but broken down into component parts and organized into a logical structure. Such a breakdown is not just useful for the architects; it is also useful for decision makers, in terms of clarifying the complex issues to be sorted out at various stages of the grid modernization process. Consistent with Grid Architecture principles and methods[67] above, a six-level taxonomy was employed to logically organize and align the identified objectives, attributes, capabilities, functions, and elements of a modern grid. This taxonomy framework seeks to provide a line of sight between what states are aiming to achieve (i.e., the key objectives and attributes of a modern grid), and how distribution system capabilities, business functions, and related elements can align to enable the full participation of DERs in the provision of electricity services. This analytical framework is illustrated below in Figure 12 with further explanation of the levels provided below.

Figure 12: Taxonomy Framework



<u>**Level 1 – Objectives**</u>: ***An objective is an envisioned or desired result or outcome.*** Broadly speaking, this level seeks to identify the key objectives of the distribution system based on state's current legislative or regulatory efforts to modernize its electric grid. Insights drawn from this evaluation help inform the key objectives guiding the subsequent levels. (e.g., *NY MDPT Report 8/2015: Enable DER integration*)

<u>**Level 2 – Attributes**</u>: ***An attribute is an inherent characteristic that may be referred to as a quality or property.*** In parallel to Level 1 efforts, attributes encompassing forward looking grid characteristics, features and qualities that enable grid modernization objectives are identified to further inform this effort. (e.g., *NY MDPT Report 8/2015: Adaptability; PNNL GA 2016: Resilient, Adaptable*)

<u>Level 3 – Capabilities</u>: *A capability is the ability to execute a specific course of action or set of qualities.* Capabilities are distilled from key industry documents to guide the functionality of the next generation distribution system. Each capability can be thought of as a broad "bucket", containing several underlying business functions and functional elements. (*e.g., PNNL GA 2016: Situational Awareness*)

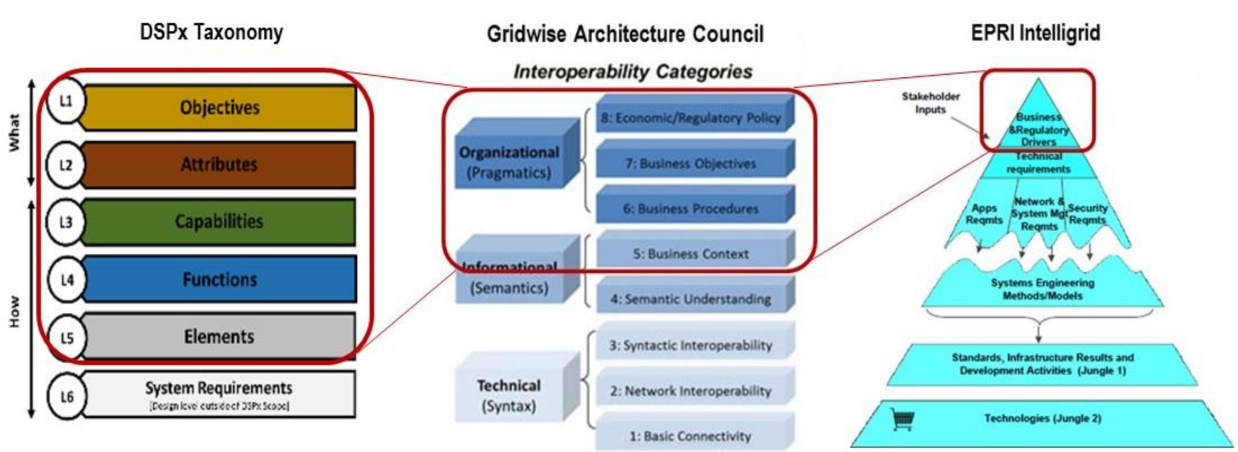
<u>Level 4 – Functions</u>: *A function defines a business process, behavior, or operational result of a process.* Functions include techniques and operations that can be used to achieve enhanced grid functionalities or enable advanced grid processes. These functionalities often work together to enable a capability. (e.g., *NY MDPT Report 8/2015: Monitoring and Observability; Coordination and Control)*

<u>Level 5 – Elements</u>: *An element is a set of activities that enable a business function.* Drilling down a further level, elements seek to further unpack the functions described in Level 4 and detail the types of activities and processes needed for innovative or advanced planning, grid and market operations. (e.g., *PNNL GA 2016: Monitor Grid State; Monitor Power Quality/Reliability*)

<u>Level 6 - System Requirements</u>: *Specific actions to be provided or performed by the system.* This level includes equipment design plans, technical considerations and specific requirements for the accommodation and incorporation of advanced grid infrastructure. System requirements falls outside of the DSPx scope. *(e.g., Prevent Islanding and Transformer Back-feeding, 30Hz Sampling Rate, IPv6 Support)*

This DSPx taxonomy should be considered a decomposition and articulation of the policy and business functions that have been identified in concept within earlier reference models, such as EPRI's Intelligrid[68] and the Gridwise Architecture Council's Interoperability Context-Setting Framework.[69] As noted in these models and companion documentation, the policy and business functions serve as the reference point for technology design considerations. Technology design and system requirements is Level 6 in the DSPx taxonomy which is more fully decomposed in the Intelligrid and GWAC models. The combination of the DSPx taxonomy and the GWAC and EPRI frameworks provides a complete systematic framework of a modern distribution grid. The figure below illustrates the interrelationship between these models.

Figure 13: Reference Models Interrelationships



2.3 SPONSORING REGULATORY COMMISSION SCENARIOS

The following list of issues was identified by the sponsoring regulatory commissions. These scenarios are drawn from input from the regulatory staff and are provided as additional context for architectural consideration and the grid capabilities and business functions and elements that follow. These issues are furthered developed into example applications of the modern grid framework to illustrate the potential use of Grid Architecture and the related taxonomy in practice as part of Volume III, "Decision Guide".

Integrated Distribution Planning

High levels of DER growth require proactive planning within an increasingly complex planning framework, to ensure infrastructure investments continue to serve customer needs. Integrated distribution system planning assesses both physical and operational changes to system necessary to continue providing safe, reliable, and cost-effective electricity delivery services to customers, while considering how DER growth and operations may continue to impact the system. Given the diversity of customer needs, distribution circuit configurations and technological advancements, planning becomes more cohesive and multidisciplinary with a wider and more complex range of engineering and economic valuation issues. Stakeholder participation and transparency into the planning process becomes increasingly important given additional assumptions into DER growth and valuation.

Situational Awareness

The analog-to-digital transformation of the distribution grid requires a much improved awareness of the current grid configuration, asset information and condition, power flows, and events to operate the distribution grid reliably, safely, and efficiently. This may include visibility of all steady-state grid conditions such as criteria violations, equipment failures, customer outages, and cybersecurity. DER situational awareness is also required to operate a grid with high DER and optimize DER services to achieve maximum public benefit.

Operational Communication Networks

The operational communication network that enables the transformation of grid modernization efforts is an important aspect that cuts across the entire industry and is a key component in any modern grid. As such, there should be a consideration of the various components of operational networks based on needed capabilities and functions. Operational communication networks will need to be reliable, efficient and resilient as systems become more automated. Questions arise on how the communication platform will evolve between distribution, transmission, wholesale, and distributed market participants including respective investments. This includes consideration of grid architectural factors discussed earlier and implementation approaches. Potential links to aging infrastructure replacement and DER adoption increases and patterns are examples.

Volt-var Management with Smart Inverters

New standards for advanced inverter functions to enable dynamic voltage and reactive power management are being developed and implemented in several states. While a national standard would ultimately benefit inverter rollouts, several states are ready to make decisions for the next phase. States like California and Hawaii plan to operationalize advanced functionalities for smart inverters by 2020. There is a need to understand the grid operational capabilities necessary to realize the benefits of these new smart inverter functions. Also, identification of considerations related to deployment of new grid systems in relation to existing and future smart inverters in relation to needs identified in system planning. This includes approaches to determine the best mix of traditional utility investments with DER to keep the system functioning smoothly.

DER Aggregation and Operational Coordination

DER aggregation of small resources is expanding at the wholesale markets as identified in FERC's recent energy storage ruling. For states, this may also suggest consideration of how smaller resources can aggregate and bid into the wholesale market, if allowed. For example, consideration of the function of this entity along with required interface/coordination with wholesale markets and distribution operations. This also includes consideration of aggregator participation in both wholesale and distribution markets. For context, DER aggregation is the establishment of both the business agreements and the technical means between an aggregator and the owners of DER that enable an aggregator to offer the combined operational capabilities of the aggregated resources to the wholesale market and/or distribution operator.

3. CAPABILITIES

OVERVIEW

A capability is the ability to execute a specified course of action or qualities as identified in the states' objectives and attributes above. Capabilities in this taxonomy provide a bridge from the policy objectives to the enabling set of platform technologies. The specific capabilities identified in this report were principally drawn from PNNL's 2015 Grid Architecture report, California's More Than Smart report based on stakeholder input, and direct feedback from the industry through DSPx initiative engagement.[70] Figure 14 highlights the 26 capabilities Chapter 3 defines to clearly identify the necessary capabilities to achieve states' policy objectives.

Figure 14: Capabilities

3.1 DISTRIBUTION SYSTEM PLANNING

3.1.1. Scalability

The capability of the distribution grid and related operational and market systems to increase capacity with additional resources rather than extensive modification or replacement of the cyber-physical systems, while delivering the same quality of service with no impact to performance, reliability, and interoperability.[71]

3.1.2. Impact Resistance and Resiliency

The ability to withstand environmental hazards or cyber-physical attacks over a period of time while maintaining a required expected level of service, which includes the ability to recover from disruptions and resume normal operations within an acceptable period of time.

3.1.3. Open and Interoperable

Enable active participation by customers, and accommodates all forms of DER, new services and markets. This is accomplished through transparent planning, operations, and market interactions that adhere to open standard architecture protocols when available, applicable and cost effective.[72]

3.1.4. Accommodate Tech Innovation

Facilitates the integration of new grid and DER types that enable net positive benefits for all customers, with due consideration to privacy and security concerns, and provide access to system, customer and third-party data (as needed) to animate market innovation.[73]

3.1.5. Convergence with Other Critical Infrastructures

Integration with other networks such as natural gas, telecommunications, water and transportation to create a more efficient and resilient infrastructure, as may be reflected in certain microgrids, while supporting economic and environmental policy objectives to achieve societal benefits including applications associated with Smart Cities.[74]

3.1.6. Accommodate New Business Models

Enables integration of new products and services that may provide additional value beyond traditional electric energy and delivery. This includes non-energy adjacent services providers seeking to create convergent value across critical infrastructure networks as in smart city initiatives, for example.[75]

3.1.7. Transparency

Timely and consistent access to relevant information by market actors, as well as public visibility into planning, market design and operational performance without putting sensitive information at risk.

3.2 DISTRIBUTION GRID OPERATIONS

3.2.1. Operational Risk Management

Operational Risk Management (ORM) examines core operations including energy delivery and reliability as well as DER-provided operational services performance and related distributed platform systems. It encompasses current and future risks and mitigation strategies to manage tangible operational risks related to environmental factors, human interaction (including errors and public safety) and equipment/system failures. Operational risks may also include complex system risks:

- Randomness (aleatory) risk, associated with stochastic variations inherent in the cyber-physical electric system;
- Knowledge (epistemic) risk, related to a lack of knowledge (known-unknowns) about characteristics of an electric network and connected devices;
- Interaction risk, created by the interaction between customers, distributed energy resources, markets and elements of the electric network; and
- Black Swan (ontological) risk, pertaining to low probability-high impact or unknown-unknowns events occurring. [76]

3.2.2. Situational Awareness

Situational awareness involves operational visibility into physical variables, events and forecasting for all grid conditions that may need to be addressed, normal operation states, criteria violations, equipment failures, customer outages, and cybersecurity events.[77]

3.2.3. Controllability and Dynamic Stability

Controllability describes the ability of an external input (the vector of control variables) to move the internal state of a system from any initial state to any other final state in a finite time interval. For the grid, this means the ability to make the grid behave as desired within the bounds of grid capability.

Dynamic stability is the property of a system by which it returns to an equilibrium state after a small perturbation. For the grid, this means the ability to tolerate and compensate for small disturbances to maintain proper settings of quantities like voltage and power flow. Disturbances would include such things as solar PV power fluctuations due to cloud cover variation, but there are many other possible sources of disturbances, including faults and fluctuating loads. For distribution, the results may differ from bulk systems (local reliability issues instead of cascading failures, for example), but the basic principle of stability is the same.

3.2.4. Management of DER and Load Stochasticity

Management of DER and load stochasticity is the ability to assess and respond to changes minimal cost and emissions impacts, while maintaining reliability.[78]

3.2.5. Contingency Analysis

Contingency analysis involves understanding and mitigating potential failures in a distribution network. Contingency analysis for distribution involves, for example, assessing potential impacts due to changes in system power flows due to real-time variations in net load resulting from DER operation and/or changes in gross load. It also includes assessment of potential impacts due to distribution component reliability and faults in specific system configurations. Contingency analysis involves two basic steps: contingency selection and contingency evaluation. [79]

3.2.6. Security

Physical and cybersecurity measures include activities that detect and respond to man-made and environmental threats, and mitigate risks. These risks include cyber-attacks, storms, fire, earthquakes, terrorism, vandalism, and numerous other physical threats. This also includes consideration of operations and the reflexive impacts of physical threats on the cyber domain, and cyber threats on the physical domain such as attacks and disruptions to critical communication channels, or compromise of compute or data integrity. This also recognizes the increasing interdependencies between physical and secure information and communication systems.[80]

3.2.7. Public and Workforce Safety

The design, construction, operation and maintenance for the distribution system, including facilities that do not belong to electric utilities, will ensure adequate service, and secure safety to workers and the general public.[81]

3.2.8. Fail Safe Modes

A fail safe device/system is expected to fail at some point and when it does it will fail in a safe manner or be placed into a safe state. Also, a fail-safe device/system may also define what occurs when a user error or loss of communications causes it to behave in an undesired manner, including notifications.

3.2.9. Attack Resistance / Fault Tolerance / Self-Healing

This property is the ability of a system to tolerate asset or function loss, through failure or attack, and act to maintain best available service despite degradation. It can enable the system to maintain its reliability and resiliency, ensuring its robustness. It can add to the security of the system and safety of the distribution grid.[82] It may also include device level control limiters that prevent a device from being commanded into out-of-band operation.

3.2.10. Reliability and Resiliency Management

Reliability and resiliency management provides adequate, efficient, safe and reasonable service and facilities, and makes repairs, changes, and improvements in or to the service and facilities necessary or proper for the accommodation, convenience and safety of its customers, employees and the public. The service will be reasonably continuous and without unreasonable interruptions or delay. Grid operator will strive to prevent interruptions of electric service and, when interruptions occur, restore service within the shortest reasonable time. Effective reliability and resiliency management includes procedures and systems to achieve the reliability performance benchmarks and minimum performance standards established by applicable authorities.[83]

3.2.11. Integrated Grid Coordination

Integrated grid coordination is focused on the physical coordination of real and reactive power flows across the transmission/distribution system interface where the coordination is between the distribution operator and the Balancing Authority (a utility Transmission System Operator (TSO) or an Independent System Operator (ISO)/Regional Transmission Operator (RTO)).[84, 85]

3.2.12. Control Federation and Control Disaggregation

Control Federation is the ability to combine and resolve multiple competing and possibly conflicting control objectives. The problem arises when more than one control process wants to make use of a particular grid resource or asset.

Control Disaggregation is the ability to decompose broad control commands into forms suitable for local consumption and decision making while accounting for local constraints. This ability enables the mix of centralized and distributed control to achieve local optimization within global coordination.[86]

3.2.13. Privacy and Confidentiality

Privacy and confidentiality allows users to maintain control over the collection, use, reuse and sharing of personal and commercial information as relates to electricity consumption, generation, storage, and/or market activity. At the same time, this includes protection against issues such as identity theft, determination of personal behavior patterns, determination of specific appliance usage and real-time surveillance. These privacy measures in turn enhance and ensure the confidentiality of customer, commercial and market information.[87]

3.3 DISTRIBUTION MARKET OPERATIONS

3.3.1. Distribution Investment Optimization

Identification and sourcing of a mix of grid infrastructure and technology assets and DER provided services to enable efficient investment and operational expenditures for a safe, reliable distribution grid addressing needs identified in distribution planning. Investment optimization includes the concept of solving multiple problems with the same investment, such as DER, to simultaneously improve reliability and capacity.

3.3.2. Distribution Asset Optimization

This is the operational utilization of physical grid assets and DER-provided services to manage distribution operations in a safe, reliable, secure and efficient manner through dynamic optimization.

3.3.3. Market Animation

Market animation involves establishing transparent distribution operational markets to enable viable market development for grid services (see Appendix B) with deep participation, to achieve a more efficient and secure electric system including better utilization of distribution system, as well as transmission system and bulk generation.[88]

3.3.4. System Performance

System performance is defined in terms of cost, quality of service, and applicable environmental and societal parameters through optimization of a portfolio of grid and DER-provided services, between the distribution and bulk power systems, and across various timescales.[89]

3.3.5. Environmental Management

Environment management involves the use and optimization of DER resources along with centralized clean resources to meet federal, state and local environmental targets.[90]

3.3.6. Local Optimization

Local optimization is the use of DER and integrated grid assets and related platform technologies to economically locate, place, manage and operate a distribution system to meet local performance requirements including least-cost service, reliability and power quality.[91] This optimization may include an assessment of the impacts of local actions on the overall system, and vice-versa.

3.4 OBJECTIVES AND ATTRIBUTES TO CAPABILITIES MAPPING

The purpose of the matrix shown below is to highlight the key relationships involving capabilities and (possibly) multiple objectives and attributes. It is these types of capability-to-objectives/attribute relationships that allow identification of potential priority and foundational areas for grid modernization in the context of other factors such as timing and affordability.

Figure 15: Attributes to Capabilities Mapping

		OBJECTIVES								ATTRIBUTES					
		Reliability	System Efficiency	Affordability	Customer Enablement	Enable DER Integration	Adopt Clean Technologies	Operational Market Animation	Reduce Carbon Emissions	Operational Excellence	Flexibility	Resiliency	Cyber-Physical Security	Transparency	Safety
3.1.4	Accommodate Tech Innovation	●	●	●	●	●	●	●	●	●	●	●	●		●
3.2.2	Situational Awareness	●	●	●				●		●	●	●	●	●	●
3.3.3	Market Animation	●	●	●	●	●	●	●	●			●	●		●
3.1.3	Open and Interoperable	●	●	●	●	●	●	●		●				●	
3.1.1	Scalability	●	●	●	●	●	●			●	●	●			
3.2.1	Operational Risk Management	●	●	●						●	●	●	●	●	●
3.1.7	Transparency	●	●	●	●	●	●	●	●				●		●
3.1.6	Accommodate New Business Models			●	●	●	●	●	●	●			●		●
3.2.4	Management of DER and Load Stochasticity	●	●	●		●			●	●	●			●	
3.3.1	Distribution Investment Optimization	●		●		●	●			●		●		●	
3.2.9	Attack Resistance / Fault Tolerance / Self-Healing	●	●	●						●	●	●		●	
3.3.2	Distribution Asset Optimization	●	●	●				●	●	●	●				
3.2.11	Integrated Grid Coordination	●	●	●				●		●	●		●		●
3.1.5	Convergence with other Critical Infrastructure	●	●	●	●					●	●			●	
3.2.10	Reliability and Resiliency Management	●	●	●		●				●	●		●		●
3.3.6	Local Optimization	●	●	●		●				●	●				
3.2.5	Contingency Analysis	●	●							●	●	●		●	
3.2.8	Fail Safe Modes	●	●	●							●	●		●	
3.2.12	Control Federation and Control Disaggregation	●	●					●		●	●				
3.2.13	Privacy and Confidentiality				●	●		●			●	●	●		●
3.2.3	Controllability and Dynamic Stability	●	●						●		●			●	
3.2.7	Public and Workforce Safety	●				●				●	●	●		●	
3.3.5	Environmental Management				●		●	●	●						
3.2.6	Security	●				●					●	●		●	
3.1.2	Impact Resistance and Resiliency	●									●	●		●	
3.3.4	System Performance	●	●	●									●		●

4. REFERENCE BUSINESS FUNCTIONS

OVERVIEW

A function defines a process, behavior, or operational result of a process to enable a capability linked to one or more policy objectives and grid attributes. Similar to the capabilities in Chapter 3, these functions are also organized into three groups: Distribution System Planning, Distribution Grid Operations and Distribution Market Operations. The functional descriptions that follow for each function are drawn from existing regulatory, standards, or industry references. The intent is to harmonize the definitions and descriptions for the purpose of clearly identifying the necessary functions to achieve one or more respective capabilities. While these functions are representative of a larger assessment of the grid modernization roadmaps of the states mentioned in Chapter 2, these items may also guide and influence the policy objectives of other states as well.

Figure 16: Modern Grid Business Functions

4.1 DISTRIBUTION SYSTEM PLANNING

4.1.1. Distribution System Planning

Distribution planning involves three general efforts: 1) forecast scenario-based studies of distribution grid impacts based on power flow analysis to identify grid needs 2) a comparison of solution assessments including potential operational changes to system configuration, needed infrastructure replacement, upgrades and modernization investments, and 3) identification of potential benefits and costs for non-wires alternatives, or grid services.[92]

4.1.2. Growth Forecasts for DER and Demand

Planners forecast demand growth for various customers, class types, transformers, line sections, circuits, banks, transferrable loads and other granular forecast groupings, based on historical seasonal, monthly, daily, hourly, and sub-hourly load data. The forecasts may reflect micro/local hourly weather, regional economics and local spatial influence, expected spot load additions, forecasted DER adoption, and the stochastic covariance between these factors due to weather, the economy or other factors. DER forecasting at specific locational and temporal levels of granularity will depend on parameters such as DER type cost-effectiveness, DER provider offerings, utility program offerings, non-price consumer preferences, third party market development plans, rate designs, government incentives and economic factors.[93]

4.1.3. DER Locational Value Analysis

DER have the potential to provide incremental value for all customers through improving system efficiency, capital deferral and supporting wholesale and distribution operations. However, the value of DER on the distribution system is generally locational and temporal in nature—that is, the value may be associated with a distribution substation, an individual feeder, a section of a feeder, or a combination of these components and for a given time period. The distribution system planning analyses, described above identify incremental infrastructure or operational requirements (grid needs) and related potential infrastructure investments. The avoided cost of these investments form the potential value that may be met by sourcing services from qualified DERs, as well as optimizing the location and timing of DER adoption on the distribution system to eliminate impacts and achieve least cost outcomes. The objective is to achieve a net positive value (net of incremental platform costs to source DER) for all grid customers while providing reliable service.[94]

4.1.4. Integrated Resource Transmission and Distribution Planning

At high levels of DER adoption, the net load characteristics on the distribution system can have material impacts on the transmission system and bulk power system operation. For vertically-integrated states, such as Minnesota, it is important to coordinate changes to distribution planning with integrated resource and transmission planning.[95] To the extent DER is considered in resource and transmission planning, it is essential to align those DER growth patterns, timing and net load shape assumptions and plans with those used for distribution planning. Further, to the extent distribution-connected DER provides wholesale energy services, it is necessary to consider the deliverability of that DER across the distribution system to the wholesale transaction point. If a state is experiencing, or anticipates, strong DER growth it is prudent to consider alignment of the recurring cyclical planning processes for resources, transmission and distribution, so that an integrated view of system needs is effectively conducted.[96]

4.1.5. Integrated Operational Engineering and System Operations

Operational engineering analyses involve assessments of planned maintenance outages, system reconfigurations and other changes to the distribution system and related operations. Some of these analyses are performed in the short term near to the day of operation as well as during service restoration, particularly in major outages. These distribution level analyses will need to incorporate DER availability and coordination with the respective transmission operational engineering.[97]

4.1.6. Multiple Forecast Scenario-based Planning

As DER adoption grows, the distribution system will increasingly exhibit variability of loading, DER performance, voltage and other power characteristics that affect the reliability and quality of power delivery. As such, the uncertainty of the types, amount and pace of DER expansion make singular deterministic forecasts ineffective for long-term distribution investment planning. Multiple DER forecast scenarios reflecting potential changes in DER and loads (see 4.1.2) and use cases to assess current system capabilities needed to identify incremental infrastructure requirements and enable analysis of the locational value of DERs. [98]

4.1.7. Interconnection Process

Provide a non-discriminatory, transparent and timely evaluation of an interconnection request from a DER provider to determine the ability to safely and reliably integrate a new DER system into the grid. Establish a clear process and system interconnection rules, online application portals and analytics tools could streamline the interconnection process. Integrate of the interconnection process into planning and operations.[99]

4.1.8. Distribution System Information Sharing

Share distribution system data that supports intended use cases for DER integration with mutual sharing between customers, third parties and utilities, complying with privacy and confidentially requirements, to promote customer choice and integration of DERs into planning and operations. This includes appropriate access to historical system and forecast planning data (e.g., load profiles, peak-demand, hosting capacity, beneficial DER locations, interconnection queue, voltage and thermal limits) in standardized formats.

4.1.9. Telecommunications

Telecommunications will be comprised of utility and services providers' systems employing various private and public infrastructure evolving, as needed, into a ubiquitous, robust network that increasingly connects distribution intelligent devices, DER, customers, and third parties over formalized communication protocols across the network.[100] Telecommunications may involve wide area networks (WAN), local area networks (LAN) and neighborhood area networks (NAN) that are public common carrier, private enterprise or private operational in terms of service level quality and security.

4.1.10. Customer Information Access

Provide customer access to their energy use data, and by customer-designated entities, complying with privacy and confidentiality requirements and utilizing standard data formats and data exchange protocols. This may include appropriate access to historical and real-time energy consumption, billing related information, and service quality data collected by retail energy services provider and/or distribution services provider.

4.1.11. Analytics

Analytics span decision support and operational algorithms for long-term planning and short-term operations and market applications. This includes centralized and decentralized software systems and platforms that utilize grid data and/or external data to provide an understanding of the dynamic value of various investment and operational options.[101]

4.1.12. DER Development and Market Participant Information Access

Provide access to DER developer and market participant information, complying with privacy and confidentiality requirements and utilizing standard data formats and data exchange protocols, needed to support planning, operations and market animation.

4.2 DISTRIBUTION GRID OPERATIONS

4.2.1. Observability

Observability is the function related to operational visibility of the distribution grid and integrated DER. Sufficient sensing and data collection can help to assemble an adequate view of system behavior for control and grid management purposes, thus providing snapshots of grid state. The data can also be utilized to validate planning models. Measurement refers to the ability to record and monitor grid parameters such as three-phase voltage, current, phase angle, and power factor as well as DER output and performance.[102]

4.2.2. Distribution Grid Controls

Coordination and control at the distribution level refers to the signaling and mobilization of distribution physical assets and DER providing grid services (directly or through an aggregator), as applicable by the system operator to meet system operational and reliability goals on a dynamic basis. Controls will include operations to coordinate and control both conventional equipment and DERs to optimize distribution system performance, and maximizing DER benefits, while avoiding adverse impacts. The system's control of elements on the distribution system will evolve as the integration of DERs increases, and will be affected via changes to market rules, economic signals, and technological advancements at the system, subsystem and device levels.[103]

4.2.3. Asset Optimization

Asset optimization refers to analytical functionality integrated with decision support systems and/or operational controls to optimize the performance of grid reliability, efficiency, hosting capacity, as well as related work and resource management.[104]

4.2.4. Integrated Operational Engineering and System Operations

Operational engineering analyses involve assessments of the impacts of planned maintenance outages, system reconfigurations and other changes to the distribution system and related operations for planned and unplanned work. These analyses are performed in the short term near to the day of operation as well as during service restoration, particularly in major outages. These distribution level analyses and forecasting capabilities will need to incorporate DER capabilities, availability, weather impacts and coordination with the respective operational engineering.[105]

4.2.5. Distribution System Model

A distribution system model is a representation of the physical distribution system infrastructure (including the characteristics of system components and system topology) and adapts to the system state/configuration; it is usually contained in a software system. It may also be referred to as a distribution connectivity or network model.[106]

4.2.6. T-D Interface Coordination

This function ensures reliability and assurance to the balancing authorities of the operational services of dispatched DERs, by efficiently coordinating, scheduling and managing DERs in real-time, including prioritization rules. T-D interface coordination functions are carried out to avoid detrimental effects on local distribution systems and regional transmission systems by coordinating power flows between the transmission operator and DSOs due to DER dispatch.[107]

4.2.7. Steady-State Volt-Var Management

The DSO manages steady-state voltage (generally >60 sec), including voltage limit violation relief, reduced voltage variability, compensating reactive power.[108] If the voltage is maintained within ANSI C84.1 Range A., no changes to voltage are required.

4.2.8. Power Quality Management

Power quality management is the process of ensuring proper power form, including mitigating voltage transients and waveform distortions, such as voltage sags, surges, and harmonic distortion as well as momentary outages. [109]

4.2.9. DER Operational Control

DER operational control is the real-time direct or indirect control or coordination of DERs through pricing and/or engineering signals, in order to optimize network operations and to maintain the reliability of the system.[110]

4.2.10. Cybersecurity

Cybersecurity is the protection of computer systems from theft or damage to the hardware, software or the information on them, as well as from disruption or misdirection of the services they provide. It includes controlling physical access to the hardware, as well as protecting against harm that may come via network access, data and code injection, and due to malpractice by operators, whether intentional, accidental, or due to deviation from secure procedures. [111,112]

4.2.11. Physical Security

Physical security is associated with technologies that detect threats, breach, unauthorized access, or physical incursion (that may or may not result in damage) and communicate that detection to authorized monitoring systems and personnel. In addition physical security pertains to technologies that improve the security posture of generation, transmission, and distribution components as well as the monitoring, communication, and computation hardware that constitute grid control systems.[113]

4.2.12. Information Technology

Information Technology (IT) refers to the data management and data processing and storage technologies, equipment and systems that are used in support of both business enterprise functions and grid operations.

4.2.13. Reliability Management

Reliability management involves a number of processes and systems that enable distribution operators to discover, locate and resolve power outages in an informed, orderly, efficient, and timely manner. Related systems work in concert to automate the process of mitigating the scope of outages and in power restoration, reducing both the impact and length of power interruptions. Worker crews and operators are informed of outages by means of field devices such as SCADA systems and smart meters. Additional information is also obtained via customer input through phone calls, text messages, social media and emails. [114]

4.2.14. Operational Forecasting

Operational forecasting uses a combination of measure data and analytics to develop short term (minutes, hours, days) projections of loads and resources for operational scheduling, management, and optimization purposes.

4.3 DISTRIBUTION MARKET OPERATIONS

4.3.1. Market Settlement

The guidelines that govern the settlement of market contractual, program, or tariff obligations by an enhanced distribution platform, requiring comparison of actual performance to commitment in terms of quantity, quality, timing, tracking and reconciling discrepancies, managing disputes and escalations. The settlement process includes calculating credits and charges for DER services and other market activity.[115]

4.3.2. DER Aggregation to Distribution and/or Wholesale Market

Assembling a portfolio of DERs, including individual customer response, for the purpose of enabling those smaller resources to participate in distribution and/or wholesale markets for which each individual DER might be ineligible, or for which the costs or complexity of participation would make it infeasible for an individual DER.[116]

4.3.3. DER Sourcing

Distribution operational markets[117,118] would enable DER to provide services as an alternative to certain utility distribution capital investments and/or operational expense. The potential types of services may include distribution capacity deferral, voltage and power quality management, reliability and resiliency, and distribution line loss reduction. The distribution grid operator is the buyer of these services. The distribution planning process defines the need for these grid operational services.

The services provided by DER providers and customers may be sourced through a combination of three general types of mechanisms:

- Prices – DER response through time-varying rates, tariffs market-based prices or cost-based distribution marginal values
- Programs – DER services developed through programs operated by the utility or third parties with funding by utility customers through retail rates, incentives, locational vendor bounties, or other means by the state
- Procurements – DER services sourced through competitive procurements such as requests for proposals/offers, auctions, etc.

4.3.4. DER Portfolio Management

DER portfolio management consists of managing a mix of DER sourced through various mechanisms involving prices, programs and procurements, as well as grid infrastructure investments. This involves optimizing the utilization of these resources to achieve desired performance in terms of response time and duration, load profile impacts, market requirements and value (net of the costs to integrate DERs into grid operations).[119]

4.3.5. Market Information Sharing

This function encompasses the communication and exchange of market information between the ISO, distribution system, and participating DER, including information on distribution area net demand, net interchanged supply, DER services scheduled by the distribution system, DER forecasts, aggregate output of DERs, and DER services that may be offered to the ISO for wholesale market participation. Due consideration is typically given to regulatory constraints that may be imposed for competitive reasons, particularly if the operator of the enhanced distribution system is involved in other market functions (e.g., retail supply).[120]

4.3.6. Market Oversight

The market oversight process includes functions to monitor distribution market activity and assess potential market manipulation, ensure market security, legitimacy and performance. This function also includes the related market rules market participant rules in terms of the responsibilities and associated requirements. Appropriate compliance mechanisms will collect and transmit data needed for independent market monitoring and controls as required by regulation, where applicable.[121]

4.4 CAPABILITIES TO FUNCTIONS MAPPING

Figures 23 – 25 in Appendix A map the functions described above to the capabilities identified in Chapter 3 in terms of support relationships. These matrices highlight the key relationships between functions and multiple capabilities. This function-to-capability mapping aids the identification of potential foundational and no-regrets types of investments in related technologies.

5. REFERENCE FUNCTIONAL ELEMENTS

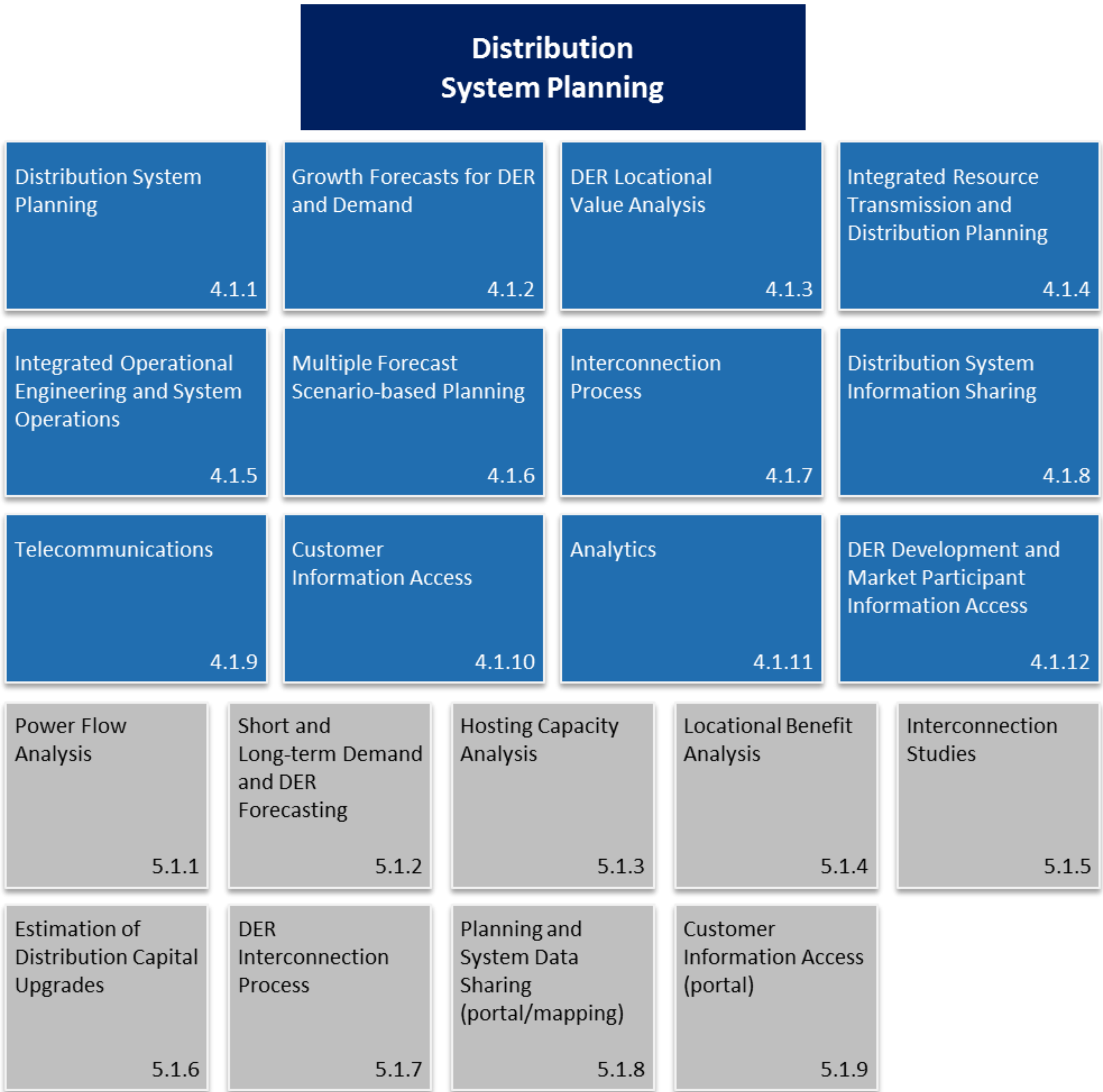
OVERVIEW

An element is a set of activities that enables one or more functions and in turn enables a capability linked to one or more policy objectives and grid attributes. As in Chapters 3 and 4, the functional elements in Chapter 5 are organized by Distribution System Planning, Distribution Grid Operations and Distribution Market Operations. The descriptions that follow for each element are drawn from existing regulatory or industry references or standards. The intent is to harmonize the definitions and descriptions for the purpose of clearly identifying the necessary elements to achieve one or more respective functions.

Furthermore, the definitions for the elements have a "functional" and an "operational" component. The "functional description" provides an account of the desired or prescribed functionality of the element. The "operational description" provides an overview of the operational considerations, characteristics and features that can enable the element.

5.1 DISTRIBUTION SYSTEM PLANNING

Figure 17: Distribution System Planning Elements



5.1.1. Power Flow Analysis

Functional Description:

A power flow study is an analysis that seeks to determine the voltages, currents, real and reactive power flows and power quality characteristics in a system under given load and operating (e.g. normal and contingency) conditions. Although the analysis can be done at a point in time, future load flow analysis will require dynamic time series analysis to fully understand the impacts of DER, voltage control, var control, demand response, etc.

Operational Description:

Power flow into and out of each of the nodes is the sum of the power flows of all of the lines connected to that node. The load flow problem consists of calculating the set of voltages - magnitude and angle - along the circuit that result from the assignment of loads at each node. To carry out such an analysis, the power system is viewed as collection of nodes, connected together by line segment of specified impedance. At each of the nodes, DER equipment may be connected which will supply or remove power from the system.[122]

5.1.2. Short and Long-term Demand and DER Forecasting

Functional Description:

Net electricity consumption is forecasted for a distribution circuit (or more granular) based on the forecast gross load, subtracting out demand-side DER growth and performance (including energy efficiency) and expected supply-side DER growth and performance. Forecast periods range from two years (short-term) to 10 years or longer (long-term).

Operational Description:

Demand growth is forecasted for various customer classes, circuits and regions based on historical hourly daily, monthly, and seasonal load data; the forecasts may reflect weather, economics, human behavior and other factors. DER forecasts at a granular level will depend on parameters such as DER type cost-effectiveness, DER provider offerings and market development plans, rate designs, government incentives and economic factors.

The effect of DER on peak load reduction is assessed on the system as well as on a circuit by circuit basis. DER contribution to peak demand reduction can be measured using factors such as contingency design of the system, type and size of DER, coincidence with peak load, and total number of DER in the circuit.[123]

5.1.3. Hosting Capacity Analysis

Functional Description:

Hosting capacity is defined as the amount of DER that can be accommodated without adversely impacting power quality or reliability under existing control and protection systems and without requiring infrastructure upgrades.

Operational Description:

In order for DER to be accommodated on the distribution system, it is necessary to assess the capability of distribution systems to "host" DER. Hosting capacity assessments can consider a wide range of grid impact factors, including voltage/flicker, protection, thermal impacts, as well as safety, reliability and power quality, among others. Hosting capacity methodology may be used to 1) provide indicative information to guide DER development, 2) as a baseline to assess distribution capability to support DER growth, and 3) as part of interconnection analysis to fast-track requests. A distribution system's hosting capacity and that of its components will change over time as load, DER and circuit configurations change.[124]

5.1.4. Locational Benefit Analysis

Functional Description:

Location benefit analysis is the analysis performed to specify net benefits that DERs may provide at any given location on the distribution system.

Operational Description:

The objective of locational benefit analysis is to identify potential net positive benefit of DER at specific locations and for a given time period on a distribution system. These net benefits may include avoided/deferred grid capital investments and operational expenses as well as certain societal benefits. DER impacts can be either beneficial or adverse, depending on a wide variety of contextual circumstances. Benefits and costs of DERs need to be characterized at the local and bulk power system levels to estimate their full value.[125]

5.1.5. Interconnection Studies

Functional Description:

Interconnection studies refer to the engineering analyses that need to be carried out in order to assess the engineering and operational impacts of specific DER connection to a distribution grid. Interconnection refers to the technical aspects and equipment required to connect generators, energy storage or other resources to the distribution system.

Operational Description:

Feasibility and system impact studies of an interconnection application assess potential grid impacts that would result if the proposed distributed generation were interconnected without DER modifications or distribution system modifications, based on adverse system impacts identified in the feasibility study. System impact studies may include the following individual studies:

- Analysis of equipment interrupting ratings;
- Distribution load flow study;
- Flicker study;
- Grounding review;

- Dynamic time-series distribution load flow study;
- Power quality study;
- Protection and coordination study;
- Short circuit analysis;
- Stability analysis;
- Steady state performance; and
- Voltage drop study. [126]

5.1.6. Estimation of Distribution Capital Upgrades

Functional Description:

Distribution capital investments are identified and costs estimated to accommodate customer net load growth, grid reliability and safety, interconnected resources, and customer service connections.

Operational Description:

Distribution capital upgrades are identified to address grid needs determined in the short and long-term planning process. These potential infrastructure upgrades are defined into specific projects with estimated engineering, equipment and construction costs. These estimates are incorporated in budget forecasts, rate cases and used as basis for avoided cost in a locational benefits analysis.[127]

5.1.7. DER Interconnection Process

Functional Description:

The DER interconnection process consists of rules and requirements that govern the connection and operation of DER within an electric grid.

Operational Description:

There are five major steps in interconnecting DER to the distribution grid: application, interconnection studies, construction, inspection and permission to operate.[128]

5.1.8. Planning and System Data Sharing (portal/mapping)

Functional Description:

This element includes sharing planning and system data that supports intended use cases for DER integration with mutual sharing between third parties and utilities to promote customer choice and integration of DERs into planning and operations. Access is recommended to maintain appropriate levels of protection on customer privacy and confidential information (e.g., market-sensitive, proprietary, intellectual property, physical, cyber or security sensitive).

Operational Description:

Functions of the data sharing portal will include:

- The ability to share granular distribution level data for each load area including DER development and market participant data;
- Network level maps of hosting capacity determinations, and locations where interconnections can be made with little to no additional cost;
- Sharing of base level of data available at no cost;
- Usage of security measures and data protection protocols to address security concerns; and
- Sharing of refined or atypical data services that the utility can perform beyond the base level that may be the subject of fees.[129]

5.1.9. Customer Information Access (portal)

Functional Description:

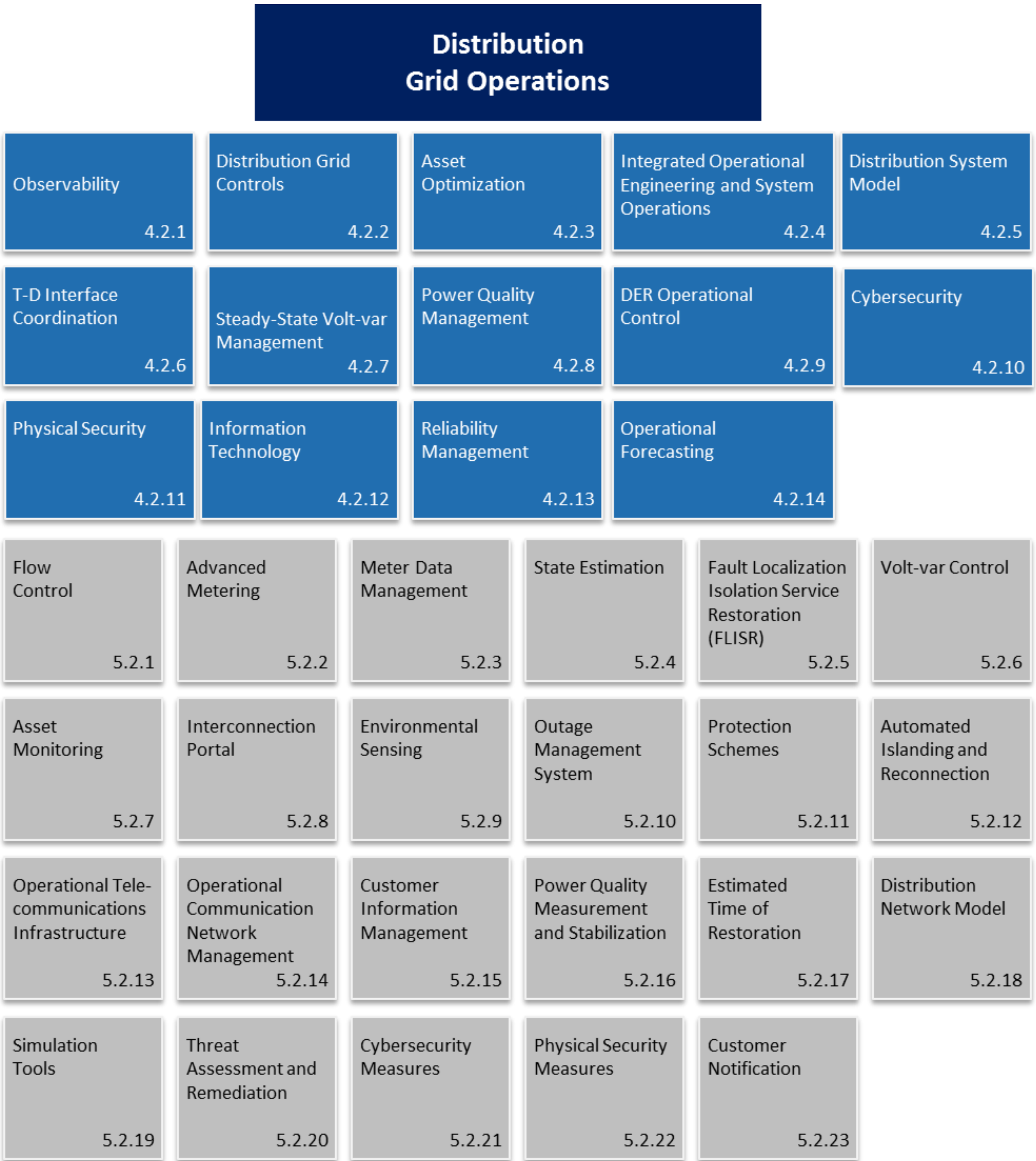
Customer information access refers to access to energy use data by customers and customer-designated entities, in compliance with privacy and confidentiality requirements. This may include appropriate access to historical and real-time energy consumption, billing related information, and service quality data collected by the retail energy services provider and/or distribution services provider.

Operational Description:

Customer energy information is accessed through a secure automated portal that maintains customers' security. Requires applications to gain authorization from consumers using authorization standards. While such authorization can be obtained in several ways, a typical method requires the consumer to provide authorization using a webpage. This results in the application gaining access to the consumer's energy data without the consumer having to provide the user id and password they use to access their energy provider's website. Once this authorization is granted, the application is able to automatically retrieve the consumer's energy data without any further involvement of the consumer.[130]

5.2 DISTRIBUTION GRID OPERATIONS

Figure 18: Grid Operations Elements



5.2.1. Flow Control

Functional Description:

Flow control is a management mechanism that can adjust the flow of real and/or reactive power in a continuous way or with enhanced granularity within a distribution system and potentially across a transmission-distribution interface.

Operational Description:

Power flow controller systems and automated switching are flexible and capable of addressing dynamic flow mitigation or redirection of power to adjacent circuits as operational requirements and markets may dictate during periods of high congestion.

Extensive deployment of power flow controllers and/or automated switching can directly alleviate circuit congestion, increase asset utilization, and optimize generator dispatch for cost savings. Additionally, power flow control enhances grid flexibility, which will be able to support increased penetration of variable distributed resources and improve distribution system resiliency.[131]

5.2.2. Advanced Metering

Functional Description:

Advanced metering consists of technologies that may measure and communicate energy use or production, power characteristics, operational events and notifications at time intervals sufficiently granular to support customer, market participant, and grid and market operations. Advanced metering may include other capabilities such as measurement, reactive power measurement and service limiting switches.

Operational Description:

Advanced metering records and transmits information on an exchange channel between the customers' premises or a DER device and grid and market operators to enable efficient system planning and support DER participation in distributed operational markets. Advanced metering applications may also include exchange of information from meter-to-meter service providers (e.g., entity providing metering service, which may be the utility or other entity depending on application and state regulation), which will aid in enhancing customer knowledge and efficient bill management.[132]

5.2.3. Meter Data Management

Functional Description:

Meter data management consists of process and tools for securely storing, organizing, normalizing data from advanced meters integrating data from other meters, and making the data available for multiple applications including customer billing, analysis for grid control, outage management and others.

Operational Description:

Meter data management systems ensure security and integrity of data obtained by accounting for time-stamping of data at the source using Global Positioning System (GPS) (evaluating physical distance of separation between assets), the steady state and transient limitations of actual sensing devices, sampling errors within the sensors, electrical noise, filtering, "aliasing" of sampled data, and the processing methods used.

Advanced meter data management systems can automatically filter and convert data into information that operators can use, or organize data into databases that analysts can study and analyze.

Meter data management will also have the ability to maintain the security of large databases with sensitive information that reside in publicly accessible cyberspace.[133]

5.2.4. State Estimation

Functional Description:

State estimation is the process of determining those parameters that can be used to determine power system conditions.

Operational Description:

The power system states include: 1) node voltage phasor (voltage magnitude, phase angle), 2) transformer turn ratios (turn ratio magnitude, phase shift angle), and 3) complex power flow (active power flow, reactive power flow).

State estimation for distribution grids involves a number of complications. These include the fact that distribution circuits operate almost always in a time-varying unbalanced mode so that estimates could be made for all three phases independently; actual connectivity may be poorly known so that models typically used in state estimation would not be sufficiently accurate to use the results; and circuit-switched configuration changes can change topology in between the time of a state estimate and the time that actions based on that estimate are taken. Consequently, it can be helpful to rely more on state measurement and less on state estimation in the distribution case whenever the necessary instrumentation is available.[134]

5.2.5. Fault Localization Isolation Service Restoration (FLISR)

Functional Description:

Fault Localization Isolation Service Restoration (FLISR) includes automatic sectionalizing and restoration, and automatic circuit reconfiguration. This is accomplished by coordinating operation of field devices, software, and dedicated communication networks to automatically determine the location of a fault, and rapidly reconfigure the flow of electricity so that some or all of the customers can avoid experiencing outages. Because FLISR operations rely on rerouting power, they typically require feeder configurations that contain multiple paths to single or multiple other substations.[135]

Operational Description:

The FLISR process includes the following applications:

- Fault Location: Locating the part of the feeder with the faulted network element (e.g. faulted cable or overhead section) using appropriate methods. These methods take into account all deployed equipment in the distribution system for fault detection and location.
- Fault Localization: Locating the part of the feeder with the faulted element using remotely and/ or manually controlled switching devices. This step is used for feeders without deployed equipment for fault location, such as fault indicators and fault measurements.
- Element (Fault) Isolation: This step isolates the faulted element from the remaining part of the feeder.
- Service Restoration: Re-supplying of de-energized sections on the faulted feeder via switch orders.
- Return to Normal State: Return the network to the state before the fault occurred.[136]

5.2.6. Volt-var Control

Functional Description:

Volt-var control is a process undertaken to maintain an optimal voltage at all points along a distribution feeder under all loading and DER conditions.

Operational Description:

Volt-var control could support and may enable the following objectives:

- Improve efficiency by reducing technical losses through voltage optimization (limits to efficiency gains related to customer's devices, constant power devices, and voltage volatility from variable distributed resources);
- Reduce electrical demand and/or accomplish energy conservation through voltage reduction;
- For any conductor in a distribution network, the current flowing through it can be decomposed into two components – active and reactive. Reactive power does not do real work but uses the current carrying capacity of the distribution lines and equipment, contributing to power loss. Reactive power compensation devices are designed to reduce or eliminate the unproductive component of the current, reducing current magnitude – and thus energy losses;
- Promote a "self-healing" grid (Volt-var control plays a role in maintaining voltage after "self-healing" has occurred); and
- Enable widespread deployment of Distributed generation, Renewables, Energy storage, and other distributed energy resources (dynamic Volt-var control).[137]

5.2.7. Asset Monitoring

Functional Description:

Asset monitoring involves advanced sensor technologies that allow utilities or distribution system operators to monitor the health and utilization of grid components of both utility owned and non-utility owned assets, by collecting real-time and frequent information.

Operational Description:

Asset monitoring technologies would provide configuration and/or real-time condition information on field assets, which can be integrated with advanced applications to help map and update the topology of transmission and distribution systems, determine asset status for more optimal operations, support better state estimation, and enable more complex real-time controls.

A condition base maintenance system obtaining specific information for each asset can be used to plan maintenance as needed, as opposed to using a fixed interval maintenance schedule. This eliminates unnecessary labor and travel for maintenance personnel, reducing maintenance costs for equipment owners.[138]

5.2.8. Interconnection Portal

Functional Description:

An interconnection portal is an internet based portal that facilitates timely and transparent processing of DER interconnection applications for the distribution grid.

Operational Description:

Functions of the interconnection portal may include:

- Customers may electronically submit interconnection requests online;
- Portal will indicate what locations may benefit from DER interconnection, and what locations may have a higher cost to connect to the system;
- Provide customers with information regarding the status of their application to interconnect;
- Auto-fill and auto-calculations to reduce human error;
- Auto population of customer information from internal systems to eliminate inaccuracies with the customer name and/or site address;
- Customer and developer satisfaction surveys; and
- Functions to update existing application information when changes occur.[139]

5.2.9. Environmental Sensing

Functional Description:

Environmental sensing extends to receiving dynamic data from grid-based sensors, DER-based sensors and third-party information sources regarding weather conditions and forecasts, fire hazards, earthquake and other environmental factors.

Operational Description:

A variety of potential sources of environmental information will be accessible to plan and operate the distribution system and inform operational markets. Data and information from grid-based sensors, environmental instrumentation incorporated in DER devices and information from government and commercial information sources may be leveraged and integrated into relevant operational systems.[140]

5.2.10. Outage Management System

Functional Description:

Outage management is a system service used by operating entities to better manage their response to power outages, integration of multiple sources of data (smart meters, customer calls, etc.) integration with other utility systems to analyze possible fault locations (Geographical Information Systems (GIS) and connectivity databases for common node analysis) and/or integrate fault location from applications such as FLISR, and integrate with computer aided dispatch systems for remedial action.

Operational Description:

The outage management function can capture meter-level outage information, real-time information on customer outages and improve the identification of interrupted equipment and circuits, thus decreasing outage times significantly. They can also provide suggested switching plans to accelerate outage restoration.

Outage management systems can monitor and observe equipment status for optimization of outage prediction and enhanced situational awareness by integrating real-time data from customers with telemetered analog data from the distribution system operators.[141]

5.2.11. Protection Schemes

Functional Description:

Protection schemes consist of static physical components that are typically set so the system will go to its safest state — de-energized — in the event a threshold limit is exceeded, to maintain grid reliability. There are backup protection mechanisms if the primary protection does not clear the fault.

Operational Description:

These schemes provide protection for the grid system from failure due to undesirable or excessive current flows or over voltages arising from natural events (e.g., lightning strikes or geomagnetic disturbance), system operations (e.g., switching surges or transients), or fault conditions (e.g., an unintentional short circuit or partial short circuit).

The protection management enables relays that support the capabilities identified including: high impedance faults, self-adjusting settings based on current system configuration, remote I/O of settings, notification generation when permanent reconfigurations affect it, pre-fault detection, bi-directional power flow monitoring, and digital fault recording.[142]

5.2.12. Automated Islanding and Reconnection

Functional Description:

A process whereby a microgrid separates itself electrically from the main power grid and operates independently, using its own internal power source(s); it may later rejoin the main grid.

Operational Description:

Islanding raises issues such as the coordination of operations. For example, when the microgrid islands, it takes over its own internal regulation, but islanding can then cause a significant change in conditions on the remainder of the feeder circuit outside of the island, if there is any. The return of the microgrid to the main grid requires bringing the microgrid into synchronism with the main grid and return of control to the main grid operation systems.

The islanded grid should be able to provide the ability to perform the following functions in islanding state:

- Perform local reactive and real power balancing;
- Voltage and Frequency control;
- Phase balancing if applicable;
- Protection; and
- Optimization.[143]

5.2.13. Operational Telecommunications Infrastructure

Functional Description:

Operational telecommunication infrastructure facilitates a highly secure, available and reliable communication channel that serves as a mission critical data-link for feedback and status updates from grid sensors and to carry protection and/or control signals to grid devices in the field to ensure safety, reliability and resiliency.

Operational Description:

Operational telecommunication infrastructure consists of communication protocols, technologies and assets that are present between operating centers and substations, and extends into the field to connect grid sensors and controllable grid devices (e.g., switches, capacitor banks, protective devices, etc.) on local feeders. The performance and security requirements of operational communications networks for mission critical uses such as the electric grid are significantly greater than public networks, internet service and standard enterprise networks.

Operational communication infrastructure is intended to maintain highly reliable connectivity under both normal and degraded system operating conditions (e.g., electrical noise, equipment failure, and physical attacks).[144] However, no communication system is invulnerable to failure and so a key modern grid design requirement for systems to operate safely and reliably in the event of loss of Operational Telecommunication Infrastructure connectivity.

5.2.14. Operational Communication Network Management

Functional Description:

Operational communication network management is responsible for the reliable, secure and efficient transport and management of data between applications subscribed and authorized to receive the data.

Operational Description:

Operational communication network management is responsible for managing large amounts of variable data that needs to be analyzed and translated into compatible signals that can be interpreted by diverse grid and end-users. It has the ability to process and filter continuous data to identify, store and transfer data pertinent to specific operations to ensure reduce redundancy and decrease costs.

Communication network management will ensure connectivity and interoperability across diverse network architectures and mixed protocols, between control rooms and field assets (which includes substations and various sensors) and customer assets either directly or through market participants.[145,146]

5.2.15. Customer Information Management

Functional Description:

Customer information management service manages the availability and seamless, digital access to customer energy data either in aggregated or granular form with appropriate restrictions and/or customer authorizations, for utility business operations, grid operations, planning or third party service providers.

Operational Description:

Customer information management manages the availability and access through standard protocols and business processes to customer data, billing, equipment, customer requirements profile, etc., as well as customer energy data of varying level of granularity and is tasked to store, process and transport this information to aid in grid and market operation planning. Customer energy data includes historical consumption data, customer charges, reported outages, power quality data, service location, assets etc.[147]

5.2.16. Power Quality Measurement and Stabilization

Functional Description:

The power quality measurement and monitoring application provides telemetry capable of sub-cycle monitoring for analysis of total harmonic distortion, flicker, power factor, voltage transients, sags and surges, incipient equipment failures or incipient system faults.[148]

Operational Description:

Monitoring may be continuous and handled by distributed intelligent devices in the field reporting unsolicited data only when accepted parameters are violated. Waveform data may be stored locally to allow for data requests and post event analysis. Stabilization of voltage (compensation for spikes, sags, etc.) is the automatic correction of system perturbations (i.e., voltage).

5.2.17. Estimated Time of Restoration

Functional Description:

After a power outage, a utility or load serving entity may provide an estimate for restoration based on current reported field conditions, damage assessments and predictions from an automated Outage Management System (OMS) (see 5.2.10).

Operational Description:

Factors that affect times of restoration include:

- Detection, localization, and characterization of the underlying faults;
- Completion of damage assessment;
- Weather;
- Accessibility to damaged areas;
- Coordination with other agencies working on the storm restoration, such as public works and tree removal, and changing public safety and health priorities; and
- Repair crews may discover additional or more complex problems, such as nested faults that require additional time, equipment or crews.[149]

5.2.18. Distribution Network Model

Functional Description:

Distribution network model is a data set, in spatial context that contains grid asset details and configuration information, customer and DER connectivity details, and other relevant information to reflect an accurate depiction of the current state of the distribution system. This model is often visually represented in a GIS as well as used in power flow studies. Distribution operations employs two versions: as-built and as-operated. As-built reflects the model prior to daily operations while as-operated reflects the actual real time model for daily operations.

Operational Description:

A distribution network model can be built based on complete, correct, and current data defining network infrastructure and devices and real time outage and grid information. Consequently, collecting and maintaining accurate data are crucial to a successful “as-built” and “as-operated” network model. A GIS enables an accurate “single source of the truth” for conductor and device data, allowing a single data foundation to be used across a utility’s engineering, design, construction, maintenance and customer service departments.[150]

5.2.19. Simulation Tools

Functional Description:

Simulation tools include analytical and software tools that can model the electric power structure as it is designed and operated. This incorporates the proliferation of DER, deployment of smart grid technologies and evolving business models, and other reasons.

Operational Description:

Tools that can be widely applied in distributed system integration analysis and in studying the impact of DER on distribution circuits. These tools should be capable of performing the following non-exhaustive list of functions:

- Able to model the subtransmission system;
- Model voltage control equipment;
- Model unbalanced systems;
- Handle load and generation profiles;
- Accommodate accurate flexible DG models;
- Load-flow planning;
- Fault current calculation; and
- Distribution state estimator.[151]

5.2.20. Threat Assessment and Remediation

Functional Description:

Identification of the threats, security constraints, and issues associated with each logical grid interface category along with the impact (low, moderate, or high) to the grid if there is a compromise of confidentiality, integrity, and/or availability.

Operational Description:

An effective threat assessment approach entails “systematically documenting and prioritizing known and suspected control system and grid vulnerabilities [threats] and their potential consequences.”[152] The threat assessment primarily focuses on grid operations, and not business operations.

5.2.21. Cybersecurity Measures

Functional Description:

Cybersecurity is usually viewed in relation to two types of assets: ICT and industrial control systems (ICS). The result is a highly complex system architecture consisting of devices, communication networks and software. Cybersecurity could be designed in these new integrated systems, along with supporting organizational and personnel policies. Integration of ICS network with higher level of reliability with IT networks, which are comparatively less reliable, will need to be addressed by future cybersecurity measures.[153]

Operational Description:

Each organization may conduct cybersecurity activities in their own manner, either via ad-hoc mechanisms, or through an established process. The key functions in the cybersecurity process include:

- Cybersecurity risks are identified;
- Risk assessments are performed to identify risks in accordance with the risk management strategy;
- Identified risks are documented e. Identified risks are analyzed to prioritize response activities in accordance with the risk management strategy;
- Identified risks are monitored in accordance with the risk management strategy;
- Risk analysis is supported by network (IT and/or OT) architecture; and
- Identified risks are mitigated, accepted, tolerated, or transferred.[154]

5.2.22. Physical Security Measures

Functional Description:

Physical security measures include activities that can harden assets, improve situational awareness, detect, deter and respond to man-made threats, and mitigate risks. Physical security provides protection from natural and weather disasters like winter storms, earthquakes, hurricanes/storms, droughts/heatwaves, flooding, ice storms, and wildfires and numerous other physical threats like vandalism, terrorism.[155]

Operational Description:

Measures to provide physical security for distribution grid infrastructure include:

Operational response to intrusion/damage – Automatic operational schemes could be armed after an intelligent adversary was detected within the boundaries of a substation or switchyard. These schemes could identify resilient configurations for the remaining system to withstand the loss of the compromised substation.

Other predictive system configurations for investigation include adaptive relaying, topological switching, and intentional islanding with microgrids. Additionally, research is needed to better understand large system behavior, identify when the system is degrading, and enable adaptive technologies for response to threats.[156]

5.2.23. Customer Notification

Functional Description:

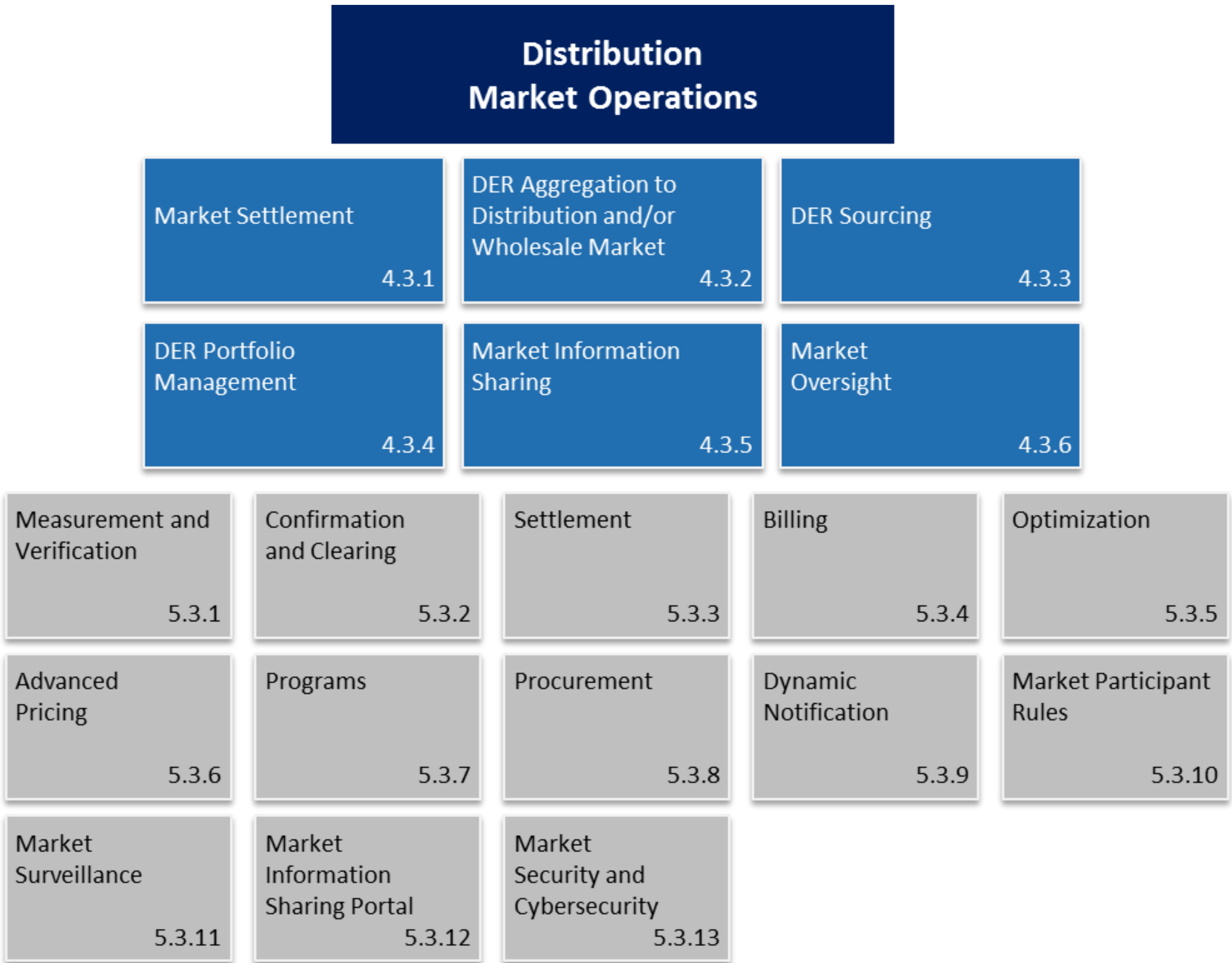
A process whereby electric customers are notified of operator actions and grid events such as billing cycles, outages, announcements of critical peak days.

Operational Description:

A range of techniques can be used for notifying customers about program actions, including traditional methods like phone calls and bill stuffers along with new methods like emails, text messages, web postings, and social media.[157]

5.3 DISTRIBUTION MARKET OPERATIONS

Figure 19: Distribution Market Operations Elements



5.3.1. Measurement and Verification

Functional Description:

Measurement and verification (M&V) includes the process and systems to assess the operational performance of DER as required in the provision of distribution grid and bulk power system services. M&V serves as the basis of financial settlements for services supplied.

Operational Description:

Any dispatchable resource that directly participates in a distribution operational market or wholesale market, regardless of the market structure, must comply with dispatch signals received from the distribution or bulk power system operator and must be metered in order to be compensated for the service it is providing. Resources that offer to provide real-time products in wholesale electricity markets are usually required to have sufficient telemetry and communications capability to receive dispatch signals from the distribution or bulk power system operator. The requirements and whether they are provided as individual resources or consolidated by an aggregator may vary by the size of resource and the type of market in which they participate.

As such, metering systems can also potentially be used for communications of dispatch instructions as well as for settlement. For demand response resources, a baseline demand is typically calculated to determine the amount of demand response that can be provided in any given hour. Changes in demand are compared to this baseline and measured and verified through a procedure established by the distribution or bulk power system operator.[158]

5.3.2. Confirmation and Clearing

Functional Description:

Confirmation and clearing involves facilitating and selecting multi-party transactions related to market participant commitments based on system's demand forecast and market rules.

Operational Description:

In order to facilitate market operations, the market operator may need to receive confirmation of market participants' contractual commitments. Commitments would need to be cleared (or selected) based on market rules. Comparing actual performance to market participants' commitments in terms of quantity, quality, timing, tracking and reconciling discrepancies, managing disputes and escalations is performed by measurement and verification.[159]

5.3.3. Settlement

Functional Description:

Settlement entails processing market quantities into invoices and processing billing and collection of amounts transacted in the wholesale or distribution markets.

Operational Description:

The settlement process could include a transaction management system that can incorporate transactions of each product and service developed. It may also allow for mechanisms to handle participant non-performance, which would require proposing a specific settlement design. Netting functions may be incorporated to offset outstanding invoice or receivable balances. Payment settlements for all distribution-level transactions that are not settled bilaterally may include the accurate invoicing of distribution system products offered in a transparent manner, providing the data that the settlements are based on.[160]

5.3.4. Billing

Functional Description:

This procedure involves assembling customer usage (and possibly production) data and combining it with the applicable rate structures to create a bill for the customer on a periodic basis.

Operational Description:

Available metered usage data and rates will be collected in the billing system platform to process and provide appropriate billing. In the case of metered DERs, the clearing price is sent to the service provider's operations system for billing. The billing system exchanges information with the smart meter at the home to obtain the energy used during the intervals so the bill can be calculated.[161]

5.3.5. Optimization

Functional Description:

The purpose of this procedure is both to improve the efficiency with which market participants can transact energy and grid related services, and to identify and report potential violations and market power abuses.

Operational Description:

Market operations optimization is done by utilizing supply and demand market data to analyze market performance, identify abnormal conditions, and determine key supply and demand relationships. Short and long-term metrics can be used to measure whether DERs are being more broadly utilized, monetized, and placed on par with traditional utility solutions. This element may also include proposing market rules to minimize the impact of market power and non-competitive behavior on consumers (this could include specific market power mitigation measures).[162]

5.3.6. Advanced Pricing

Functional Description:

Pricing that can change in response to various factors such as time, variable peak, location and proximity to load, resource, supply conditions, system conditions, incentives/penalties, and "controllability" of supply and demand resources.

Operational Description:

Traditionally, prices at the transmission level have been calculated as the system energy price plus the "basis" differential (transmission constraints and losses value) to a node. An advanced pricing mechanism could transfer this paradigm to the distribution system, while considering the factors mentioned previously. An advanced pricing mechanism will also include the establishment of rates that vary by season or by time of day to reflect changes in an operator's cost of providing service.[163]

5.3.7. Programs

Functional Description:

DERs may be developed through programs operated by the utility or third parties with funding by utility customers through retail rates or by the state.

Operational Description:

Existing commission-approved programs, incentives, and tariffs are coordinated to maximize the benefits that distributed energy resources provide to the grid.[164]

5.3.8. Procurement

Functional Description:

Procurement is defined as competitive sourcing of grid services from DERs through request for proposals and offers or bilateral contracts, such as power purchase agreements (PPAs) to defer transmission and distribution investments.

Operational Description:

As advanced grid platform technologies and operating procedures evolve, the grid operators will be able to call upon DERs when needed in real-time and track their performance. Such a framework would essentially create an initial market for DER services in which the operator would be the sole or primary buyer, perhaps in the form of request for offer-based procurement under bilateral contracts between the operator and DER providers.[165]

5.3.9. Dynamic Notification

Functional Description:

Automatic event notification signals are sent to market participants regarding events such as price changes, incentives, penalties, or special circumstances; events or conditions that may affect electrical network performance or availability such as equipment failure, weather or other hazards; or events achieving or exceeding various production or consumption targets or thresholds. Such notification would be intended to provide market participants the ability to respond to important situations or conditions in a timely manner.

Operational Description:

Participants might be notified of high load days, transmission outages, or other situations that could create a particular need for DERs to operate or be available to respond to contingencies. It is recommended that event notifications be functionally consistent across all utilities in the state, although conditions triggering these events may differ depending on the specific network conditions. To ensure transparency, in addition to providing notifications to market participants, notifications may also be made available through a publicly accessible portal.[166]

5.3.10. Market Participant Rules

Functional Description:

This set of rules define the requirements and responsibilities of market participants regarding service delivery and compliance standards. Market participants include DER providers or directly participating customers.

Operational Description:

Market participants may need to regularly communicate specific DER operational data and provide for inter- and intra-day market operations and processes. The grid operator will likely be responsible for ensuring that market participants are aware of their responsibilities in their individual roles, including providing training courses and documents. Additional related activities could include qualification (e.g., credit and performance checking) of new participants, management of participant interactions (e.g., service complaints), case management and escalations, monitoring of satisfaction levels, marketing, and relationship building, and developing customized services and solutions. To enable synchronization of participation data and efficient participant access, the forms, format, and participation criteria is recommended to be consistent across utilities.[167]

5.3.11. Market Surveillance

Functional Description:

Market monitoring provides continuous surveillance and evaluation of the markets. It helps prevent any wrongdoing or anti-competitive behavior, and ensures markets perform as intended, and may instill confidence in market participants that the market is functioning properly.

Operational Description:

Market monitoring and surveilling activities include, but are not limited to the review of:

- Generator and load bidding behavior, including trends;
- Economic and physical withholding actions of generators;
- Actions that may adversely impact market operations;
- Uneconomic overproduction by generators;
- Underbidding by loads;
- Audit the posted clearing prices; and
- Compliance by market participants with market rules.[168]

5.3.12. Market Information Sharing Portal

Functional Description:

This element is an online portal through which market participants may interact with the market maker or market operator as well as the grid operator. This could include passive interaction like viewing market data or active interactions to submit offers or bids.

Operational Description:

Market participant access to specific data and content will enable development of DER markets. Utilities will need to design processes to be able to report on individual DER performance at least once a day so that both the DER providers and utilities can assess what happened at the end of the day to be able to project what's available/likely the following day. This information may be needed for commercial market functions. This data and content, and its access restrictions, can ensure transparency and opportunities for innovation and may be provided via standard protocols and standardized business processes, an example of which is Green Button Connect. Participant-facing web portals can be consistent across the state (or wider region if feasible) and across individual products to minimize the burden on participants seeking to engage in markets in multiple areas.[169]

5.3.13. Market Security and Cybersecurity

Functional Description:

Capabilities put in place to ensure that all information communications networks and programmable electronic devices, including the hardware, software, and data in those devices are secure in order to deliver reliable service.

Operational Description:

As market data, system data, and third-party data is shared with DER providers, and utilities, mechanisms to ensure that data provided does not enable market gaming and respects privacy and cybersecurity concerns must be established.[170]

5.4 ELEMENTS TO FUNCTIONS MAPPING

The elements described above relate to the functions identified in Chapter 4 in varying degrees. Certain elements are strongly related and others have weaker or no relationship. The elements to functions mapping in Figures 26 – 28 in Appendix A illustrate these key relationships between elements and multiple functions. This mapping provides the ability to identify potential foundational and no-regrets types of investments.

SUMMARY

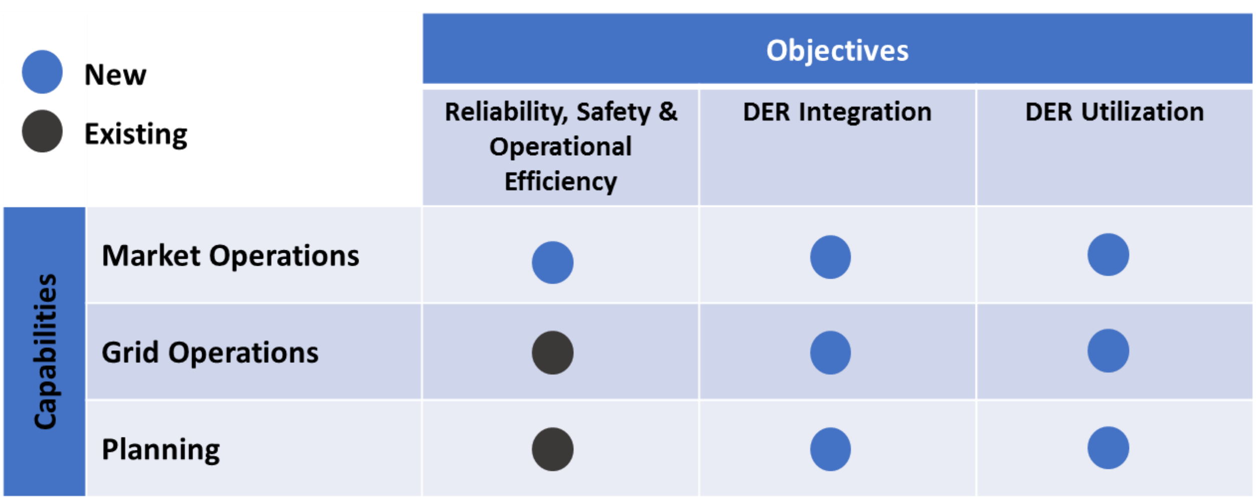
Translation of the sponsoring regulatory commissions' policy objectives and attributes for a modern grid platform employing the grid architecture methodology described in this volume provides a line of sight to those functional requirements and ultimately the technology needed. The taxonomy employed in this report provides linkage to the detailed business functions and related elements which are illustrated in Appendix A. This level of detail may be useful to consider for specific business function enhancements. However, for most readers the analysis is more useful in summary to understand in relation to outcomes of interest to policy makers, utilities, services providers and other stakeholders.

This volume is organized around the capability grouping used in New York's REV: distribution planning, grid operations and market operations. However, other states are looking at these functions and related technologies from the perspective of general outcomes for a modern grid in relation to their policy objectives. In simple terms these are:

- Reliability, safety and operational efficiency of the distribution system
- DER integration to enable customer choice and other policy objectives
- DER utilization in bulk power system and/or as distribution non-wires alternatives.

These 3 summary objectives map to the New York capability groups as shown in Figure 20, below. The gray dots identify those aspects that currently exist and the blue dots identify the areas of enhancement needed to fully support the additional objectives that may be desired.

Figure 20: Outcomes in Relation to Grid Capabilities

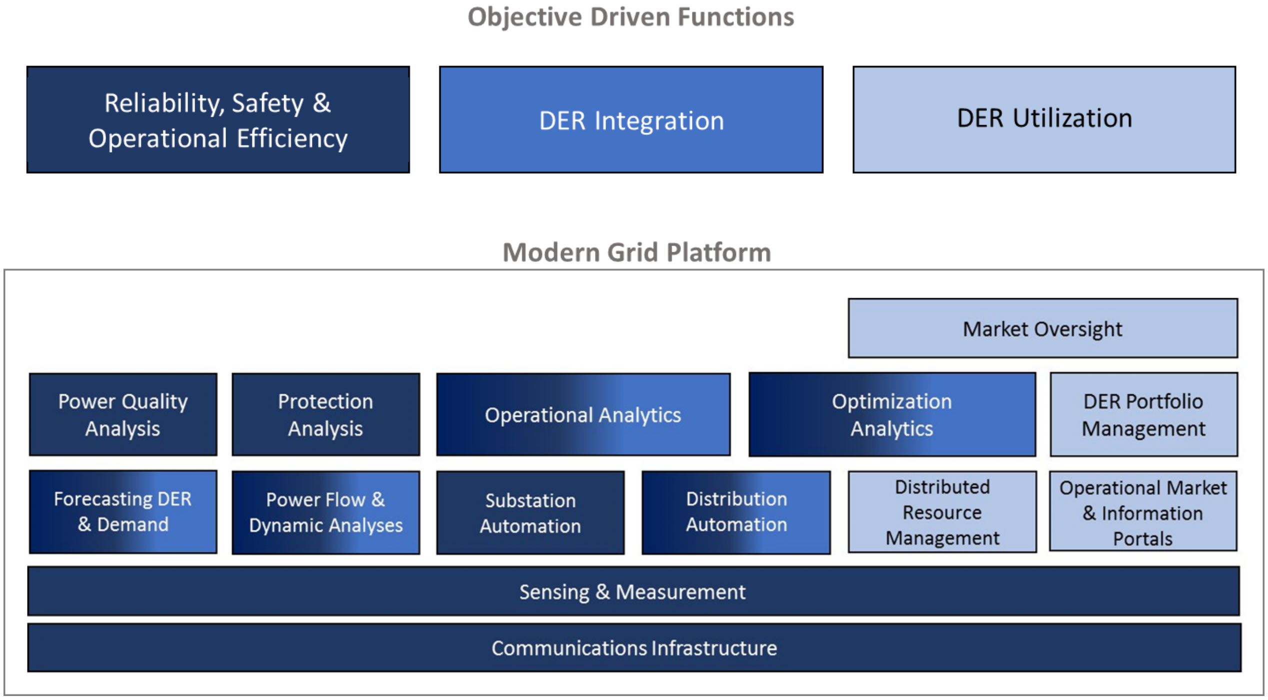


Development of a modern grid and related business functions and technology investments to support these 3 outcomes are interwoven to create an enabling platform. That is the functions and technologies are many cases support multiple objectives as described in this volume and illustrated in Appendix A. These overlapping relationships are illustrated in Figure 21 to the right. In concept, the starting point of a modern grid is with a foundation built upon enhancements to reliability, safety and operational efficiency. This is augmented with new functions and technology to support DER integration in line with the timing, scale and scope of customer adoption and value for all customers. This additional layer of functionality and related technology is represented by the overlapping areas of the Venn diagram. This creates the foundational distribution system platform that enables further locationally or opportunity driven functionality and related technology deployment is layered onto the foundational platform.

Figure 21: Three Dimensions of Grid Modernization

Taking this a step further, the technology categories identified and described in Volume 2, "Advanced Technology Maturity Assessment," can be viewed in relation to the 3 outcomes as shown in Figure 22, below. This figure illustrates the layered relationships between these technology categories in terms of the supporting technologies and the applications that layer upon to create a holistic modern grid as envisioned by several states. It is important to recognize that this figure does not include a representation of the underlying physical infrastructure that itself is undergoing enhancements as aging infrastructure is replaced. Also, note that cybersecurity is not identified as a separate box as effective cybersecurity requires it to be built into the various communications, information and operational systems. As such, it is expressly implied that cybersecurity is appropriately embedded into this platform, as described earlier in this Volume and in Volume 2.

Figure 22: Modern Grid Platform in Relation to Objective Functions



These technology categories are decomposed into more specific technology descriptions and assessment of current state of industry adoption. Volume 2 also identifies key gaps in product development and/or adoption to highlight considerations for the development of grid modernization strategies and related implementation roadmaps.

Finally, the evolution of a modern grid, particularly those enhancements to integrate DER and utilize their services, will necessarily need to align with the pace and scope of changes to customer adoption and policy objectives, including value for all customers. This raises a number of considerations such as which investments are foundational system-wide or which are locational? Also, which investments are primarily reliability in nature and those driven by DER integration and/or utilization as non-wires alternatives? These considerations are explored in Volume 3, "Decision Guide," to evaluate needed functions and related investments.

APPENDIX A: MAPPING KEY RELATIONSHIPS OF CAPABILITIES, FUNCTIONS AND ELEMENTS

CAPABILITIES TO FUNCTIONS MAPPING

Figure 23: Capabilities to Functions Mapping – Distribution System Planning

FUNCTIONS: 4.1 Distribution System Planning

CAPABILITIES		1 Distribution System Planning	2 Growth Forecasts of DER and Demand	3 DER Locational Value Analysis	4 Integrated Resource T&D Planning	5 Integrated Operational Engineering and System Ops	6 Multiple Forecast Scenario-based Planning	7 Interconnection Process	8 Distribution System Information Sharing	9 Telecommunications	10 Customer Information Access	11 Analytics	12 DER Development and Market Participant Information Access
3.1.5	Convergence with Other Critical Infrastructures	●		●	●			●	●	●		●	●
3.1.6	Accommodate New Business Models	●	●	●	●		●		●		●		●
3.3.4	System Performance	●	●	●	●	●	●		●			●	●
3.2.10	Reliability and Resiliency Management	●	●	●	●	●	●	●	●	●		●	●
3.2.1	Operational Risk Management	●	●	●	●	●	●	●		●		●	●
3.2.2	Situational Awareness	●	●	●	●	●	●	●		●		●	●
3.3.2	Distribution Asset Optimization	●	●	●	●	●	●	●		●		●	●
3.3.6	Local Optimization	●	●	●		●	●	●		●	●	●	●
3.1.4	Accommodate Tech Innovation	●	●		●	●	●	●	●	●	●	●	●
3.2.4	Management of DER and Load Stochasticity	●	●	●	●	●	●			●		●	●
3.1.7	Transparency	●	●	●	●			●	●		●		●
3.3.5	Environmental Management	●	●	●	●				●				●
3.2.3	Controllability & Dynamic Stability			●	●	●	●	●		●		●	●
3.2.5	Contingency Analysis	●			●	●	●	●		●		●	●
3.2.11	Integrated Grid Control	●	●		●	●	●			●		●	●

FUNCTIONS

CAPABILITIES

		4.1 Distribution System Planning											
		1	2	3	4	5	6	7	8	9	10	11	12
		Distribution System Planning	Growth Forecasts of DER and Demand	DER Locational Value Analysis	Integrated Resource T&D Planning	Integrated Operational Engineering and System Ops	Multiple Forecast Scenario-based Planning	Interconnection Process	Distribution System Information Sharing	Telecommunications	Customer Information Access	Analytics	DER Development and Market Participant Information Access
3.2.13	Privacy & Confidentiality	●		●	●			●	●		●		●
3.3.1	Distribution Investment Optimization	●	●	●	●		●		●			●	●
3.1.1	Scalability	●			●		●	●	●	●			
3.2.12	Control Federation and Control Disaggregation	●			●	●		●		●		●	
3.2.7	Public and Workforce Safety	●				●	●	●		●			
3.2.9	Attack Resistance/Fault Tolerance/Self-Healing	●			●	●	●			●		●	
3.1.3	Open and Interoperable							●	●	●	●		●
3.1.2	Impact Resistance and Resiliency	●				●	●			●			
3.3.3	Market Animation			●	●						●	●	●
3.2.6	Security	●						●		●			
3.2.8	Fail Safe Modes	●					●			●			

Figure 24: Capabilities to Functions Mapping – Distribution Grid Operations

FUNCTIONS

4.2 Distribution Grid Operations

CAPABILITIES		1 Observability	2 Distribution Grid Control	3 Asset Optimization	4 Integrated Operational Engineering and System	5 Distribution System Model	6 T-D Interface Coordination	7 Steady-State Volt-var Management	8 Power Quality Control	9 DER Operational Control	10 Cybersecurity	11 Physical Security	12 Information Technology	13 Reliability Management	14 Operational Forecasting
3.2.2	Situational Awareness	●			●	●	●	●		●	●		●		
3.3.2	Distribution Asset Optimization	●	●	●	●	●	●	●	●	●	●		●	●	●
3.2.3	Controllability and Dynamic Stability	●	●	●		●	●	●	●	●	●		●		
3.2.11	Integrated Grid Control	●	●	●			●		●	●	●	●	●		
3.2.10	Distributed Reliability Management	●	●	●	●	●	●	●	●	●		●	●		●
3.3.6	Local Optimization	●	●	●	●	●	●	●	●	●	●		●		●
3.2.1	Operational Risk Management	●	●		●	●	●			●	●	●	●	●	●
3.1.2	Impact Resistance and Resiliency		●		●	●	●			●	●	●	●		●
3.2.9	Attack Resistance / Fault Tolerance / Self-Healing	●	●		●	●	●			●	●	●	●		●
3.2.12	Control Federation and Control Disaggregation	●	●	●			●	●	●	●	●		●		
3.2.4	Management of DER and Load Stochasticity	●	●	●	●	●	●	●	●	●	●			●	●
3.2.5	Contingency Analysis	●	●	●	●		●			●			●	●	●
3.2.8	Fail Safe Modes	●	●					●	●	●	●	●	●	●	●
3.2.6	Security	●	●	●	●	●	●	●	●	●	●	●	●	●	●
3.2.7	Public and Workforce Safety	●	●	●	●		●				●	●		●	●
3.3.4	System Performance	●	●	●	●	●	●	●	●	●	●		●	●	●
3.1.1	Scalability	●	●	●	●	●		●	●	●	●		●	●	
3.3.5	Environmental Management	●	●		●		●	●		●	●				●
3.1.4	Accommodate Tech Innovation	●	●	●	●			●	●	●	●				
3.3.1	Distribution Investment Optimization	●	●	●	●	●	●	●	●	●	●		●		●
3.1.6	Accommodate New Business Models		●		●					●	●				●

FUNCTIONS

CAPABILITIES		4.2 Distribution Grid Operations													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Observability	Distribution Grid Control	Asset Optimization	Integrated Operational Engineering and System	Distribution System Model	T-D Interface Coordination	Steady-State Volt-var Management	Power Quality Control	DER Operational Control	Cybersecurity	Physical Security	Information Technology	Reliability Management	Operational Forecasting
3.1.5	Convergence with Other Critical infrastructures	●	●	●	●	●	●			●	●		●		●
3.1.3	Open and Interoperable	●	●	●			●	●	●	●			●		
3.2.13	Privacy and Confidentiality	●	●	●	●	●	●	●	●	●	●	●	●		●
3.1.7	Transparency			●										●	●
3.3.3	Market Animation	●	●	●	●	●	●	●	●	●	●		●	●	●

Figure 25: Capabilities to Functions Mapping – Distribution Market Operations

FUNCTIONS

CAPABILITIES		4.3 Distribution Market Operations					
		1	2	3	4	5	6
		Market Settlement	DER Aggregation to Distribution and/or Wholesale Market	DER Portfolio Management	DER Sourcing	Market Information Sharing	Market Oversight
3.2.6	Security	●	●	●	●	●	●
3.1.1	Scalability	●	●	●	●	●	●
3.2.13	Privacy & Confidentiality	●	●	●	●	●	●
3.3.3	Market Animation	●	●	●	●	●	●
3.3.4	System Performance		●	●	●	●	●
3.3.6	Local Optimization		●	●	●	●	●
3.1.6	Accommodate New Business Models		●	●	●	●	●
3.3.5	Environmental Management		●	●	●	●	●
3.1.7	Transparency		●	●	●	●	●
3.2.5	Contingency Analysis		●	●	●	●	●
3.3.1	Distribution Investment Optimization		●	●	●	●	●
3.2.4	Management of DER and Load Stochasticity		●	●	●	●	●
3.1.5	Convergence w/ Other Critical infrastructures		●	●	●	●	●
3.1.4	Accommodate Tech Innovation		●	●	●	●	●
3.2.10	Reliability and Resiliency Management		●	●	●		●
3.2.1	Operational Risk Management		●	●	●		●
3.3.2	Distribution Asset Optimization		●	●	●	●	
3.1.3	Open and Interoperable	●		●		●	●
3.2.2	Situational Awareness		●	●		●	
3.1.2	Impact Resistance and Resiliency		●	●		●	
3.2.11	Integrated Grid Coordination		●	●			
3.2.3	Controllability and Dynamic Stability		●	●			
3.2.9	Attack Resistance / Fault Tolerance / Self-Healing		●	●			
3.2.12	Control Federation and Control Disaggregation		●	●			
3.2.8	Fail Safe Modes		●	●			
3.2.7	Public and Workforce Safety		●	●			

ELEMENTS TO FUNCTIONS MAPPING

Figure 26: Elements to Functions Mapping – Distribution System Planning

ELEMENTS		FUNCTIONS: 4.1 Distribution System Planning											
		1	2	3	4	5	6	7	8	9	10	11	12
		Distribution System Planning	Growth Forecast of DER and Demand	DER Locational Value Analysis	Integrated Resource T&D Planning	Integrated Operational Engineering & System Operations	Multiple Forecast Scenario-based Planning	Interconnection Process	Distribution System Information Sharing	Telecommunications	Customer Information Access	Analytics	DER Development and Market Participant Information Access
5.1.2	Short and Long-term Demand and DER Forecasting	●	●	●	●	●	●	●				●	●
5.1.1	Power Flow Analysis	●	●	●	●	●	●	●				●	●
5.1.4	Locational Benefit Analysis	●	●	●	●		●	●	●			●	●
5.3.1	Measurement and Verification	●	●	●	●	●	●			●	●	●	
5.2.2	Advanced Metering	●	●		●	●	●	●		●	●	●	
5.1.3	Hosting Capacity Analysis	●	●	●	●		●	●	●			●	●
5.1.6	Estimation of Capital Upgrades	●	●	●	●		●	●				●	●
5.2.19	Simulation Tools	●	●	●	●	●	●	●				●	
5.2.9	Environmental Sensing	●	●	●	●	●	●			●		●	
5.1.5	Interconnection Studies	●	●		●		●	●	●			●	●
5.1.8	Planning and System Data Sharing (portal/mapping)	●	●	●	●		●		●		●		●
5.3.5	Optimization	●	●	●	●	●	●			●		●	
5.2.6	Volt-var Control	●		●		●		●		●		●	●
5.3.8	Procurement	●		●	●	●	●		●	●			
5.2.16	Power Quality Measurement and Stabilization	●		●		●		●		●		●	●
5.3.12	Market Information Sharing Portal	●		●	●		●		●				●
5.1.7	DER Interconnection Process	●	●				●	●	●				●
5.2.4	State Estimation	●		●		●				●		●	●
5.3.6	Advanced Pricing	●		●	●						●	●	●
5.3.7	Programs	●		●	●						●		●
5.2.15	Customer Information Management	●	●				●	●			●		

FUNCTIONS

4.1 Distribution System Planning

ELEMENTS

		1 Distribution System Planning	2 Growth Forecast of DER and Demand	3 DER Locational Value Analysis	4 Integrated Resource T&D Planning	5 Integrated Operational Engineering & System Operations	6 Multiple Forecast Scenario-based Planning	7 Interconnection Process	8 Distribution System Information Sharing	9 Telecommunications	10 Customer Information Access	11 Analytics	12 DER Development and Market Participant Information Access
5.2.18	Distribution Network Model	●			●				●			●	●
5.2.5	FLISR	●				●		●		●		●	
5.2.3	Meter Data Management		●				●		●		●	●	
5.2.1	Flow Control	●				●				●		●	
5.2.11	Protection Schemes	●			●	●				●			
5.2.7	Asset Monitoring	●				●				●		●	
5.2.21	Cybersecurity Measures								●	●	●		●
5.2.8	Interconnection Portal	●						●	●				●
5.2.7	Asset Monitoring	●				●				●		●	
5.2.10	Outage Management System					●					●	●	
5.3.3	Settlement			●							●		●
5.3.4	Billing			●							●		●
5.3.11	Market Surveillance			●								●	●
3.2.17	Estimated Time of Restoration				●						●	●	
5.3.9	Dynamic Notification								●		●		●
3.2.0	Threat Assessment and Remediation	●			●							●	
5.2.13	Operational Telecommunications Infrastructure					●				●			
5.3.13	Market Security and Cybersecurity											●	●
5.2.23	Customer Notification				●						●		
5.2.14	Operational Communication Network Management									●			
5.1.9	Customer Information Access (portal)										●		
5.2.22	Physical Security Measures									●			
5.3.2	Confirmation and Clearing												●
5.3.10	Market Participant Rules												●

Figure 27: Elements to Functions Mapping – Distribution Grid Operations

ELEMENTS		FUNCTIONS: 4.2 Distribution Grid Operations													
		1 Observability	2 Distribution Grid Controls	3 Asset Optimization	4 Integrated Operational Engineering and System Ops	5 Distribution System Model	6 T-D Interface Coordination	7 Steady-State Volt-var Management	8 Power Quality Management	9 DER Operational Control	10 Cybersecurity	11 Physical Security	12 Information Technology	13 Reliability Management	14 Operational Forecasting
5.2.9	Environmental Sensing	●	●	●	●	●	●	●	●	●	●	●	●	●	●
5.2.2	Advanced Metering	●	●	●	●	●		●	●	●	●		●	●	●
5.2.4	State Estimation	●	●	●	●	●	●	●	●	●			●	●	●
5.2.1	Flow Control	●	●	●	●	●	●	●	●	●	●			●	
5.2.16	Power Quality Measurement and Stabilization	●	●	●	●	●		●	●	●	●			●	
5.2.19	Simulation Tools		●	●	●	●	●	●	●	●				●	●
5.2.18	Distribution Network Model		●	●	●	●	●	●	●	●				●	●
5.3.1	Measurement and Verification	●	●	●	●	●	●	●	●	●					●
5.2.12	Automated Islanding and Reconnection	●	●		●	●		●	●	●	●			●	●
5.2.10	Outage Management System	●	●		●	●	●				●		●	●	●
5.2.13	Operational Telecommunications Infrastructure	●	●					●	●	●	●	●	●	●	
5.1.1	Power Flow Analysis	●		●	●		●	●	●	●				●	●
5.2.7	Asset Monitoring	●		●	●	●				●	●	●		●	●
5.2.6	Volt-var Control	●	●	●	●	●		●	●	●	●				
5.3.5	Optimization	●	●	●	●		●	●	●	●				●	
5.2.21	Cybersecurity Measures	●	●					●	●	●	●	●	●	●	
5.1.2	Short and Long-term Demand and DER Forecasting			●	●	●	●	●	●	●				●	
5.2.11	Protection Schemes	●			●	●	●			●	●			●	●
5.3.7	Programs	●			●	●	●	●	●	●					
5.3.8	Procurement	●			●	●	●	●	●	●					
5.2.5	FLISR	●	●		●	●					●		●	●	
5.1.3	Hosting Capacity Analysis			●		●	●	●	●					●	●
5.3.6	Advanced Pricing				●	●	●	●	●	●					
5.1.4	Locational Benefit Analysis			●				●	●	●				●	●
5.1.5	Interconnection Studies			●		●	●	●	●						●

FUNCTIONS

ELEMENTS

		4.2 Distribution Grid Operations													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Observability	Distribution Grid Controls	Asset Optimization	Integrated Operational Engineering and System Ops	Distribution System Model	T-D Interface Coordination	Steady-State Volt-var Management	Power Quality Management	DER Operational Control	Cybersecurity	Physical Security	Information Technology	Reliability Management	Operational Forecasting
5.3.9	Dynamic Notification	●		●	●					●		●		●	
3.2.0	Threat Assessment and Remediation		●		●					●	●	●		●	
5.2.22	Physical Security Measures		●							●	●	●	●		
5.3.11	Market Surveillance						●	●	●	●	●			●	
5.2.15	Customer Information Management				●	●					●		●		●
5.2.3	Meter Data Management	●						●	●		●			●	
5.1.8	Planning and System Data Sharing (portal/mapping)	●					●				●		●		
5.3.2	Confirmation and Clearing							●	●	●					
5.3.3	Settlement							●	●	●					
5.1.9	Customer Information Access (portal)										●		●	●	
5.2.14	Operational Communication Network Management	●	●										●		
3.2.17	Estimated Time of Restoration				●	●								●	
5.1.6	Estimation of Capital Upgrades			●						●					●
5.3.12	Market Information Sharing Portal									●	●				
5.3.13	Market Security and Cybersecurity									●	●				
5.3.4	Billing										●				●
5.2.8	Interconnection Portal										●				
5.1.7	DER Interconnection Process					●									
5.3.10	Market Participant Rules									●					
5.2.23	Customer Notification													●	

Figure 28: Elements to Functions Mapping – Distribution Market Operations

ELEMENTS		4.3 Distribution Market Operations (FUNCTIONS) 1 Market settlement	2 DER Aggregation to Distribution and/or Wholesale Market	3 DER Sourcing	4 DER Portfolio Management	5 Market Information Sharing	6 Market Oversight
5.3.7	Programs	●	●	●	●	●	●
5.3.8	Procurement	●	●	●	●	●	●
5.3.10	Market Participant Rules	●	●	●	●	●	●
5.3.6	Advanced Pricing	●	●	●	●		●
5.3.11	Market Surveillance		●	●	●	●	●
5.3.1	Measurement and Verification	●	●		●		●
5.1.4	Locational Benefit Analysis			●	●	●	●
5.3.5	Optimization		●	●	●		●
5.1.2	Short and Long-term Demand and DER Forecasting		●	●	●	●	
5.1.1	Power Flow Analysis		●	●	●		●
5.3.9	Dynamic Notification	●	●		●		●
5.2.19	Simulation Tools		●	●	●		●
5.3.2	Confirmation and Clearing	●			●		●
5.3.3	Settlement	●		●			●
5.3.13	Market Security and Cybersecurity		●		●		●
5.2.1	Flow Control		●		●		●
5.1.3	Hosting Capacity Analysis		●	●	●		
5.2.11	Protection Schemes		●	●	●		
5.2.15	Automated Islanding and Reconnection		●	●	●		
5.2.19	Power Quality Measurement and Stabilization		●	●	●		
5.2.3	Meter Data Management	●			●		●
5.3.4	Billing	●				●	●
5.2.2	Advanced Metering	●			●		●
5.1.6	Estimation of Capital Upgrades			●		●	●
5.2.6	Volt-var Control			●	●		
5.3.12	Market Information Sharing Portal					●	●
5.1.8	Planning and System Data Sharing (portal/mapping)			●		●	

FUNCTIONS

ELEMENTS

		4.3 Distribution Market Operations					
		1	2	3	4	5	6
		Market settlement	DER Aggregation to Distribution and/or Wholesale Market	DER Sourcing	DER Portfolio Management	Market Information Sharing	Market Oversight
5.2.9	Environmental Sensing		●		●		
5.2.21	Cybersecurity Measures		●		●		
5.2.10	Outage Management System	●			●		
5.2.18	Customer Information Management	●			●		
5.1.5	Interconnection Studies			●		●	
3.2.0	Threat Assessment and Remediation				●		●
5.2.18	Distribution Network Model		●		●		
5.2.23	Customer Notification	●			●		
5.1.9	Customer Information Access (portal)	●					
5.2.12	Physical Security Measures			●			
5.2.4	State Estimation				●		
5.2.7	Asset Monitoring				●		
5.1.7	DER Interconnection Process					●	
5.2.8	Interconnection Portal					●	
5.2.13	Operational Telecommunications Infrastructure				●		
3.2.17	Estimated Time of Restoration						
5.2.5	FLISR						
5.2.17	Operational Communication Network Management						

APPENDIX B: DISTRIBUTION GRID SERVICES

DER-provided distribution grid services, as defined in the context of several states' activities over the next five years, depend on location, timing, level of service, and availability of the DER. These services, which provide an alternative to distribution capital investments, have been defined by California's Competitive Solicitations Framework Working Group (CSFWG), along with the associated attributes and performance requirements necessary for those services. [171,172] Similar discussions between utilities and the DER market took place over Summer 2016 in New York around the suitability criteria of non-wires alternatives.[173,174]

The grid services below, as defined by the CSFWG, include 1) distribution capacity 2) voltage support and 3) Reliability and Resiliency:

Distribution Capacity

Distribution Capacity services are defined as load modifying or supply services that DERs provide via the dispatch of power output (megawatts, MW) for generators or reduction in load that is capable of reliably and consistently reducing net loading on desired distribution infrastructure. These Distribution Capacity services can be provided by a single DER resource and/or an aggregated set of DER resources that reduce the net loading on a specific distribution infrastructure location coincident with the identified operational need in response to a control signal from the utility.

Examples of traditional "Wires" equipment that currently support providing this type of service include, but are not limited to: transformers, overhead and underground line conductors, circuit breakers, and line and substation switches.

Voltage Support

Voltage support services are defined as a substation and/or feeder level dynamic voltage management services provided by an individual resource and/or aggregated resources capable of dynamically correcting excursions outside voltage limits as well as supporting conservation voltage reduction strategies in coordination with utility voltage/reactive power control systems. DERs providing these services will be delivering or absorbing real or reactive power (var) or a combination thereof to ensure the voltage is within Rule 2[175] limits.

Examples of traditional "Wires" equipment that currently support providing this type of service include, but not limited to, fixed or switchable capacitors, fixed or switchable variable voltage regulators, overhead and underground line conductors, substation load tap changers, and reactors.

Reliability (Back-Tie)

Reliability (back-tie) services are defined as load modifying or supply services capable of improving local distribution reliability and/or resiliency. Specifically, these services provide a fast reconnection and availability of excess reserves to reduce demand when restoring customers during abnormal configurations. These Reliability back-tie services can be provided by a single DER resource and/or an aggregated set of DER resources that are able to reduce the net loading on specific distribution infrastructure coincident with the identified operational need in response to a control signal from the utility.

Examples of traditional "Wires" equipment that currently support providing this type of service include: circuit breakers and relays, reclosers and recloser controllers, switches, sectionalizers, fault interrupters, SCADA, and FLISR (Fault Location, Isolation and Service Restoration).

Resiliency (Microgrid)

Reliability (Microgrid) services are defined as load modifying or supply services capable of improving local distribution reliability and/or resiliency. Specifically, these services provide a fast reconnection and availability of excess reserves to reduce demand when restoring customers during abnormal configurations.

In addition, this service will also provide power to islanded end use customers when central power is not supplied as well as reduce duration of outages. These resiliency services can be provided by a single DER resource and/or an aggregated set of DER resources that are able to reduce the net loading on specific distribution infrastructure coincident with the identified operational need in response to a control signal from the utility. In a microgrid application it is necessary for a system to match generation to load while maintaining voltage, frequency, power factor and power quality within appropriate limits. This requires an isochronous supply resource.

Examples of traditional "Wires" equipment that currently support providing this type of service include: circuit breakers and relays, reclosers and recloser controllers, switches, sectionalizers, fault interrupters, SCADA, FLISR (Fault Location, Isolation and Service Restoration), and DERMS (Distributed Energy Resource Management Systems).

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