


# MODERN DISTRIBUTION GRID (DSPx)

## Volume I: Objective Driven Functionality

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# DISCLAIMER



## COVER PHOTO CREDITS

**Top:** The Ántukš-Tińqapapt or "sun trap" solar array recently installed by the Confederated Tribes of the Umatilla Indian Reservation in Oregon. Courtesy of the U.S. Department of Energy.

**Middle:** NREL-owned electric vehicles below solar canopy at the Vehicle Testing & Integration Facility. Courtesy of the U.S. Department of Energy.

**Bottom Left:** Smart Meters in Washington, DC. Photo by Patricia D'Costa. Courtesy of ICF.

**Bottom Right:** Lotus Energy designed a solar plus storage system. Photo by Christine Bennett. Courtesy of the U.S. Department of Energy.

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# GLOSSARY

A glossary is provided below for industry and technology terms 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 and resilience.

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 another 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.

Structure is an architectural structure created by the configuration of functional partitions 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 is typically at a distribution substation. 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 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. [4]

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.[5]

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.[6]

Electric Vehicles (EVs) (also known as plug-in electric vehicles) typically derive all or part of their power from electricity. They include all-electric vehicles (AEVs) and plug-in hybrid electric vehicles (PHEVs).

Outage Management System (OMS) is a computer-aided system used by operators of electric utilities to better manage their response to power outages.[7]

Supervisory Control and Data Acquisition (SCADA) systems operate with coded signals over communications channels to provide control of remote equipment of assets.[8]

Var is the standard abbreviation for volt-ampere-reactive, written "var,"[9] which results when electric power is delivered to an inductive load such as a motor.[10]

# INTRODUCTION

## PURPOSE

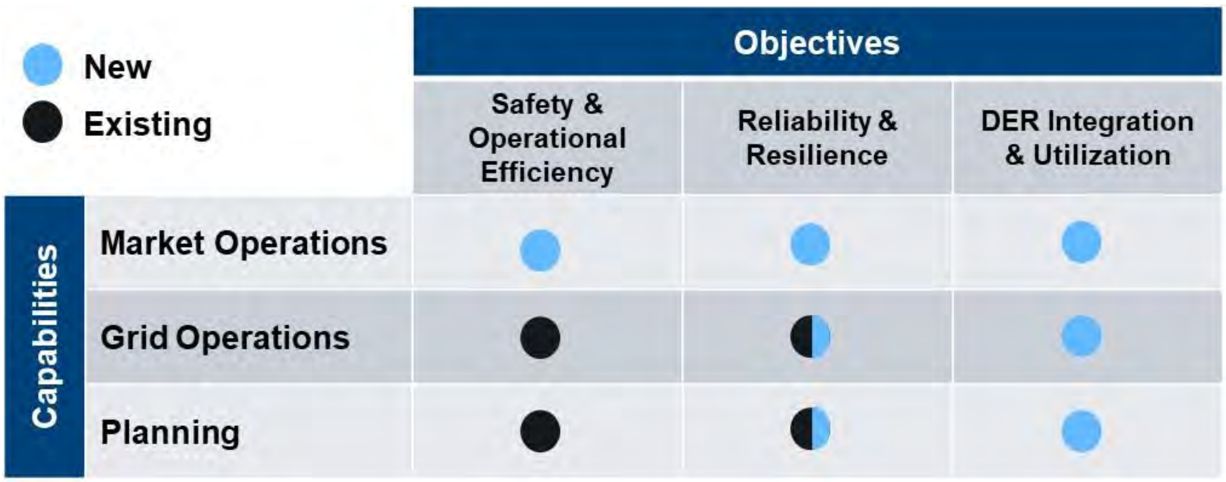
The U.S. Department of Energy is working with state regulators, the utility industry, energy services companies, and technology developers to determine the functional requirements for a modern distribution grid that provides enhanced safety, reliability, resilience and operational efficiency, and integrates and utilizes distributed energy resources (DERs). The objective is to develop a common framework for distribution grid modernization that establishes a consistent understanding of functional requirements necessary to inform investments in grid modernization and serve as a guide for the industry. These requirements include those needed to support grid planning, operations, and markets.

The Modern Distribution Grid taxonomy framework provides a line of sight between the sponsoring regulatory commissions' policy objectives, desired attributes of a modern grid platform employing the grid architecture methodology described in this volume, functional requirements, and ultimately the technology needed. The taxonomy in this report provides a line-of-sight from objectives and capabilities 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 summary of the analysis is more useful to understand the relation of outcomes of interest to policymakers, utilities, services providers, and other stakeholders to the required technologies. In concept, the starting point of a modern grid is a foundation built upon enhancements to safety and operational efficiency, and reliability and resilience. This is augmented with new functions and technology to support grid resilience as well as to enable DER integration and utilization for grid services in line with the timing, scale, and scope of customer adoption and value for all customers. This additional layer of functionality and related technology deployment is represented by the overlapping areas of the Venn diagram in Figure 1.

**Figure 1: Grid Modernization Scope**

These three general outcomes or objectives categories are supported by related business functions and technology investments that work together to create an enabling platform. These objective categories map to capability groups shown in Figure 2 below. The gray dots identify aspects that currently exist, and the blue dots identify the areas of enhancement needed to fully support the additional objectives that may be desired. In the case of reliability and resilience; reliability planning and operations capabilities exist, but resilience planning and operations is an emerging area for most of the U.S. in relation to applying grid modernization technology.

**Figure 2: Objectives in Relation to Grid Capabilities**




Finally, the evolution of a modern grid is ultimately specific to individual utility situations and will necessarily need to align with the pace and scope of the specific customer needs, jurisdictional objectives and value for all customers.

## APPROACH AND ORGANIZATION

The approach to developing Volume I involved extensive use of existing reference material and 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. This revision also reflects a 15-year time-horizon, compared with the original five-year horizon based on industry and regulatory feedback. 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:

- **15-year time horizon**: This initiative focuses on the set of potential functions and related technologies that may be required over the next 15 years to support customers' needs and state 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. It is recognized that aspects of the taxonomy presented, including objectives and functions, are situation dependent. Nothing in this Modern Distribution Grid Report should be construed to imply that all utilities should have all of these functions.

Volume I includes three chapters follow a taxonomy, described in Chapter 1. The taxonomy structure includes the following levels: L0) policy principles, L1) state policy objectives, L2) grid capabilities, L3) functionalities and L4) technologies. 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:** Examines a cross-section of U.S. states' legislative and regulatory documents to extract objectives with respect to a future grid. Chapter 1 provides a summary of this analysis across states and draws out a set of key objectives for a modern grid.

**Chapter 2 – Capabilities**: Identifies grid capabilities in relation to the policy objectives analysis in Chapter 1.

**Chapter 3 – Functionalities:** Identifies and defines reference business functions in relation to the identified grid capabilities in Chapter 2.

Chapters 1-3 in Volume I are organized into three general categories in order to support development of detailed capability and function definitions: Distribution System Planning, Distribution Grid Operations, and Distribution Market Operations. This follows a similar organizational structure used in the NYPSC's Distributed System Implementation Plan (DSIP) guidance and other industry characterizations.[11]

These general categories are defined as follows:

- **Distribution System Planning:** An integrated planning approach that assesses physical and operational changes to the electric distribution grid necessary to enable safe, reliable, resilient 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, reliable and resilient 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, reliability and resilience, 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 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, reliability and resilience. These are often described as non-wires alternatives or non-wires solutions.[12, 13]

# TAXONOMY FRAMEWORK

A grid architecture provides a holistic view of what is to be developed. The architectural approach starts with an enumeration of various drivers including emerging trends, systemic issues, user or customer needs, and public policies. These drivers must be collected and broken down into component parts and organized into a logical structure. Such a breakdown is not just useful for the architects, but also 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, a multi-level taxonomy was employed to logically organize and align the identified objectives, capabilities, and functionalities of a modern grid drawn from a set of existing state principles.[14] This taxonomy framework (DSPx taxonomy) seeks to provide a line-of-sight between what states are aiming to achieve (i.e., policy principles and key objectives of a modern grid), and how distribution system capabilities, functionalities, and related technologies can align to enable the full participation of DERs in the provision of electricity services.

In this updated Version 2 of Volume I, the DSPx taxonomy has been simplified to improve the practical use of the framework. The updated taxonomy includes a five-level structure to logically organize and align the identified objectives, capabilities, and functionalities of a modern grid. A Level 0 was added to indicate policy principles, which can help clarify or identify objectives in Level 1. In addition, the attributes were consolidated into objectives or capabilities, while the function and elements were consolidated into functionalities, describing only the operational definition and reducing duplication. These refinements were based on feedback from industry and regulatory staff experience. The revised framework is illustrated below in Figure 3 with further explanation of the levels provided below.

Figure 3: Revised DSPx Taxonomy Framework


Level 0 – Principles: ***A principle is a fundamental proposition that serves as the foundation for a chain of reasoning.*** A jurisdiction's or utility's existing principles (or mission) provide the foundational context for grid modernization.

Level 1 – Objectives: ***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 the 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. In some instances, these objectives are also called Grid Modernization "principles" (e.g., *see* Hawaii PUC Order 35268).

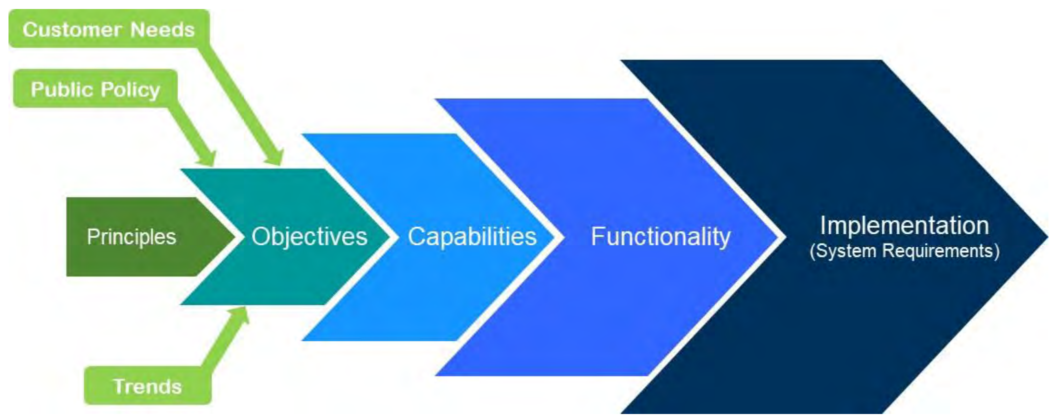
Level 2 – Capabilities: ***A capability is the ability to execute a specific course of action or set of qualities.*** Capabilities are distilled from key industry documents to guide the functionality of the next generation distribution system. Each capability can be thought of as a broad "bucket," containing several underlying business functions and functional elements (e.g., *see* PNNL GA 2016: Situational Awareness).

Level 3 – Functionalities: ***A functionality 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., *see* NY MDPT Report 8/2015: Monitoring and Observability; Coordination and Control).

Level 4 – Technologies: ***A technology provides the functional requirements for the system (i.e., a combination of hardware and software technologies) to perform a set of functionalities.*** This level includes identification of technology solutions that can meet use cases following specific business and technical requirements (e.g., asset management tools, operational systems, data and analytics platform).

This volume introduces mission statements and principles at Level 0 as a way to inform the development of grid modernization objectives. These may echo general organizational mission statements or principles, or in some cases, jurisdictions have developed a set of guiding principles specific to grid modernization. In either instance, these principles provide the foundational reference for the logical structure that is the DSPx taxonomy. As illustrated in Figure 4 below, the level of complexity grows as the level of information and details expand from a very small set of principles to ultimately thousands of business and technical requirements. This logical structure provides a line of sight from an objective to technology selection and deployment.

**Figure 4: Taxonomy Logical Structure**




For context with other industry taxonomy models, 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[15] and the Gridwise Architecture Council's (GWAC) Interoperability Context-Setting Framework.[16] As noted in these models and companion documentation, the policy and business functions served as the reference point for technology design considerations. Technology design and system requirements are Level 4 in the revised 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.  Figure 5 below illustrates the interrelationship between these models.

**Figure 5: Reference Models Interrelationships**

# 1. OBJECTIVES FOR A MODERN GRID

## 1.1 STATE OBJECTIVES

### 1.1.1 Overview and Purpose

Many parts of the country are experiencing fundamental changes in customer expectations for distribution grid performance, with a large number of customers utilizing the grid to integrate DER and other new technologies or seeking a platform for market transactions. Even in areas in which such demands are muted, the grid faces new challenges in fulfilling its role of delivering reliable, affordable power. These challenges include:

- Customer service expectations and requirements to support new energy technologies, some of which have low tolerances for disturbances or produce multi-directional power flow;
- Increased threats to the system from environmental, electromagnetic, physical and cyber events;
- The need to improve capital and system efficiencies to reduce outages, enhance customer satisfaction and affordability; and
- The ability of the distribution platform to enable the utilization of distributed resources to provide alternatives to traditional investment and bulk power services.

A modernized grid possesses attributes and delivers services that enhance customer value and avoids imposing the cost of capabilities and functionalities that are neither desired nor valued on customers. This may seem self-evident, but it is important to expressly incorporate customer expectations, as articulated in state policy objectives, into any grid planning and modernization efforts.

Since the cost of the grid is typically socialized over a broad customer base, including customers with varying needs and tolerances for rate increases, regulators and customers want to know the value proposition of any proposed changes in the grid in order to justify rate recovery. Regulators are unlikely to approve 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 the 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.

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 fundamentally similar operational needs for safety, operational efficiency, reliability, resilience and enabling customer choice. Jurisdictional and geographic differences shape approaches to resilience and DER integration and utilization. As discussed below, this can be seen by looking at states such as California, New York, the District of Columbia, Minnesota, and Hawaii, and others, including non-ISO/RTO states such as Oregon, Florida, and North Carolina (only part of which is in an RTO), all of which have commenced grid modernization proceedings.

Examining each state's objectives for a future grid reveals an emerging consensus around certain key concerns, such as reliability, resilience, integration of newer technologies, environmental responsibility, and response to more complex customer demands, including for distributed generation and "smart" services. Different states might rank their concerns differently and have different timelines over which these policy objectives will be addressed. However, when looking at the distribution system platform, similar technical issues and functionality will need to be considered across all states, albeit at differing paces and scope.

As noted above, in this updated volume, state regulatory principles (and mission statements) are introduced as a starting point to inform the development of grid modernization objectives. These principles provide the foundational reference for the logical structure that is the DSPx taxonomy. 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, resilience or enabling DER integration and present the first level in the DSPx taxonomy. The second level in the taxonomy refers to the grid "capabilities" desired to accomplish the objectives, followed by the "functionalities" the grid may perform to enable the capabilities.

The grid modernization objectives identified in this initiative are based on a cross-cutting survey of eleven jurisdictions' policy principles or vision that are also representative of the breadth of other states' direction. These objectives and desired capabilities represent a range of potential future distribution systems. 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

#### Selected States

In 2016, when the DSPx initiative was launched, a sample of 10 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 principles and objectives. For most of the states, the objectives for grid modernization were drawn directly from legislative or regulatory documents in the assumption 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 to the utilities. For this reason, literature sources in these two states also include utility filings related to grid modernization technology deployment. Table 1 details the resources used to extract objectives in 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.<br>❖ Oregon 10-Year Energy Action Plan, 2012. |
| **North Carolina** | ❖ Docket E-100, SUB 126, 2012.<br>❖ Duke NC Smart Grid Technology Plan, 2014. |
| **Florida** | ❖ Florida Energy Efficiency and Conservation Act (FEECA) Report, 2006.<br>❖ 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.<br>❖ Rule 25.130 Advanced Metering.<br>❖ 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. Accordingly, the objectives should be read as collectively indicative of states' interests at that time, with the understanding that any particular state's objectives may be further developed and refined.

**Normalized State Objectives Definitions**

A normalized set of definitions was developed for the identified state objectives, using a common language to express similar concepts, for ease of comparison and interpretation. Figure 6 illustrates the result of this analysis in a matrix identifying the normalized objectives in relation to a respective state's current policies. State regulatory participants and industry experts reviewed and validated these materials throughout an engagement process.

### 1.1.3 Objectives

**Safety:** Operate the distribution grid in a manner that ensures public and workforce safety, operational risk management, and appropriate fail-safe modes.[17]

**Affordability:** Provide efficient, cost-effective, and accessible grid platforms for new products, new services, and opportunities for adoption of new distributed technologies.[18]

**Reliability:** Operate the power system within thermal, voltage and stability limits to withstand sudden disturbance or unanticipated failure of elements and maintain electric delivery within accepted standards.[19]

**Resilience:** Withstand grid stress events without suffering operational compromise or to adapt to the strain so as to minimize compromise via graceful degradation.[20]

**Technology Innovation:** Enable customer adoption of new and clean grid technologies to facilitate greater customer choice and resource diversity; to improve resilience, reliability, and security; and to foster economic growth and provide system and customer benefits.[21]

**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.[22]

**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.[23, 24]

**Cyber-physical Security:** Apply 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.[25]

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

**Emissions Reduction:** Reduce carbon dioxide emissions and other greenhouse gases. 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]

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

**Operational Excellence:** Enhance customer service and optimized utilization of electricity grid assets and resources to minimize total system costs.[28,29]

**DER Integration:** Ensure that the grid can integrate or host DER with the necessary communication and cyber-physical security protocols and operational coordination mechanisms.

**DER Utilization:** Enable the provision of energy, ancillary services, and/or non-wires alternative services from DER to improve system efficiencies and customer benefits.

**Electrification:** Enable substitution of direct combustion-based fuels (e.g. gasoline, diesel, or natural gas) for electricity in the transportation, building, and industrial sector.[30]

### 1.1.4 Key Findings

Figure 6 below provides a summary of the comparative assessment reflecting normalized labels for each objective based on the respective states' descriptions. Safety, reliability, affordability, resilience, technology innovation, customer enablement, system efficiency, cyber-physical security, emissions reduction, operational excellence, DER integration, DER utilization, and electrification are all identified as objectives. While there is a common interest in DER integration, the use of DERs as non-wires alternatives is fairly nascent.

In the previous version of this volume, flexibility and transparency were characterized as states' attributes; in this updated volume, they are included as capabilities. The states documents reviewed reflected the need for flexibility based on the ongoing changes in customer expectations and DER adoption creating 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 seeking to improve customer enablement that supports DER integration. To date, this has focused on increasing stakeholder visibility into the distribution planning processes (e.g., assumptions, methods, etc.).

**Figure 6: Normalized State Objectives**

| OBJECTIVES | CA | DC | FL | HI | IL | MA | MN | NC | NY | OR | TX |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Safety | • | • | • | • | • | • | • | • | • | • | • |
| Reliability | • | • | • | • | • | • | • | • | • | • | • |
| Affordability | • | • | • | • | • | • | • | • | • | • | • |
| Resilience | • | • | • | • | • | • | • | • | • | • | • |
| Technology Innovation | • | • | • | • | • | • |  | • | • | • | • |
| Customer Enablement | • | • | • | • | • | • | • | • | • | • | • |
| System Efficiency | • | • | • | • | • | • | • | • | • | • | • |
| Cyber-physical Security | • | • | • | • | • | • | • | • | • | • | • |
| Emissions Reduction | • | • |  | • | • | • | • | • | • | • |  |
| Operational Excellence | • | • | • | • | • | • | • | • | • | • | • |
| DER Integration | • | • | • | • | • | • | • | • | • | • | • |
| DER Utilization | • | • |  | • |  | • | • |  | • | • |  |
| Electrification | • | • |  | • | • | • | • | • | • | • |  |

In sum, the industry's long-term goals of delivering safe, reliable, and affordable service and achieving a high degree of customer satisfaction are reflected in these objectives. The objectives that are explicitly linked to new challenges build upon and support these priority areas. For example, the strong interest in DER integration supports customer enablement and emissions reduction. While the grid will need to be able to interconnect new customer-selected technologies without a loss of safety, reliability, or resilience. In addition, more states are looking at microgrids and local generation to facilitate reliability and resiliency. The interest in system efficiency reflects a continuing concern with cost containment and affordability, as well as conservation of resources. Similarly, the interest in DER utilization and technology innovation is directly related to seeking lower-cost alternatives to traditional grid investments to address affordability of electric service. Additionally, customer enablement, including opportunities for customers to participate in energy markets, is an element of customer satisfaction. Overall, the key objectives reinforce one another to advance traditional and new goals, through a modern grid tailored to meet 21st-century challenges and customer demands.

# 2. CAPABILITIES

## OVERVIEW

A capability is the ability to execute a specified course of action or qualities as identified in the states' objectives 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 initially drawn from PNNL's 2015 Grid Architecture report, California's More Than Smart report, and subsequently informed by direct feedback from industry and commissions through DSPx initiative engagement.[31] Figure 7 highlights the 28 capabilities associated with the reference objectives. In this updated version of Volume I, the capabilities have been modified to include flexibility and workforce management under Distribution Grid Operations and a modification to the definition of local grid optimization under Distribution Market Operations.

**Figure 7: Capabilities**

| Distribution System Planning | Distribution Grid Operations | | Distribution Market Operations |
|---|---|---|---|
| Scalability 2.1.1 | Operational Risk Management 2.2.1 | Situational Awareness 2.2.2 | Distribution Investment Optimization 2.3.1 |
| Impact Resistance and Impact Resiliency 2.1.2 | Controllability and Dynamic Stability 2.2.3 | Management of DER and Load Stochasticity 2.2.4 | Distribution Asset Optimization 2.3.2 |
| Open and Interoperable 2.1.3 | Contingency Management 2.2.5 | Security 2.2.6 | Market Animation 2.3.3 |
| Accommodate Tech Innovation 2.1.4 | Public and Workforce Safety 2.2.7 | Fail Safe Modes 2.2.8 | System Performance 2.3.4 |
| Convergence with other Critical Infrastructure 2.1.5 | Attack Resistance / Fault Tolerance / Self-Healing 2.2.9 | Reliability and Resilience Management 2.2.10 | Environmental Management 2.3.5 |
| Accommodate New Business Models 2.1.6 | Integrated Grid Coordination 2.2.11 | Control Federation and Control Disaggregation 2.2.12 | Local Grid Optimization 2.3.6 |
| Transparency 2.1.7 | Privacy and Confidentiality 2.2.13 | Flexibility 2.2.14 | |
| | Workforce Management 2.2.15 | | |

# 2.1 DISTRIBUTION SYSTEM PLANNING

## 2.1.1. Scalability

The capability of the distribution grid and related operational and market systems to increase capacity with additional resources rather than an extensive modification or replacement of the cyber-physical systems, while delivering the same quality of service with no impact to performance, reliability, resilience and interoperability.[32]

## 2.1.2 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.

## 2.2.3 Open and Interoperable

Enable active participation by customers, and accommodate 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.[33]

## 2.2.4 Accommodate Technological 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 provides access to system, customer and third-party data (as needed) to animate market innovation.[34]

## 2.2.5 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.[35]

## 2.2.6 Accommodate New Business Models

Enables integration of new products and services that provide additional value beyond traditional electric energy and delivery. These include non-energy adjacent services providers seeking to create convergent value across critical infrastructure networks, as in smart city initiatives, for example.[36]

## 2.2.7 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.

# 2.2. DISTRIBUTION GRID OPERATIONS

## 2.2.1 Operational Risk Management

Operational Risk Management (ORM) examines core operations including energy delivery reliability and resilience 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, such as:

- 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.[37]

## 2.2.2 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.[38]

## 2.2.3 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 and resilience issues instead of cascading failures, for example), but the basic principle of stability is the same.

## 2.2.4 Management of DER and Load Stochasticity

Management of DER and load stochasticity is the ability to assess and respond to changes with minimal cost and emissions impacts while maintaining reliability.[39]

### 2.2.5 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 an 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.[40]

### 2.2.6 Security

Physical security and cybersecurity measures include activities that detect and respond to man-made and environmental threats and to 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 computer or data integrity. This also recognizes the increasing interdependencies between physical and secure information and communication systems.[41]

### 2.2.7 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.[42]

### 2.2.8 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.

### 2.2.9 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 the 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 the safety of the distribution grid.[43] It may also include device-level control limiters that prevent a device from being commanded into out-of-band operation.

### 2.2.10 Reliability and Resiliency Management

Reliability and resiliency management provide adequate, efficient, safe, and reasonable service and facilities, and make 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. The 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.[44]

### 2.2.11 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 bulk system Balancing Authority (a utility Transmission System Operator (TSO) or an Independent System Operator (ISO)/Regional Transmission Operator (RTO)).[45, 46]

### 2.2.12 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.[47]

### 2.2.13 Privacy and Confidentiality

Privacy and confidentiality allow users to maintain control over the collection, use, reuse, and sharing of personal and commercial information as it 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.[48]

### 2.2.14 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.

### 2.2.15 Workforce Management

Enabling an electricity industry workforce to meet the needs of the 21st-century electricity system including the management of workflow as well as the information and tools to perform work on a technology-driven power system.[49]

# 2.3 DISTRIBUTION MARKET OPERATIONS

## 2.3.1 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 that addresses 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, resilience and capacity.

## 2.3.2 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.

## 2.3.3 Market Animation

Market animation involves establishing transparent distribution operational markets to enable viable market development for grid services with deep participation, to achieve a more efficient and secure electric system including better utilization of the distribution system, as well as transmission system and bulk generation.[50]

## 2.3.4 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.[51]

## 2.3.5 Environmental Management

Environment management involves the use and optimization of DERs along with centralized clean resources to meet federal, state, and local environmental targets.[52]

## 2.3.6 Local Grid Optimization

Strategic use of grid assets, DERs, and platform technologies to economically locate, place, manage, and operate a distribution system to meet local performance requirements including least-cost service, resilience, reliability, and power quality.[53] Local grid optimization may include an assessment of the impacts of local actions on the overall distribution system and vice-versa.

## 2.4 OBJECTIVES TO CAPABILITIES MAPPING

The purpose of Figure 8 below is to highlight, in matrix form, the key relationships between capabilities and (possibly) multiple objectives. It is these types of capability-to-objectives relationships that allow identification of stat priority and foundational areas for grid modernization in the context of other factors such as timing and affordability.

**Figure 8: Objectives to Capabilities Mapping**

| CAPABILITIES | | OBJECTIVES: Safety | Affordability | Reliability | Resilience | Technology Innovation | Customer Enablement | System Efficiency | Cyber-physical Security | Emissions Reduction | Operational Excellence | DER Integration | DER Utilization | Electrification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.1.1 | Scalability | | • | • | • | • | • | • | | | • | • | | • |
| 2.1.2 | Impact Resistance and Impact Resiliency | • | | • | • | | | | • | | | | | • |
| 2.1.3 | Open and Interoperable | | • | • | | • | • | • | | | • | • | • | • |
| 2.1.4 | Accommodate Tech Innovation | • | • | • | • | • | • | • | • | • | • | • | • | • |
| 2.1.5 | Convergence with other Critical Infrastructure | | • | • | • | | • | • | | | • | | | |
| 2.1.6 | Accommodate New Business Models | | • | | | • | • | | | • | • | • | • | • |
| 2.1.7 | Transparency | • | • | • | | • | • | • | | | | • | • | |
| 2.2.1 | Operational Risk Management | • | • | • | • | | | • | • | | • | | | |
| 2.2.2 | Situational Awareness | • | • | • | • | | | • | • | | • | • | • | • |
| 2.2.3 | Controllability and Dynamic Stability | | | • | | | | • | | • | | | | |
| 2.2.4 | Management of DER and Load Stochasticity | | • | | • | | | • | | • | • | • | | • |
| 2.2.5 | Contingency Management | | | • | | | | • | • | • | • | | | |
| 2.2.6 | Security | | | • | | | | | • | | • | • | • | • |
| 2.2.7 | Public and Workforce Safety | • | | • | | | • | | • | • | • | | | |

| | CAPABILITIES | Safety | Affordability | Reliability | Resilience | Technology Innovation | Customer Enablement | System Efficiency | Cyber-physical Security | Emissions Reduction | Operational Excellence | DER Integration | DER Utilization | Electrification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.2.8 | Fail Safe Modes | | • | • | • | | | • | | | | | | |
| 2.2.9 | Attack Resistance / Fault Tolerance / Self-Healing | | • | • | • | | | • | | | • | | | |
| 2.2.10 | Reliability and Resiliency Management | • | | • | | | | • | • | | • | • | | |
| 2.2.11 | Integrated Grid Coordination | • | • | | • | | | • | • | | • | | • | |
| 2.2.12 | Control Federation and Control Disaggregation | | | • | | | | • | | | • | | • | |
| 2.2.13 | Privacy and Confidentiality | • | | | | | • | | • | | | • | • | |
| 2.2.14 | Flexibility | | | | • | • | | • | | | • | • | • | • |
| 2.2.15 | Workforce Management | • | • | • | • | • | | | • | | • | | | |
| 2.3.1 | Distribution Investment Optimization | | • | • | • | • | | • | | | • | • | • | • |
| 2.3.2 | Distribution Asset Optimization | | • | • | • | • | | • | | | • | • | • | |
| 2.3.3 | Market Animation | | • | | • | • | • | • | | • | | • | • | |
| 2.3.4 | System Performance | • | • | • | | | | • | • | | | | | |
| 2.3.5 | Environmental Management | | | | | • | • | | | • | • | | | |
| 2.3.6 | Local Grid Optimization | • | • | • | | | | • | • | | | | | |

# 3 FUNCTIONALITIES

## OVERVIEW

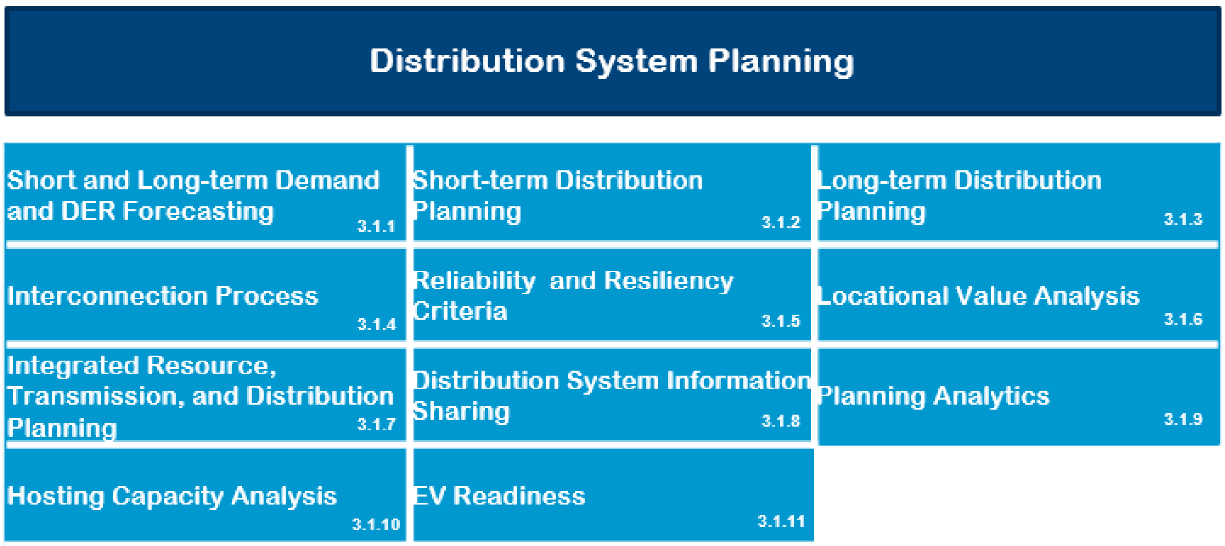
A “functionality” defines a process, behavior, or operational result of a process to enable a capability linked to one or more policy objectives. These functionalities include the people, processes, and technologies that will be needed. Similar to the capabilities in Chapter 2, these functionalities are also organized into three groups: Distribution System Planning, Distribution Grid Operations, and Distribution Market Operations. The operational descriptions that follow for each functionality 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 functionalities 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 1, these items may also guide and influence the policy objectives of other states as well.

In this volume, a simplified reference set of functionalities are provided in Figures 9-11 below. This list consolidates the prior list of functions and sub-functional elements from the original version of this volume. In practice, the functional decomposition proved to be unnecessarily complicated for grid modernization strategic planning purposes. This revised list, organized by functional area, also includes new functions based on industry and regulatory staff feedback. For example, short-term and long-term distribution planning, reliability and resilience criteria, DER integration, and EV readiness are all new functionalities included under Distribution System Planning. Under Distribution Market Operations, market settlement under was consolidated into settlement and market surveillance was consolidated into market oversight.

## 3.1 DISTRIBUTION SYSTEM PLANNING

Figure 9 summarizes the revised functionalities under Distribution System Planning.

**Figure 9: Distribution System Planning Functionalities**




### 3.1.1 Short and Long-term Demand and DER Forecasting

Electricity consumption is forecasted for a distribution circuit (or more granular) based on the forecast gross load, including any growth forecast from electrification. Additional layers are considered for each type of forecasted 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). Longer-term forecasts may include multiple scenarios of demand growth and DER forecasts.

Multiple DER forecast scenarios reflecting potential changes in DER and loads (see 4.1.2) and use cases to assess current system capabilities needed may be employed to identify incremental infrastructure requirements and enable analysis of the locational value of DERs.[54]

### 3.1.2 Short-term Distribution Planning

Assessment of distribution system needs over a one- to three-year horizon, including identification of capital projects and costs estimated to accommodate customer load growth, grid reliability, resilience and safety, interconnected resources, and customer service connections.[55] These potential infrastructure upgrades are defined into specific projects with estimated engineering, equipment and construction costs and need dates. These estimates are incorporated in budget forecasts, rate cases and used as basis for avoided cost in a locational benefits analysis.

### 3.1.3 Long-term Distribution Planning

Multiple scenario-based assessment of distribution system needs over a three- to 10-year horizon including potential operational changes to system configuration, needed infrastructure replacement, upgrades and modernization investments, and potential for non-wires alternatives.[56] A qualified subset of upgrade projects suitable for non-wires alternatives are subsequently identified.[57]

### 3.1.4 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.

Feasibility and system impact studies are critical aspects of an interconnection application to assess potential grid impacts that would result if the proposed distributed generation were interconnected without DER modifications or distribution system modifications. 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.[58]

### 3.1.5 Reliability and Resiliency Criteria

Technical planning criteria used to assess the operational performance of the distribution system in terms of availability and robustness and inform the identification of upgrades needed to improve performance to acceptable levels.

### 3.1.6 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 forms 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.[59]

### 3.1.7 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 states with vertically-integrated utilities, such as Minnesota, it is important to coordinate changes to distribution planning with integrated resource and transmission planning.[60] 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[61]

### 3.1.8 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.

### 3.1.9 Planning Analytics

Planning 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.[62]

### 3.1.10 Hosting Capacity Analysis

Hosting capacity is defined as the amount of DER that can be accommodated without adversely impacting power quality, reliability or resilience under existing control and protection systems and without requiring infrastructure upgrades. 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.[63]

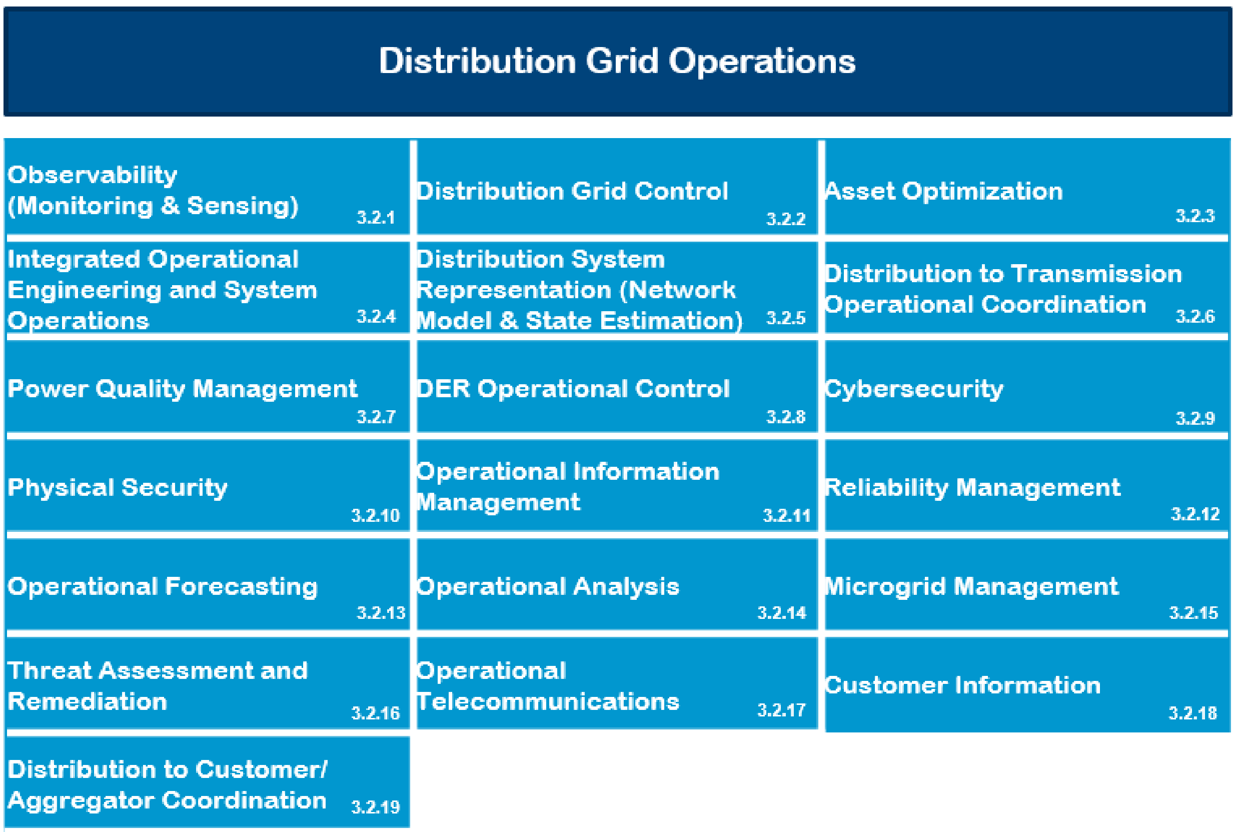
### 3.1.11 EV Readiness

Enable the advancement of transportation electrification by upgrading and enhancing the distribution cyber-physical infrastructure and systems as needed to support the adoption of personal vehicles, commercial fleets, and public transportation.[64] This may also include charging infrastructure depending on the jurisdiction.

## 3.2 DISTRIBUTION GRID OPERATIONS

Figure 10 summarizes the revised functionalities under Distribution System Operations.

Figure 10. Distribution Grid Operations Functionalities




### 3.2.1 Observability (Monitoring & Sensing)

The ability to provide actionable information on the operating state and condition of the distribution grid, grid and DER assets, and environmental conditions necessary to safely, securely, and reliably operate the electric system. It includes visibility, which is the ability to obtain timely sensing and measurement data.

### 3.2.2 Distribution Grid Control

The ability to manage distribution power flows while maintaining distribution operational parameters (e.g., voltage, reactive power, and power quality) within specific operating ranges through the application of performance criteria to the dynamic management of grid devices and DER in response to changes in load and injected power flows, and system disturbances.[65]

### 3.2.3 Asset Optimization

Asset optimization refers to analytical functionality integrated with decision support systems and/or operational controls to optimize the performance of grid reliability, resilience, efficiency, hosting capacity, as well as related work and resource management.[66]

### 3.2.4 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.[67]

### 3.2.5 Distribution System Representation (Network Model & State Estimation)

A topological model of the physical distribution system, and customer and DER connectivity (including asset characteristics) that reflects dynamic changes to the state of the system.[68]

### 3.2.6 Distribution to Transmission Operational Coordination

This function ensures reliability, resilience, security 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.[69]

### 3.2.7 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.[70]

### 3.2.8 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 and resilience of the system.[71]

### 3.2.9 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.[72, 73]

### 3.2.10 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.[74]

### 3.2.11 Operational Information Management

Operational data recording, processing, and storage used to support operational businesses functions and related processes.

### 3.2.12 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. The reliability management function involves operations to capture and analyze fault current indicator, meter-level outage information, and real-time customer provided information on outages to improve the identification and isolation of electric distribution system faults, as well as service restoration of unaffected segments. [75]

### 3.2.13 Operational Forecasting

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

### 3.2.14 Operational Analysis

Operational analysis involves the dynamic assessment of the state of the distribution system to inform real-time contingency planning, system operations including switching plans, and operational controls and DER dispatch.

### 3.2.15 Microgrid Management

Coordination of interconnected microgrid operation with a distribution system in normal conditions, island mode, and safely synchronize return to interconnection with a distribution system after islanding is ended.

### 3.2.16 Threat Assessment and Remediation

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.

### 3.2.17 Operational Telecommunications

Operational telecommunication 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 telecommunications are intended to maintain highly reliable connectivity under both normal and degraded system operating conditions (e.g., electrical noise, equipment failure, and physical attacks).[76] However, no communication system is invulnerable to failure, making it a key modern grid design requirement for systems to operate safely and reliably in the event of loss of telecommunication infrastructure connectivity.

### 3.2.18 Customer Information

Provide access to customer energy use data to customers and 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, service quality data, as well as outage information collected by distribution services provider and/or retail energy services provider.

### 3.2.19 Distribution to Customer / Aggregator Coordination

Coordination of the operation of the distribution system with DER operations directly with customer/merchant devices and/or through a market intermediary such as an aggregator to ensure safety, reliability, resilience and security for the electric system and customer assets. This includes the use of grid codes and event notification signals sent to market participants regarding events such as market-based signals; 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.

# 3.3 DISTRIBUTION MARKET OPERATIONS

Figure 11 summarizes the revised functionalities under Distribution Market Operations.

**Figure 11: Distribution Market Operations Functionalities**

| Distribution Market Operations | | |
|---|---|---|
| DER Aggregation to Distribution and/or Wholesale Market 3.3.1 | Solution Sourcing 3.3.2 | Solution Evaluation 3.3.3 |
| Market Information Sharing 3.3.4 | Market Oversight 3.3.5 | Solutions Portfolio Optimization 3.3.6 |
| Advanced Pricing 3.3.7 | Programs 3.3.8 | Market Participant Rules 3.3.9 |
| Market Clearing & Settlement 3.3.10 | Billing 3.3.11 | Market Security and Cybersecurity 3.3.12 |

## 3.3.1 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.[77]

## 3.3.2 Solution Sourcing

Distribution operational markets 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 planning process defines the need for these grid operational services.[78,79]

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.

### 3.3.3 Solution Evaluation

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).[80]

### 3.3.4 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).[81]

### 3.3.5 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.[82]

### 3.3.6 Solutions Portfolio Optimization

Operational utilization of sourced grid solutions under changes to solution capabilities, and availability, or grid operational conditions to achieve optimal performance in terms of addressing system requirements and customer value.

### 3.3.7 Advanced Pricing

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.

### 3.3.8 Programs

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.[83]

### 3.3.9 Market Participant Rules

This set of rules defines the requirements and responsibilities of market participants regarding service delivery and compliance standards. Market participants include DER providers or directly participating customers. Market participants may need to regularly communicate specific DER operational data and provide for inter- and intra-day market operations and processes.[84]

### 3.3.10 Market Clearing & Settlement

Confirmation and clearing involve facilitating and selecting multi-party transactions related to market participant commitments based on a system's demand forecast and 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 (M&V).[85]

This serves as the basis of financial settlements for services supplied, identifying the quantity, quality, and timing. The settlement process includes calculating credits and charges for DER services and other market activity. Other market settlement activities include tracking and reconciling discrepancies, managing disputes, and escalations.[86]

### 3.3.11 Billing

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

### 3.3.12 Market Security and Cybersecurity

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. As market data, system data, and third-party data are 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.[87]

## 3.4 CAPABILITIES TO FUNCTIONS MAPPING

Figures 12-14 in Appendix A map how the functionalities described above support the capabilities identified in Chapter 2. These matrices highlight the key relationships between functionalities and multiple capabilities. This functionality-to-capability mapping aids the identification of potential foundational and no-regrets types of investments in related technologies.

# APPENDIX A: CAPABILITIES TO FUNCTIONALITIES MAP

**Figure 12: Capabilities to Functionalities Mapping – Distribution System Planning**

| | | FUNCTIONALITIES | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.1 DISTRIBUTION SYSTEM PLANNING | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| CAPABILITIES | | Short and Long-term Demand and DER Forecasting | Short-term Distribution Planning | Long-term Distribution Planning | Interconnection Process | Reliability and Resiliency Criteria | Locational Value Analysis | Integrated Resource, Transmission, and Distribution Planning | Distribution System Information Sharing | Planning Analytics | Hosting Capacity Analysis | EV Readiness |
| 2.1.1 | Scalability | ● | | ● | ● | ● | | ● | ● | | | |
| 2.1.2 | Impact Resistance and Impact Resiliency | ● | ● | ● | ● | ● | | | | | ● | ● |
| 2.1.3 | Open and Interoperable | | | | ● | | | | ● | | | ● |
| 2.1.4 | Accommodate Tech Innovation | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● |
| 2.1.5 | Convergence with other Critical Infrastructure | ● | ● | ● | | ● | ● | ● | ● | ● | | ● |
| 2.1.6 | Accommodate New Business Models | ● | ● | ● | | | ● | ● | ● | | ● | |
| 2.1.7 | Transparency | ● | ● | ● | ● | ● | ● | ● | ● | | ● | |
| 2.2.1 | Operational Risk Management | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● |
| 2.2.2 | Situational Awareness | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● |
| 2.2.3 | Controllability and Dynamic Stability | ● | | | ● | ● | ● | | | ● | | ● |
| 2.2.4 | Management of DER and Load Stochasticity | ● | ● | ● | ● | | ● | ● | | ● | ● | |
| 2.2.5 | Contingency Management | | ● | ● | ● | ● | ● | ● | | ● | | |
| 2.2.6 | Security | | ● | ● | ● | ● | | | | | | |
| 2.2.7 | Public and Workforce Safety | | ● | ● | ● | ● | | | | | | |

| CAPABILITIES | | FUNCTIONALITIES | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.1 DISTRIBUTION SYSTEM PLANNING | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | | Short and Long-term Demand and DER Forecasting | Short-term Distribution Planning | Long-term Distribution Planning | Interconnection Process | Reliability and Resiliency Criteria | Locational Value Analysis | Integrated Resource, Transmission, and Distribution Planning | Distribution System Information Sharing | Planning Analytics | Hosting Capacity Analysis | EV Readiness |
| 2.2.8 | Fail Safe Modes | | • | • | • | • | | | | | | • |
| 2.2.9 | Attack Resistance / Fault Tolerance / Self-Healing | | • | • | • | • | | • | | • | • | • |
| 2.2.10 | Reliability and Resilience Management | • | • | • | • | • | • | • | • | • | • | • |
| 2.2.11 | Integrated Grid Coordination | • | • | • | | • | • | • | • | • | • | • |
| 2.2.12 | Control Federation and Control Disaggregation | | • | • | • | • | | • | | • | • | • |
| 2.2.13 | Privacy and Confidentiality | | • | • | • | | • | • | • | | • | • |
| 2.2.14 | Flexibility | | • | • | • | • | | | • | • | • | • |
| 2.2.15 | Workforce Management | | • | • | • | • | • | | • | • | • | • |
| 2.3.1 | Distribution Investment Optimization | • | • | • | • | • | • | • | • | • | • | • |
| 2.3.2 | Distribution Asset Optimization | • | • | • | • | • | • | • | • | • | | • |
| 2.3.3 | Market Animation | • | | • | • | | • | • | • | • | • | • |
| 2.3.4 | System Performance | • | • | • | | • | • | • | • | • | | • |
| 2.3.5 | Environmental Management | • | • | • | • | | • | • | • | | • | • |
| 2.3.6 | Local Grid Optimization | • | • | • | • | • | • | | | • | • | • |

### Figure 13: Capabilities to Functions Mapping – Distribution Grid Operations

| | | FUNCTIONALITIES – 3.2 DISTRIBUTION GRID OPERATIONS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| CAPABILITIES | | Observability (Monitoring & Sensing) | Distribution Grid Control | Asset Optimization | Integrated Operational Engineering and System Operations | Distribution System Representation (Network Model & State Estimation) | Distribution to Transmission Operational Coordination | Power Quality Management | DER Operational Control | Cybersecurity | Physical Security | Operational Information Management | Reliability Management | Operational Forecasting | Operational Analysis | Microgrid Management | Threat Assessment and Remediation | Operational Telecommunications | Customer Information | Distribution to Customer/ Aggregator Coordination |
| 2.1.1 | Scalability | ● | ● | ● | ● | ● | | ● | ● | ● | | ● | ● | | ● | ● | ● | ● | ● | ● |
| 2.1.2 | Impact Resistance and Impact Resiliency | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● |
| 2.1.3 | Open and Interoperable | ● | ● | ● | | | ● | ● | ● | | | ● | | | | | | ● | ● | ● |
| 2.1.4 | Accommodate Tech Innovation | ● | ● | ● | ● | | | ● | ● | ● | ● | | | | ● | ● | ● | ● | ● | ● |
| 2.1.5 | Convergence with other Critical Infrastructure | ● | ● | ● | ● | ● | ● | | ● | ● | | | | ● | ● | ● | ● | ● | ● | ● |
| 2.1.6 | Accommodate New Business Models | ● | ● | ● | ● | | | | ● | ● | | | | ● | | ● | ● | ● | ● | ● |
| 2.1.7 | Transparency | | | ● | | | | | | | | | ● | ● | | | | ● | ● | ● |
| 2.2.1 | Operational Risk Management | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● |
| 2.2.2 | Situational Awareness | ● | | | ● | ● | ● | ● | ● | ● | ● | ● | | | ● | | | ● | ● | ● |
| 2.2.3 | Controllability and Dynamic Stability | | ● | ● | | ● | ● | ● | ● | ● | | ● | | | ● | | ● | ● | | ● |
| 2.2.4 | Management of DER and Load Stochasticity | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.2.5 | Contingency Management | ● | ● | ● | ● | | ● | | ● | ● | ● | ● | ● | ● | | ● | ● | ● | | ● |
| 2.2.6 | Security | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● |
| 2.2.7 | Public and Workforce Safety | ● | ● | ● | ● | | ● | | | ● | ● | | ● | ● | | ● | ● | ● | ● | ● |

FUNCTIONALITIES

CAPABILITIES

| | | 3.2 DISTRIBUTION GRID OPERATIONS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | Observability (Monitoring & Sensing) | Distribution Grid Control | Asset Optimization | Integrated Operational Engineering and System Operations | Distribution System Representation (Network Model & State Estimation) | Distribution to Transmission Operational Coordination | Power Quality Management | DER Operational Control | Cybersecurity | Physical Security | Operational Information Management | Reliability Management | Operational Forecasting | Operational Analysis | Microgrid Management | Threat Assessment and Remediation | Operational Telecommunications | Customer Information | Distribution to Customer/ Aggregator Coordination |
| 2.2.8 | Fail Safe Modes | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | ● | ● | | ● | ● | | | ● |
| 2.2.9 | Attack Resistance / Fault Tolerance / Self-Healing | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | | ● | | ● | ● | ● | | ● |
| 2.2.10 | Reliability and Resilience Management | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | | ● | | ● | ● | ● | ● | ● |
| 2.2.11 | Integrated Grid Coordination | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | | ● | ● | ● |
| 2.2.12 | Control Federation and Control Disaggregation | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | | | ● | ● | ● | ● | ● |
| 2.2.13 | Privacy and Confidentiality | ● | | ● | ● | ● | | | ● | ● | ● | ● | | ● | ● | ● | | | ● | ● |
| 2.2.14 | Flexibility | | ● | ● | ● | | ● | ● | ● | ● | | ● | ● | | | ● | ● | ● | | ● |
| 2.2.15 | Workforce Management | | | ● | | | ● | ● | | | ● | ● | ● | ● | ● | | ● | ● | ● | |
| 2.3.1 | Distribution Investment Optimization | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.3.2 | Distribution Asset Optimization | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.3.3 | Market Animation | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | | ● | ● | ● |
| 2.3.4 | System Performance | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.3.5 | Environmental Management | ● | ● | | ● | | ● | | ● | ● | | | | ● | ● | ● | | ● | ● | ● |
| 2.3.6 | Local Grid Optimization | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |

**Figure 14: Capabilities to Functions Mapping – Distribution Market Operations**

| CAPABILITIES | | FUNCTIONALITIES: 3.1 DISTRIBUTION MARKET OPERATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 DER Aggregation to Distribution and/or Wholesale Market | 2 Solution Sourcing | 3 Solution Evaluation | 4 Market Information Sharing | 5 Market Oversight | 6 Solutions Portfolio Optimization | 7 Advanced Pricing | 8 Programs | 9 Market Participant Rules | 10 Market Clearing & Settlement | 11 Billing | 12 Market Security and Cybersecurity |
| 2.1.1 | Scalability | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.1.2 | Impact Resistance and Impact Resiliency | ● | ● | ● | ● | ● | ● | | | ● | | | ● |
| 2.1.3 | Open and Interoperable | ● | ● | | ● | ● | ● | ● | ● | ● | ● | ● | |
| 2.1.4 | Accommodate Tech Innovation | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.1.5 | Convergence with other Critical Infrastructure | | ● | ● | | ● | ● | ● | ● | ● | | ● | ● |
| 2.1.6 | Accommodate New Business Models | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.1.7 | Transparency | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| 2.2.1 | Operational Risk Management | ● | ● | ● | | ● | ● | ● | ● | ● | ● | | ● |
| 2.2.2 | Situational Awareness | ● | ● | | ● | ● | ● | | | ● | ● | ● | ● |
| 2.2.3 | Controllability and Dynamic Stability | ● | ● | ● | | | ● | | ● | | | | ● |
| 2.2.4 | Management of DER and Load Stochasticity | ● | ● | ● | | | ● | ● | ● | ● | ● | | ● |
| 2.2.5 | Contingency Management | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | ● |
| 2.2.6 | Security | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 2.2.7 | Public and Workforce Safety | ● | ● | ● | | ● | ● | | ● | ● | | | ● |

FUNCTIONALITIES

| CAPABILITIES | | 3.1 DISTRIBUTION MARKET OPERATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | | DER Aggregation to Distribution and/or Wholesale Market | Solution Sourcing | Solution Evaluation | Market Information Sharing | Market Oversight | Solutions Portfolio Optimization | Advanced Pricing | Programs | Market Participant Rules | Market Clearing & Settlement | Billing | Market Security and Cybersecurity |
| 2.2.8 | Fail Safe Modes | • | • | • | | | • | | • | | • | | • |
| 2.2.9 | Attack Resistance / Fault Tolerance / Self-Healing | • | • | • | | • | • | • | • | • | • | • | • |
| 2.2.10 | Reliability and Resilience Management | • | • | • | | • | • | • | • | • | • | | • |
| 2.2.11 | Integrated Grid Coordination | • | • | • | | • | • | • | • | • | • | | • |
| 2.2.12 | Control Federation and Control Disaggregation | • | • | • | | | • | | | | • | | • |
| 2.2.13 | Privacy and Confidentiality | • | • | • | • | • | • | • | | • | • | • | • |
| 2.2.14 | Flexibility | • | • | • | • | • | • | • | • | • | • | • | • |
| 2.2.15 | Workforce Management | • | | • | | | | • | • | | | • | |
| 2.3.1 | Distribution Investment Optimization | • | • | • | • | • | • | • | • | • | • | | • |
| 2.3.2 | Distribution Asset Optimization | • | • | • | | • | • | • | • | | • | | • |
| 2.3.3 | Market Animation | • | • | • | • | • | • | • | • | • | • | • | • |
| 2.3.4 | System Performance | • | • | • | | • | • | • | • | • | • | | • |
| 2.3.5 | Environmental Management | • | • | • | • | • | • | • | • | • | • | | |
| 2.3.6 | Local Grid Optimization | • | • | • | • | • | • | • | • | • | • | | • |

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