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# Modern Distribution Grid Decision Guide (Version 3.0)

## Volume I: Objective Driven Functionality

March 2026

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U.S. Department of Energy
ICF

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This paper was prepared by Rosalie Dahyeon Yu of ICF, Surhud Vaidya of ICF, Paul De Martini of Newport Consulting, and Torrey Beek of ICF.

The previous volume (Version 2.0) was collectively developed by Joe Paladino of DOE, Merrill Smith of DOE, Thomas Pearce of DOE, Paul De Martini, Jeff Taft, and Pacific Northwest National Laboratory (PNNL).

# Glossary

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

## Industry Definitions

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

Distribution System is the portion of the electric system that delivers electricity from the transmission system to end-use customers through distribution substations, feeders, transformers, secondary circuits, and related equipment. It is operated and supported 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 Facility Owner or Distribution System Operator Distribution Facility Owner is an entity that owns an electric distribution grid and associated distribution facilities within a defined service territory. Distribution System Operator (DSO) means the entity responsible for planning, monitoring, and operational control of the distribution system to ensure safe and reliable service. In some jurisdictions, the Distribution Facility Owner and the DSO are the same entity; in others, those roles may be functionally distinguished. In vertically integrated or traditionally regulated utility structures, these functions are often performed by the same utility. 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 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.

FERC Order No. 2222, issued by the Federal Energy Regulatory Commission (FERC) in 2020, is a rule that requires RTOs and ISOs to develop plans to allow aggregations of GERs to participate in wholesale electricity markets directly.

Flexibility Market is a GER engagement method where local distribution flexibility markets provide a platform for utilities and others to buy and sell distribution services through an over-the-counter forward and day-ahead local distribution level market.

Flexible Service Connections are control approaches to enable customer service connections for larger loads such as EV fleet charging and data centers based on dynamic operating envelope parameters.

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[1] Industry definitions, as referenced in the DSPx initiative and unless otherwise noted, have been adapted from the following: De Martini, P. and Kristov, L. Distribution Systems in a High Distributed Energy Resources Future – Planning, Market Design, Operation and Oversight. Lawrence Berkeley National Laboratory. October 2015. Available online: https://gridarchitecture.pnnl.gov/media/advanced/FEUR_2%20distribution%20systems%2020151022.pdf

Flexible Interconnections are control approaches to enable more GER interconnections based on dynamic operating envelop parameters.

Grid Edge Resources (GERs) refers to any resource located on the distribution system, any subsystem thereof or behind a customer meter.[2]

GER Aggregator is the entity that aggregates one or more GERs for purposes of participation in the capacity, energy and/or ancillary services markets of the RTOs/ISOs and/or in distribution-level markets or programs administered by a DSO.[3]

GER Orchestration is an operational design that coordinates across a variety of disparate programs/DERs to optimize the delivery of specific grid services.

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

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

Local Distribution Area (LDA) consists of all the distribution facilities and connected GERs and customers below a single transmission-distribution (T&D) interface. 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 GERs 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.

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[2] FERC, Order No. 2222 Docket No. RM18-9-002, P 114, Marh 2021. Available online: https://www.ferc.gov/sites/default/files/2021-03/E-1.pdf

[3] FERC, Order No. 2222, Docket No. RM18-9-002, P 118, Marh 2021. Available online: https://www.ferc.gov/sites/default/files/2021-03/E-1.pdf

Net Load is the load measured at a point on the electric system resulting from gross energy consumption and production (e.g., energy generation and storage discharge). Net load is 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 FERC.

Relevant Electric Retail Regulatory Authorities (RERRAs) are state or local regulatory bodies that have jurisdiction over retail electric service, such as public utility commissions (PUCs), municipal boards, or cooperative utility boards. Under FERC Order No. 2222, RERRAs coordinates with RTOs/ISOs and electric utility companies (EDCs) on GER aggregation eligibility, registration process, interconnection standards/requirements and manage dispute resolution and oversight.

Reliability Metrics[4] are used to assess the operational performance of the distribution system in terms of reliability and resilience. Some of the more commonly used metrics are:

- SAIDI (System Average Interruption Duration Index) means the total duration of interruptions for the average customer during a specified period of time, measured in minutes of interruption, as given in the following equation: total customer minutes of interruption divided by total number of customers served.
- SAIFI (System Average Interruption Frequency Index) means how often the average customer experiences a sustained interruption over a predefined period of time, as given in the following equation: total number of customers interrupted divided by total number of customers served.
- CAIDI (Customer Average Interruption Duration Index) means the average time required to restore service, as given in the following equation: total customer minutes of interruption divided by total number of customers interrupted.
- MAIFI (Momentary Average Interruption Frequency Index) means the average frequency of monetary interruptions.

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

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

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[4] IEEE Std 1366-2022, IEEE Guide for Electric Power Distribution Reliability Indices. Available online: https://standards.ieee.org/ieee/1366/7243/

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

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

## Technology Definitions

Advanced Distribution Management Systems (ADMS) are software platforms that integrate numerous operational systems, provide automated outage restoration, and optimize distribution grid performance. ADMS enables utilities to monitor, analyze, and control the distribution network. ADMS components and functions can include distribution management system (DMS); demand response management system (DRMS); automated fault location, isolation, and service restoration (FLISR); conservation voltage reduction (CVR); and Volt-var optimization (VVO), while supporting interoperability with DERMS and SCADA systems.[5]

Advanced Metering Infrastructure (AMI) is an integrated network of advanced meters, communications networks, and data management systems. It 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 and data reception and management systems that make the information available to the service provider.[6]

Customer Information System (CIS) is the repository of customer data required for billing and collection purposes. CIS is used to produce bills from rate or pricing information and usage determinants from meter data collection systems and/or manual processes.[7]

Customer Relationship Management (CRM) is a system that provides tools for documenting and tracking all customer interactions. CRM also provides analytical tools to track and adjust marketing campaigns, forecast participation rates, and move customers from potential participants to fully engaged customers.[8]

Conservation Voltage Reduction (CVR) is an operating strategy of the equipment and control system used for VVO that reduces energy and peak demand by managing voltage at the lower part of the required range.[9]

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[5] U.S. Department of Energy. Voices of Experience – Insights into Advanced Distribution Management Systems. Page 3, February 2015. Available online: https://www.energy.gov/sites/default/files/2024-02/11-02-2015_doe-voe-insights-into-advanced-distribution-management-systems-report_508.pdf

[6] U.S. Department of Energy, Federal Metering Guidance, October 2022. Available online: https://www.energy.gov/sites/default/files/2022-10/federal-metering-guidance-2022.pdf

[7] LeCrone, K. CIS Technology: What's the Advantage? 2002. Available online: http://www.electricenergyonline.com/show_article.php?mag=7&article=50

[8] Adapted from Consolidated Edison Company of New York. Distributed System Implementation Plan (DSIP). Page 124, June 2016.

[9] U.S. Energy Information Agency Glossary Available online: https://www.eia.gov/tools/glossary/

Demand Response Management System (DRMS) is a software solution used to administer and operationalize DR aggregations and programs. Building on a legacy of telephone calls requesting load reduction, DRMS uses a one-way or two-way communication link to effect control over and gather information from enrolled systems, including some commercial and industrial loads, and residential devices such as pool pumps, air conditioners and water heaters.[10] DRMS allows DR capacity to be scaled in a cost-effective manner by automating the manual events that are typically used to execute DR events, as well as most aspects of settlement.

Distribution Management System (DMS) is an operational system capable of monitoring, collecting, analyzing, and optimizing real-time or near-real-time electric distribution system information and performance. A DMS can also allow operators to plan and execute complex distribution system operations to increase system efficiency, optimize power flow, and prevent overloads. A DMS can interface with other operations applications, such as geographic information systems (GIS), outage management systems (OMS), meter data management system (MDMS), and CIS to create an integrated view of distribution operations.[11]

Distributed Energy Resource Management System (DERMS) is a software-based solution that increases an operator's real-time visibility into the status of GER, and allows for the heightened level of control and flexibility necessary to optimize GER and distribution grid operation.[12] A DERMS can also be used to monitor and control GER aggregations, forecast GER capability, and communicate with other enterprise systems and GER aggregators.[13]

Distribution SCADA (DSCADA) is the application of supervisory control and data acquisition software to the distribution grid. SCADA is defined below.

Energy Management System (EMS) is a system to monitor, control, and optimize the performance of generation and/or transmission system and in some cases primary distribution substations. The primary objective of an EMS is to provide situational awareness for system operators and allow remote control of devices to provide secure and stable operation of the bulk electric system.[14] The EMS is the transmission system's analog to the DMS.

Electric Vehicle Supply Equipment (EVSE) provides electric power to the vehicle and uses that to recharge the vehicle's batteries. It includes electrical conductors, related equipment, software, and communications protocols that deliver energy efficiently and safely to the vehicle.[15]

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[10] U.S. Department of Energy, Energy.gov, Office of Electric Delivery and Energy Reliability Available online: https://energy.gov/oe/services/technology-development/smart-grid/demand-response

[11] EPRI, Distribution Management Systems Planning Guide, March 2013. Available online: https://dop.epri.com/

[12] US Department of Energy. Quadrennial Technology Review 2015, Chapter 3: Enabling Modernization of the Electric Power System – Technology Assessments, Flexible and Distributed Energy Resources. Page 15, 2015. Available online: http://energy.gov/sites/prod/files/2015/09/f26/QTR2015-3D-Flexible-and-Distributed-Energy_0.pdf

[13] Electric Power Research Institute. Common Functions for DER Group Management, Third Edition. Product ID 3002008215. Available online: https://www.epri.com/#/pages/product/3002008215/

[14] North American Electric Reliability Corporation (NERC), Risk and Mitigations for Losing EMS Functions Reference Document (Version 4), September 2024. Available online: https://www.nerc.com/globalassets/who-we-are/standing-committees/rstc/emswg/risks_mitigations_losing_ems_functions_refdoc.pdf

[15] NEMA, https://www.nema.org/membership/products/view/electric-vehicle-supply-equipment-system

Fault Location, Isolation and Service Restoration (FLISR) includes the automatic sectionalizing, restoration and reconfiguration of circuits. These applications accomplish distribution automation operations by coordinating operation of field devices, software, and dedicated communications networks to automatically determine the location of a fault and rapidly reconfigure the flow of electricity so that some or all customers can avoid experiencing outages.[16] FLISR may also be known as Fault Detection, Isolation and Restoration (FDIR).

Geographic Information System (GIS) is a software system that maintains a database of grid assets, including transmission and distribution equipment, and their geographic locations to enable presentation of the electric power system or portions of it on a map.[17] GIS may also serve as the system of record for electrical connectivity of the assets.

Global Positioning System (GPS) is a system of satellites and receivers that determines the position (latitude, longitude and altitude) of a receiver on Earth.[18] GPS is also used as a source of precision time signals for device synchronization.

Grid Following and Grid Forming Inverter are two basic categories of grid-connected inverters. Grid following inverter works as a current source that synchronizes its output with the grid voltage and frequency and injects or absorbs active or reactive power by controlling its output current. A grid-forming inverter works as a voltage source that sets the amplitude and frequency of the grid.[19]

Internet Protocol (IP) Packet Communication uses IP digital protocol to handle data in variable length packets that are routed digitally to their destinations asynchronously rather than making a fixed circuit connection or relying on fixed time intervals.[20]

Microgrid Interface is the set of power electronics at the point of interconnection[21] between the “island-able” portions of a grid, and the larger distribution grid, that support the essential microgrid[22] functions of islanding and reconnection.[23] The microgrid interface may also have the capability to provide services to the grid including Volt-var control. As services are dropped from the distribution grid side of the interconnection, the microgrid interconnect disconnects, and the microgrid continues to provide service to critical loads in the islanded area.[24]

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[16] U.S. Department of Energy. Smart Grid Investment Grant Program. Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration. Page 1, December 2014. Available online: https://www.smartgrid.gov/files/B5_draft_report-12-18-2014.pdf

[17] Electric Power Research Institute (EPRI). Abstract: Electric Utility Guidebook for Geographic Information Systems Data Quality: Metadata. Product ID: 3002007921. Available online: https://www.epri.com/#/pages/product/3002007921/

[18] GPS Definition, TechTerms. Available online: https://techterms.com/definition/gps

[19] Imperix, Grid-Following Inverter (GFLI), https://imperix.com/doc/implementation/grid-following-inverter?currentThread=static-synchronous-compensator-statcom

[20] Internet Protocols, Internet Engineering Task Force. Available online: https://www.ietf.org/

[21] Transitions at the POI are managed by the microgrid controller, see IEEE p2030.7

[22] U.S. Department of Energy. The Role of Microgrids in Helping to Advance the Nation’s Energy System. Available online: https://energy.gov/oe/services/technology-development/smart-grid/role-microgrids-helping-advance-nation-s-energy-system

[23] Tenti, P. and Costabeber, A. University of Padova. Smart Micro-Grids: Properties, Trends and Local Control of Energy Sources. Available online: http://www.dsce.fee.unicamp.br/~antenor/pdffiles/SG.pdf

[24] The impact of microgrids on the distribution grid is within the scope of this document, while the explanation of the operation of an islanded microgrid is not. Hence, the functionality of a microgrid is not explained here.

Microwave Radio communications are high frequency radio systems that may be point-to-point or point-to-multipoint systems. They are widely used for substation and SCADA communications.[25]

Optical Fiber communication systems send data via modulated light through a transparent glass or plastic fiber. Optical fiber systems are capable of very high bandwidths and form the backbone of high-capacity communication systems.[26]

Outage Management System (OMS) is a computer-aided system used to better manage the response to power outages or other planned or unplanned power quality events. It can serve as the system of record for the as-operated distribution connectivity model, as can the DMS.

Peer-to-Peer Communication (P2P) may be a network service or standalone capability that permits two devices to communicate with one another. As a network service, the central part[27] of the system responds to a request by providing each device with the information and resources necessary to establish direct communication. As a standalone capability, P2P becomes synonymous with point-to-point and is a dedicated channel between devices.[28]

Reclosers are self-controlled electro-mechanical switches for automatically interrupting and reclosing an alternating-current circuit, with a predetermined sequence of opening and reclosing followed by resetting, hold closed, or lockout. Reclosers respond to a short circuit or other temporary faults by interrupting electrical flow and automatically reconnecting it a short time later. Reclosers function as circuit breakers on the feeder circuit and are located throughout the distribution system to prevent a temporary fault from causing an outage.[29]

Supervisory Control and Data Acquisition (SCADA) is a system of remote control and telemetry used to monitor and control the distribution and transmission asset, forming the data foundation for EMS, DMS, DERMS, and other operational platforms.[30]

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[25] Adapted from: Federal Communications Commission. “Microwave.” Available online: https://www.fcc.gov/microwave

[26] Adapted from: Poole, I. Radio-electronics.com. “Fibre Optics Communications Tutorial.” Available online: http://www.radio-electronics.com/info/telecommunications_networks/fiber-fibre-optics/communications-basics-tutorial.php

[27] U.S. Department of Energy. Quadrennial Technology Review 2015, Chapter 3: Enabling Modernization of the Electric Power System – Technology Assessments, Measurements, Communications and Controls. Page 24, 2015. Available online: http://energy.gov/sites/prod/files/2015/09/f26/QTR2015-3E-Measurements-Communications-and-Controls.pdf

[28] Camarillo, G. Internet Engineering Task Force. Network Working Group. Peer-to-Peer (P2P) Architecture: Definition, Taxonomies, Examples, and Applicability. November 2009. Available online: https://tools.ietf.org/html/rfc5694

[29] Eaton, Comparison of Recloser and Breaker Standards. May 2019. Available online: https://www.eaton.com/content/dam/eaton/products/medium-voltage-power-distribution-control-systems/reclosers/recloser-and-breaker-standards-comparison-information-td280024en.pdf

[30] NERC, Risk and Mitigations for Losing EMS Functions Reference Document (Version 4), September 2024. Available online: https://www.nerc.com/globalassets/who-we-are/standing-committees/rstc/emswg/risks_mitigations_losing_ems_functions_refdoc.pdf

# Contents

# Figures

# 1.0 Introduction

## 1.1 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 grid edge resources (GERs). 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 to desired attributes of a modern grid platform employing the grid architecture methodology described in this volume, functional requirements, and ultimately the technology needed. In concept, the starting point of a modern grid is a foundation built upon enhancements to safety, operational efficiency, reliability and resilience, while ensuring affordability. This is augmented with new functions and technology to support grid resilience as well as to enable GER integration and utilization for grid services in line with the timing, scale, and scope of customer adoption of GERs 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.

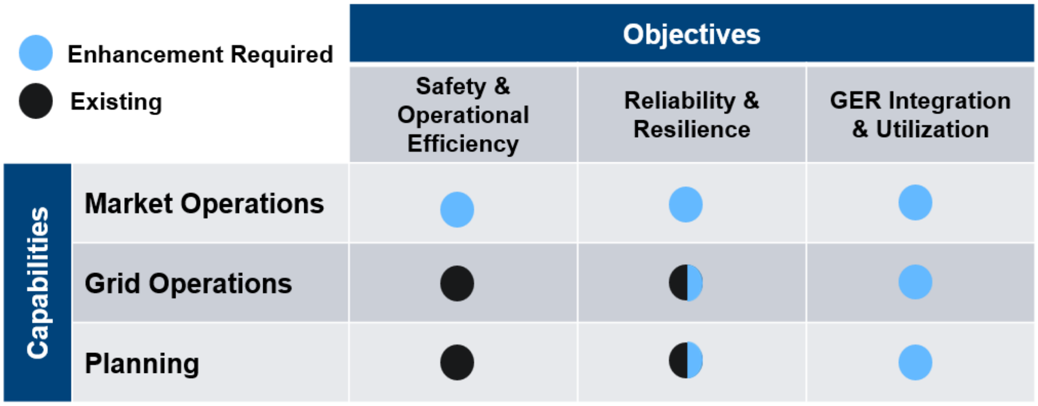
Figure 1. Grid modernization scope.

These three general outcomes or objectives categories are supported by related capabilities and functionalities that work together to create a modern distribution grid. These capabilities and related functionality can be logically organized into three groups:

- **Distribution System Planning:** An integrated planning approach that assesses physical and operational requirements and develop infrastructure investment strategies in order to provide safe, reliable, resilient and affordable service that satisfies customers' changing expectations and use of GERs, including the provision of GER services to operate the distribution system. This includes evaluating current and future grid conditions; forecasting load and DER impacts; conducting studies such as power flow, hosting capacity, and interconnection analyses; and identifying the equipment upgrades, operational changes, and non-wires solutions needed to support evolving customer needs and GER integration.[31]

- **Distribution Grid Operations:** Safe and reliable and operation of a distribution system (including non-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 GER and microgrid operation and interconnections to ensure safety, reliability and resilience, as well as physical coordination of GER services and scheduled and real-time power flows between the distribution and transmission systems.
- **Distribution Market Operations:** Several states are developing markets mechanisms to source GER-provided grid services at the distribution level, including tariffs, programs, and procurements.[32] Examples of such grid services include providing alternatives to distribution infrastructure upgrades and supporting operational requirements to manage voltage, reliability and resilience.

The three capability groups are mapped to the objectives in Figure 2 below to show the interrelationships The black 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.



🔵 Enhancement Required
⚫ Existing

| | | Objectives | | |
|---|---|---|---|---|
| | | Safety & Operational Efficiency | Reliability & Resilience | GER Integration & Utilization |
| Capabilities | Market Operations | 🔵 | 🔵 | 🔵 |
| | Grid Operations | ⚫ | ◐ | 🔵 |
| | Planning | ⚫ | ◐ | 🔵 |

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.

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[31] U.S. Department of Energy, Integrated Distribution System Planning. Available online: https://www.energy.gov/oe/integrated-distribution-system-planning

[32] U.S. Department of Energy, Sourcing Distributed Energy Resources for Distribution Grid Services, December 2024. Available online: https://www.energy.gov/sites/default/files/2024-12/Sourcing%20DER%20for%20Dist%20Services%20final%2012.17.24.pdf

## 1.2 Approach and Organization

The approach to developing version 3.0 of this Volume I report involved reviewing the prior version for potential updates given changes to applicable regulations, utility business processes and engineering practices, and technological advancements. This version retains the still relevant capabilities and functionalities that were previously developed through extensive use of reference material and collaborative and iterative engagement with representative industry experts, including state regulators, electric utilities, RTOs/ISOs and energy services and technology providers. The prior versions also benefited from a series of DOE hosted interactive webinars with industry experts to share working draft materials and elicit feedback. This revision reflects the capabilities and functions that are being pursued by utilities to support grid modernization through 2035 as reflected in recent 10-year distribution system plans.

The following are the key assumptions guiding the scope of this effort:

- **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 these functions.

Volume I includes two chapters, describing the capabilities and functionalities needed for a modern grid. Existing regulatory documents, industry references, and reviews 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 Capabilities:** Identifies grid capabilities in relation to the policy objectives analysis in Chapter 1.

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

Chapters 1 and 2 in Volume I are organized into three general categories: Distribution System Planning, Distribution Grid Operations, and Distribution Market Operations.

## 1.3 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. This taxonomy framework (DSPx taxonomy) seeks to provide a line-of-sight between what states are aiming to achieve (i.e., key objectives of a modern grid), and how distribution system capabilities, functionalities, and related technologies can align to achieve the desired outcomes.

In this updated Version 2.0 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 (see Figure 3). 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.

<u>**Level 0 – Principles:**</u> ***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.

**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 capability.

**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 expands 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.

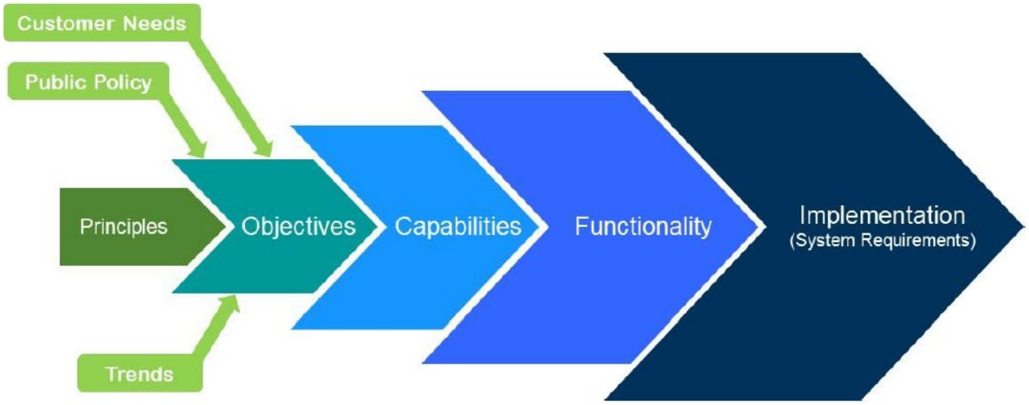

Figure 4. Taxonomy logical structure.

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[33] and the Gridwise Architecture Council's Interoperability Context-Setting Framework.[34] As noted in these models and companion documentation, the objectives and business functions served as the reference point for technology design considerations.

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[33] M. Samotyj, Intelligrid Architecture: Integrated Energy and Communications System Architecture, EPRI, IEEE PES Swiss Chapter, Summer 2002. https://xanthus-consulting.com/IntelliGrid_Architecture/IECSA_Volumes/IECSA_VolumeI.pdf

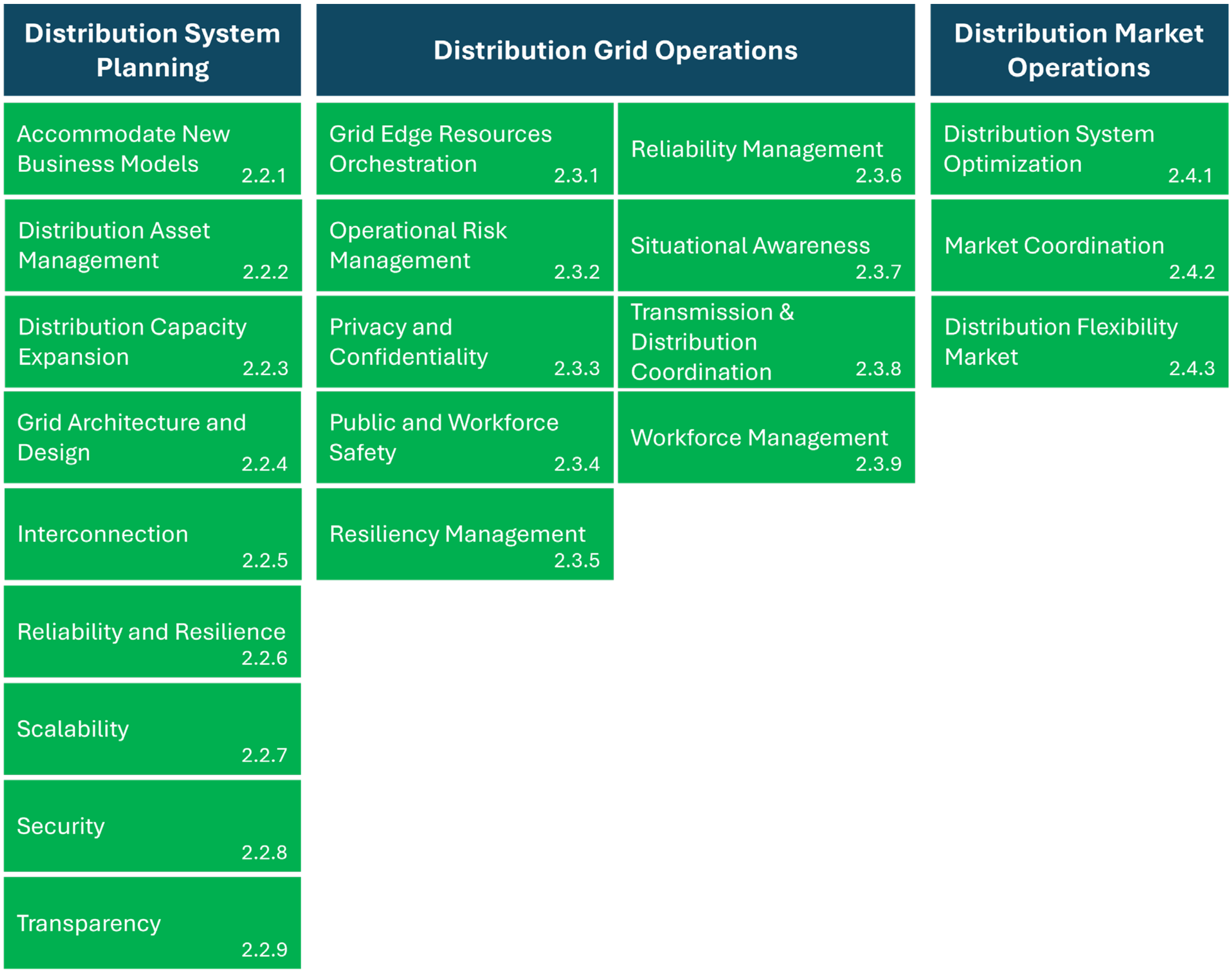
[34] GridWise® Interoperability Context-Setting Framework, Gridwise Architecture Council, March 2008 https://www.researchgate.net/publication/239883349_GridWise_Interoperability_Context-Setting_Framework

# 2.0 Capabilities

## 2.1 Overview

A capability is the ability to execute a specified course of action to achieve the broader outcome for distribution system in order to meet evolving grid needs and policy objectives. Capabilities represent higher-level end states or strategic attributes of the distribution system, rather than the specific processes, mechanisms, or activities used to realize them (i.e., functionalities, which are addressed in a later section).

In the context of this paper, capabilities describe the broader abilities that distribution system needs to support key business outcomes associated with building a modern distribution grid. The capabilities addressed in this paper are listed in Figure 5.



| Distribution System Planning | Distribution Grid Operations | | Distribution Market Operations |
|---|---|---|---|
| Accommodate New Business Models 2.2.1 | Grid Edge Resources Orchestration 2.3.1 | Reliability Management 2.3.6 | Distribution System Optimization 2.4.1 |
| Distribution Asset Management 2.2.2 | Operational Risk Management 2.3.2 | Situational Awareness 2.3.7 | Market Coordination 2.4.2 |
| Distribution Capacity Expansion 2.2.3 | Privacy and Confidentiality 2.3.3 | Transmission & Distribution Coordination 2.3.8 | Distribution Flexibility Market 2.4.3 |
| Grid Architecture and Design 2.2.4 | Public and Workforce Safety 2.3.4 | Workforce Management 2.3.9 | |
| Interconnection 2.2.5 | Resiliency Management 2.3.5 | | |
| Reliability and Resilience 2.2.6 | | | |
| Scalability 2.2.7 | | | |
| Security 2.2.8 | | | |
| Transparency 2.2.9 | | | |

Figure 5. Modern distribution system capabilities.

## 2.2 Distribution System Planning

### 2.2.1 Accommodate New Business Models

The ability to support the integration and scaling 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, transportation, telecommunications, for example.[35]

### 2.2.2 Distribution Asset Management

A systematic and strategic approach to managing physical assets and infrastructure across their entire lifecycle from procurement and installation to maintenance, upgrades, and eventual decommissioning. This approach involves technical, financial, and operational considerations to optimize capital investments, improve system reliability and efficiency, and ensure peak performance of the assets and infrastructure at minimum life-cycle cost while leveraging the smart grid's digital instrumentation and communications.[36] It involves continuous strategic planning, decision-making, and coordinated execution to align asset performance with organizational goals and regulatory requirements and to bolster reliability and resiliency.

### 2.2.3 Distribution Capacity Expansion

The ability to forecast and identify demand capacity needs relative to system constraints and to plan and execute risk-adjusted, least-cost portfolios of wires and non-wires alternatives (NWAs) so that feeders, substations, and connected assets remain within thermal and voltage limits under normal and relevant contingency conditions across the planning horizon (typically a 5-to-10-year horizon). It involves consideration of locational adoption trends, demand modifiers (e.g., solar photovoltaics, storage, and electric vehicle (EV)), applies scenario/probabilistic methods to manage uncertainty, and systematically evaluates NWAs alongside traditional upgrades by developing standardized objective criteria for decision making such as hosting capacity, cost, reliability, resiliency, and energy efficiency.[37]

### 2.2.4 Grid Architecture and Design

Grid architecture is the framework that defines the structural, behavioral, and interface arrangements of the electric power system. It applies system architecture, network theory, and control theory to the electric power grid to identify structural limits, decouple legacy constraints, remove systemic barriers, and enable new capabilities, thereby guiding the design of specific system components and their interactions.[38]

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[35] U.S. Department of Energy, 2020 Smart Grid System Report, January 2022. Available online: https://www.energy.gov/oe/articles/2020-smart-grid-system-report

[36] C.-M. Jung, P. Ray, and S. R. Salkuti, Asset Management and Maintenance: A Smart Grid Perspective, International Journal of Electrical and Computer Engineering Vol 9, No. 5, October 2019: pp. 3391–3398, https://doi.org/10.11591/ijece.v9i5.pp3391-3398

[37] National Renewable Energy Laboratory (NREL), Distribution Capacity Expansion Planning: Current Practice, Opportunities, and Decision Support. November 2022. Available online: https://docs.nrel.gov/docs/fy23osti/83892.pdf

[38] PNNL, Grid Architecture website. Available online: https://gridarchitecture.pnnl.gov/

Grid architecture defines what the grid must achieve—its fundamental structural and behavioral properties, such as how power, data, and control signals flow through interconnected systems, and how the grid behaves under various conditions. On the other hand, design determines how those architectural elements are realized in practice through specific technologies, configurations, and operating procedures.[39] A well-structured grid architecture provides stakeholders with a clear understanding of the "shape" of a system, its component parts, and how those parts interact across physical, cyber, organizational, and market layers. This high-level visibility helps planners and regulators identify and remove structural barriers that prevent modernization and limit new capabilities and offer a coherent framework to guide planning, investment, and policy decisions.

### 2.2.5 Interconnection

Interconnection refers to the technical, procedural, and regulatory framework that enables customers and third-party service providers to connect GERs to a distribution system safely and reliably. This connection allows GERs to provide grid services to the utility at either the distribution or bulk power system level, while operating in parallel with the utility system. The interconnection process encompasses activities such as application submission, development of technical requirements, engineering studies, system impact assessments, agreement execution, and commissioning. To support this, the distribution system is required to accommodate GERs through advanced interconnection technologies, integrated communication systems, and robust cyber-physical security. As GER deployment expands and grid capacity becomes increasingly constrained, interconnection practices are evolving to emphasize improved interconnection process and timelines and promoting economic efficiency.[40]

### 2.2.6 Reliability and Resilience

Reliability refers to the ability of the distribution system to consistently deliver electricity to customers in the quantity and quality required, without interruption, under normal operating conditions. In the distribution context, reliability includes maintaining voltage levels, minimizing outages, and ensuring timely restoration when service is disrupted. It reflects the system's performance in delivering electricity as expected, day-to-day and hour-to-hour.

Resilience is the ability to anticipate, withstand, adapt to, and recover from high-impact, low-frequency events such cyber-physical attacks or environmental hazards and resume normal operations within an acceptable period of time.[41]

### 2.2.7 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 on

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[39] PNNL, Grid Architecture – Basic Terms & Principles website. Available online: https://gridarchitecture.pnnl.gov/basic-terms-and-principles.aspx

[40] U.S. Department of Energy, Distributed Energy Resource Interconnection Roadmap, January 2025. Available online: https://www.energy.gov/eere/i2x/doe-distributed-energy-resource-interconnection-roadmap

[41] NREL, Explained: Fundamentals of Power Grid Reliability and Clean Electricity, January 2024. Available online: https://docs.nrel.gov/docs/fy24osti/85880.pdf

performance, reliability, resilience and interoperability.[42] To achieve the scale needed to address the growing distribution grid needs, it is necessary to balance two fundamental dimensions:[43]

- A compelling value proposition for participating customers and third-party service providers. This requires appropriate risk allocation that stimulates participation and provides sufficient certainty to justify their investment.
- Value certainty for utility ratepayers. GER services should be aligned with system performance requirements, delivering the right capabilities when and where they are needed on the grid.

### 2.2.8 Security

Security, from a system planning perspective, includes incorporating physical security and cybersecurity considerations into distribution system architecture, communications design, asset selection, and risk mitigation strategies. It includes planning activities intended to prevent, detect, and respond to man-made and environmental threats and to reduce associated risks. These risks include cyber-attacks, storms, fire, earthquakes, terrorism, vandalism, and numerous other physical threats.

Physical security[44] involves technologies that detect breaches, unauthorized access, or physical incursions, and communicate those events to authorized monitoring systems and personnel. It also includes protective measures for generation, transmission, and distribution infrastructure, as well as the monitoring, communication, and computational hardware that support grid control systems.

Cybersecurity[45] focuses on safeguarding computer systems from theft, damage, or disruption, whether through network access, data or code injection, or operator error. It includes controlling physical access to hardware and protecting against threats that may compromise system integrity or service continuity. Security practices also account for the reflexive impacts between physical and cyber domains, recognizing the increasing interdependence between physical infrastructure and secure information and communication systems.

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[42] Definition developed from the following resources along with industry review:

a) Taft, JD and Becker-Dippmann, A. Grid Architecture. January 2015. Available online: http://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf
b) Taft, Jeffrey and De Martini, Paul, Cisco. Scalability, Resilience, and Complexity Management in Laminar Control of Ultra-Large Scale Systems. Page 15. http://www.cisco.com/c/dam/en/us/products/collateral/cloud-systems-management/connected-gridnetwork-management-system/scalability_and_resilience_in_laminar_control_networks.pdf

[43] U.S. Department of Energy, Sourcing Distributed Energy Resources for Distribution Grid Services. December 2024. Available online: https://www.energy.gov/sites/default/files/2024-12/Sourcing%20DER%20for%20Dist%20Services%20final%2012.17.24.pdf

[44] Cybersecurity and Infrastructure Security Agency (CISA) and U.S. Department of Energy, Sector Spotlight: Electricity Substation Physical Security, February 2023. Available online: https://www.cisa.gov/resources-tools/resources/sector-spotlight-electricity-substation-physical-security

[45] U.S. Department of Energy, Energy Sector Cybersecurity Preparedness. Available online: https://www.energy.gov/ceser/energy-sector-cybersecurity-preparedness?__hstc=249664665.ed33918867e382a9cf776517f870dc63.1755612613864.1755612613864.1757190559943.2&__hssc=249664665.1.1757190559943&__hsfp=3474073941&nrg_redirect=321254

As a modern distribution system capability, security is incorporated not only into planning decisions but also into operational monitoring and response.

### 2.2.9 Transparency

The ability to provide timely, accurate, and consistent access to distribution function information by market actors (e.g., customers, aggregators, and other stakeholders) to promote fair competition and protect consumers by enabling informed decision-making. This includes public visibility into planning, market design, prices, operational performance without putting sensitive information at risk. Additionally, regulatory authorities implement and support open-access governance responsibilities.[46]

## 2.3 Distribution Grid Operations

### 2.3.1 Grid Edge Resources Orchestration

Orchestration[47] is the capability to coordinate diverse GERs engaged through various mechanisms or participation pathways such as programs, bilateral contracts, or flexibility markets, to optimize the delivery of specific grid services in a reliable and cost-effective manner. This comprehensive approach involves evaluating and aligning GER operations based on their capabilities and compatibility for providing grid support, identifying feasible opportunities, quantifying the value of orchestrated GERs in delivering dependable and cost-effective grid services, and managing the dispatch of GERs in accordance with established performance requirements to ensure reliable grid operation.

### 2.3.2 Operational Risk Management

Operational Risk Management (ORM) examines core operations including energy delivery reliability and resilience as well as GER-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

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[46] Definition developed from the following resources:

a) 16 U.S. Code § 824t - Electricity market transparency rules. Retrieved from: https://www.law.cornell.edu/uscode/text/16/824t

b) U.S. Department of Energy, Office of Electricity, Distribution Standard of Conduct, November 2023. Available online: https://www.energy.gov/sites/default/files/2023-11/2023-11-01%20Distribution%20Standard%20of%20Conduct%20nov%202023_optimized_0.pdf

[47] U.S. Department of Energy, Distribution Grid Orchestration, November 2024. Available online: https://www.energy.gov/sites/default/files/2024-12/2024-11-18%20Distribution%20Grid%20Orchestration_Clean.pdf

- Black Swan (ontological) risk, pertaining to low probability-high impact or unknown-unknowns events occurring.[48]

### 2.3.3 Privacy and Confidentiality

The ability to protect grid users from unauthorized access or misuse of their data and allow users to maintain control over personal and commercial information related to electricity consumption, generation, storage, and/or market activity. As the electric grid evolves into a digitally enhanced, bidirectional system, driven by the integration of information and communication technologies (ICTs) such as smart meters and advanced sensors, the volume of generated, collected, and processed data grows substantially, requiring thoughtful governance throughout the entire data lifecycle. These measures include protection against issues such as identity theft, inference 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.[49]

### 2.3.4 Public and Workforce Safety

The ability to promote secure working conditions and safe public interaction with distribution infrastructure in a manner that protects workers and the general public from electrical, mechanical, and environmental hazards. The design, construction, operation, and maintenance, including facilities that do not belong to electric utilities, are carried out to maintain safe conditions around infrastructure, ensure adequate service, and uphold safety standards.[50]

### 2.3.5 Resiliency Management

Resiliency management focuses on the distribution system’s ability to anticipate, absorb, adapt to, and rapidly recover from high-impact, low-frequency events such as extreme weather, cyber-physical attacks, or equipment failures.[51] It includes infrastructure design, operational flexibility, and the integration of grid edge resources and advanced controls to maintain critical functionality during disruptions and restore full service efficiently. Resiliency management enhances reliability by reducing the scope, duration, and impact of outages, and is essential for ensuring energy access during emergencies and maintaining essential services.

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[48] Definition developed from the following resources:
  a) De Martini, Paul, Caltech, Risky Business, T&D World, April 2013.
  b) Christopher Isakson, DNV KEMA, Operational Risk Management During Uncertainty, November 2012.

[49] Electronic Privacy Information Center, The Smart Grid and Privacy – Concerning Privacy and Smart Grid Technology, 2016.

[50] Definition developed from the following resources:
  a) CPUC, General Order No. 95, January 2020, Available online: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M338/K730/338730245.pdf
  b) U.S. Department of Labor Occupational Safety and Health Administration, Title 29, Standard 1910 - Electric power generation, transmission, and distribution. Available online: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.269_2

[51] Definition developed from the following resources:
  a) U.S. Department of Energy, Terms and Definition website. Available online: https://www.directives.doe.gov/terms_definitions/resilience
  b) National Infrastructure Advisory Council, Critical Infrastructure Resilience Final Report and Recommendations, September 2009. Available online: https://www.dhs.gov/xlibrary/assets/niac/niac_critical_infrastructure_resilience.pdf

In the operational timeframe, resiliency is actively managed through strategies such as microgrid deployment, intentional islanding, battery energy storage utilization, and circuit sectionalization. These approaches enable localized energy balancing, fault isolation, and autonomous operation of critical loads when the main grid is compromised.[52, 53, 54]

### 2.3.6 Reliability Management

Reliability management refers to the coordinated set of operational processes, technologies, and procedures that ensure the electric distribution system delivers electricity in a secure, stable, and adequate manner. At the operational level, this includes outage management, such as detecting, isolating, and restoring service interruptions. Reliability management supports both resource adequacy and operational reliability, ensuring the system can meet demand and recover quickly from routine disturbances.[55]

### 2.3.7 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.[56] The ability to generate actionable information on the current and near-future operating state and condition of the distribution grid, its physical and digital assets, GERs, and surrounding environmental and cybersecurity conditions is necessary to safely, securely, and reliably operate the electric system. It includes visibility, defined as the timely acquisition of sensing and measurement data, and relies on integrating data from diverse sources such as sensors, smart meters, weather forecasts, ICT infrastructure, and public datasets with grid models and analytics tools. This provides operators with a comprehensive understanding of the grid's current state, potential future scenarios, and supports informed decisions.

### 2.3.8 Transmission and Distribution Coordination

T&D coordination spans both the physical management of active and reactive power flows across the transmission–distribution interface and the alignment of market structures and operational practices between system operators. This occurs between the distribution operator and the bulk system Balancing Authority (a utility TSO) or an RTO/ISO. T&D coordination also extends beyond simply balancing physical flows. It encompasses the coordination of market rules and planning/operational practices across RTOs/ISOs, DSOs, aggregators, and retail

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[52] U.S. Department of Energy. White paper: Integrated Models and Tools for Microgrid Planning and Designs with Operations. Available online: https://www.energy.gov/sites/default/files/2022-09/6-Integrated%20Models%20and%20Tools%20for%20Microgrid%20Planning%20and%20Designs%20with%20Operations.pdf

[53] IEEE, Resilience Framework, Methods, and Metrics for the Electricity Sector, October 2020. Available online: https://resourcecenter.ieee-pes.org/publications/technical-reports/pes_tp_tr83_itslc_102920

[54] IEEE, The Definition and Quantification of Resilience, April 2018. Available online: https://resourcecenter.ieee-pes.org/publications/technical-reports/pestr0065_04-18

[55] FERC, Reliability Explainer. Available online: https://www.ferc.gov/reliability-explainer

[56] Definition developed from the following resources:

a) Southern California Edison. Grid Modernization Distribution System Concept of Operations, Version 1.0, Page 9, January 2016.
b) Taft, JD and Becker-Dippmann, A. “Grid Architecture”. Page 5.3, January 2015. Available online: https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf

regulators to support grid reliability and the efficient utilization of GERs. The implementation of FERC Order No. 2222 heightens the significance of this capability, and as GER participation grows, T&D coordination becomes the critical interface that harmonizes jurisdictional responsibilities, balances multi-directional power flows, and supports the layered optimization of system operations.[57]

### 2.3.9 Workforce Management

Workforce management refers to the strategic organizational practices for the planning, development, and coordination of a skilled and adaptable labor force to support the evolving needs of grid operation and modernization efforts. It involves aligning workforce capabilities with evolving technological, regulatory, and operational demands, while proactively anticipating shifts in labor needs and equipping staff with skills to support the safe and reliable operation of the grid.[58]

## 2.4 Distribution Market Operations

### 2.4.1 Distribution System Optimization

Distribution system optimization consists of operational utilization of physical grid assets and GER-provided services to manage distribution operations in a safe, reliable, secure, and efficient manner and to improve the performance and efficiency, such as managing peak loads, optimizing power flows, and maintaining voltage stability across the grid. It leverages advanced monitoring, control systems, and automation to ensure that the distribution system operates at optimal levels under varying conditions. In the context of distribution market operations, this functionality enables the operational dispatch and coordination of GER-provided services sourced through tariffs, programs, procurements, or emerging local flexibility market arrangements to address local distribution needs efficiently.

### 2.4.2 Market Coordination

The capability to facilitate the efficient operation and management of electricity markets by integrating processes, technologies, and governance structures that enable transparent,

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[57] Definition developed from the following resources:

a) U.S. Department of Energy, TSO-DSO-Aggregator Market and Operational Coordination Requirements, April 2024. Available online: https://www.energy.gov/sites/default/files/2024-07/47990_DOE_OE_TDC_Project_Coordination_Platform_v9_RELEASE_508.pdf
b) Greentech Leadership Group and Caltech Resnick Institute, More Than Smart – A Framework to Make the Distribution Grid More Open, Efficient and Resilient, Page 17, August 2014. Available online: https://authors.library.caltech.edu/records/ef5kx-3en85
c) U.S Department of Energy, Electricity Transmission Virginia Polytechnic Institute and State System Research University and Development: Emma M. Stewart Distribution Integrated Lawrence Livermore National Laboratory with Transmission Operations, April 2021. Available online: https://www.energy.gov/sites/default/files/2021-05/Distribution%20Liu%20Stewart_0.pdf

[58] Definition developed from the following resources:

a) Center for Energy Workforce Development, A Workforce Development Maturity Model to Navigate the New Era of Load Growth. 2025. Available online: https://cewd.org/resources/workforce-development-maturity-model/
b) NREL, Workforce Analysis. Website available online: https://www.nrel.gov/workforce/analysis

accurate, and secure interactions among all market stakeholders, including GER aggregators, EDCs, RERRAs, and market operators. The core elements include:[59]

- Data sharing: Establishes standardized protocols for secure data exchange and implements data governance.
- GER registration: Maintains a uniform registry for GERs and aggregators, cataloging technical specifications, operational constraints, and market participation detail to ensure that entities are properly registered and tracked.
- Service provisioning: Coordinates the scheduling, dispatch, and operational integration of GERs and aggregations that enables real-time and day-ahead coordination between market operators, EDCs, and aggregators, including sharing of dispatch schedules, grid constraints, and DER availability.
- Settlement: Requires aggregator settlement data, performance records, metering and telemetry data for accurate financial transactions (payment processing, charges for consumption, dispute resolution).

### 2.4.3 Distribution Flexibility Market

A distribution flexibility market is a localized, market-based platform operated at the distribution level that enables utilities, aggregators, and customers to buy and sell grid services from GERs to address local distribution system needs.[60] Depending on market design, these services may be sourced through forward, day-ahead, or other time-specific market arrangements. It allows utilities, distribution system operators, aggregators and customers to procure short-duration, location-specific services (such as temporary load reduction, generation curtailment, storage discharge, or voltage support) from grid edge resources when and where the network needs them. Flexibility markets complement wholesale markets by focusing on substation, feeder, or even segment-level constraints that arise from congestion, voltage limits, maintenance outages, or high GER output. They help convert operational needs into commercial transactions that flexible resources can respond to.

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[59] FERC, Order No. 2222, Docket No. RM18-9-002, Marh 2021. Available online: https://www.ferc.gov/sites/default/files/2021-03/E-1.pdf

[60] U.S. Department of Energy, Sourcing Distributed Energy Resources for Distribution Grid Services. December 2024. Available online: https://www.energy.gov/sites/default/files/2025-01/Sourcing%20DER%20for%20Dist%20Services%20final%201.9.24.pdf

# 3.0 Functionalities

## 3.1 Overview

A functionality defines an activity, behavior, or operational result of a process to enable one or more capabilities. Functionalities include the people, processes, and technologies that will be needed to support the achievement of broader distribution system outcomes (i.e., capabilities).

Similar to the capabilities in Chapter 1, 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 corresponding capabilities.

## 3.2 Distribution System Planning

Figure 6 shows a total of 16 revised functionalities under Distribution System Planning.

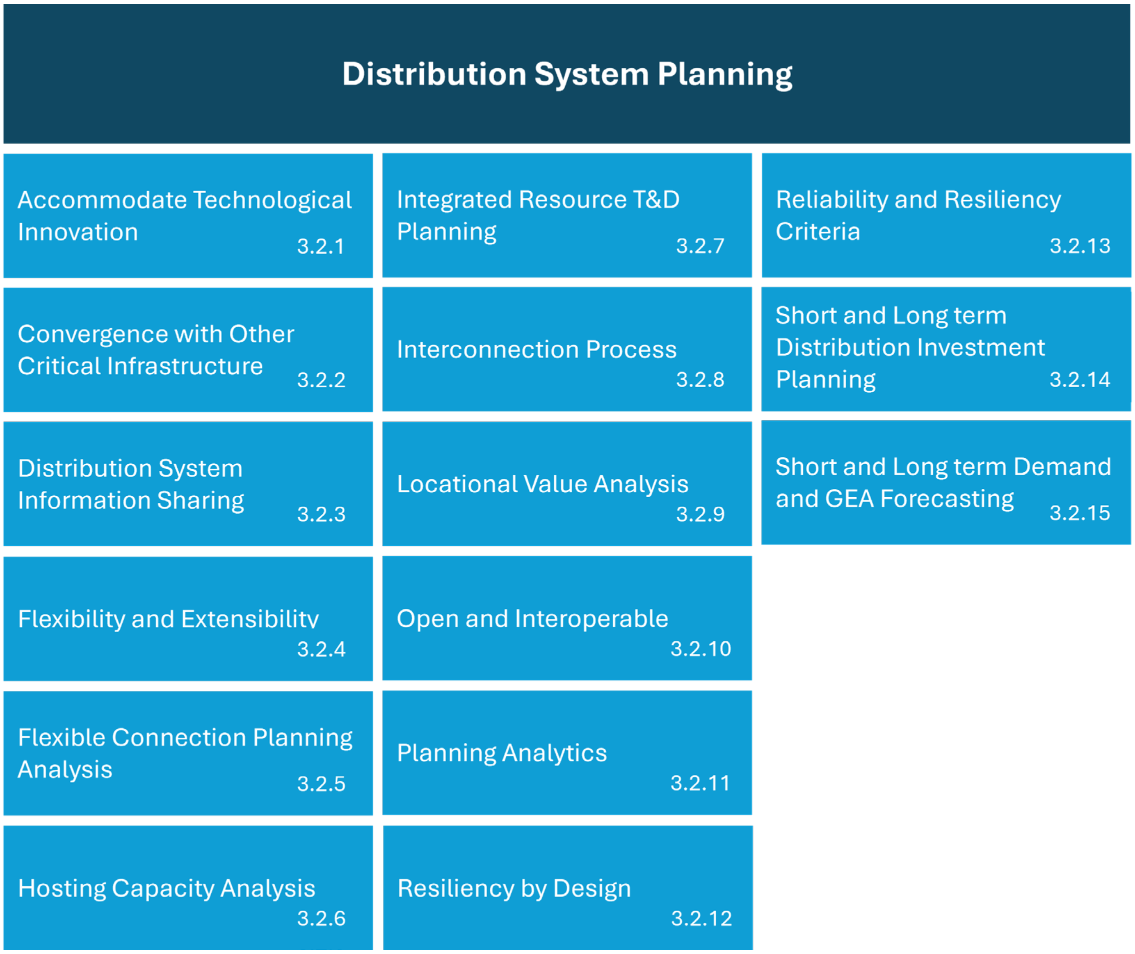

Figure 6. Distribution system planning functionalities.

### 3.2.1 Accommodate Technological Innovation

Accommodating technological innovation involves integrating diverse GER types and absorbing emerging grid technologies, including IoT, artificial intelligence, automated control, other and advanced digital tools to meet the scale and pace of growing demand and the evolving structure of the future energy marketplace, delivering net positive benefits to all customers for greater efficiency, reliability, and sustainability. It also enables the enhancement of real time grid monitoring and predictive maintenance, with due consideration to privacy and security concerns, and provides access to system, customer and third-party data (as needed) to animate market innovation.

### 3.2.2 Convergence with Other Critical Infrastructure

The ability to coordinate with and jointly manages interdependencies across other critical infrastructures such as natural gas, telecommunications, water, and transportation, as the disruption or discontinuation of the services provided by the energy sector can impact the security and resilience of other numerous sectors. A comprehensive understanding of such interdependence enables the potential mitigation of vulnerabilities while supporting economic and environmental policy objectives by enabling broader societal benefits, including applications associated with smart cities, load growth, and integrated infrastructure planning.[61]

### 3.2.3 Distribution System Information Sharing

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

### 3.2.4 Flexibility and Extensibility

Operation and design of the electric grid to allow multi-directional flows of energy and enable all types of GER technologies to interconnect and participate in market opportunities. The distribution grid should be designed to adjust or compensate for variations in operating conditions, such as dynamic changes in load or directions of energy flow. It is capable of adding, removing, and scaling system functions and capabilities with only incremental structural changes and without affecting other functions or capabilities. Additionally, it supports both traditional energy resource connections and variations, as well as the increasing variability introduced by the use of GERs.

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[61] Definition developed from the following resources:

a) U.S. Department of Energy, State Energy Security Plan Optional Drop-In: Cross Sector Interdependency Diagrams, May 2022. Available online: https://www.energy.gov/sites/default/files/2022-06/DOE%20CESER%20SESP%20Drop-In_Cross-Sector%20Interdependency%20Diagrams_FINAL_508.pdf

b) Federal Emergency Management Agency (FEMA), Community Lifelines. Available online: https://www.fema.gov/emergency-managers/practitioners/lifelines

### 3.2.5 Flexible Connection Planning Analysis

The ability to assess and design time-varying, non-firm access arrangements for both generation-side interconnections and demand-side service connections. Unlike the broader interconnection process, this functionality focuses specifically on defining the technical and operational parameters under which non-firm GERs or new loads can connect without violating thermal, voltage, or protection limits.[62]

- Flexible interconnection planning analysis determines how GER can connect to the grid under dynamic operating envelopes or other non-firm arrangements, allowing GERs to adjust their output in accordance with real-time grid capacity limits or to export up to pre-defined levels set in advance, thereby avoiding violations of thermal, voltage, or protection limits.
- Flexible service connection planning analysis uses a parallel approach to flexible interconnection, applying the same dynamic operating envelope framework to new loads, but focusing on import rather than export. This method enables faster integration of large new loads, most commonly public EV fleet charging centers by defining time-varying import limits at the customer's point of connection. By shaping demand around available feeder and substation headroom, customers gain earlier access to service without waiting for traditional infrastructure upgrades

Both methods strategically improve distribution system utilization by using existing grid capacity more effectively, lowering the cost of integration.

### 3.2.6 Hosting Capacity Analysis

Hosting capacity analysis (HCA) evaluates the ability of a distribution system to accommodate additional GERs at a given location without violating defined technical limits, such as thermal, voltage, or protection constraints. HCA results help streamline interconnection processes and support distribution system planning.

Hosting capacity is defined as the amount of GER that can be added to a distribution system 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:

- Provide indicative information to guide GER development. The results of hosting capacity analysis are typically published as interactive maps on utility websites, supporting customers and developers target GER site and providing early visibility into system constraints. This information helps streamline interconnection processes to fast-track requests.
- Serve as a baseline distribution system planning tool to evaluate distribution capability to support GER growth before violating voltage, thermal, or protection constraints. Hosting capacity analysis is used alongside load forecasts, GER adoption scenarios, and asset condition data to inform long-term grid investments.

A distribution system's hosting capacity and that of its components will change over time as load, GER and circuit configurations change. Traditional HCA uses static snapshots, assuming worst-case scenarios based on fixed load and generation assumptions, which often

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[62] U.S. Department of Energy, Flexible DER & EV Connections. July 2024. Available online: https://www.energy.gov/sites/default/files/2024-08/Flexible%20DER%20%20EV%20Connections%20July%202024.pdf

underestimate the temporal differences of actual hosting capacity. A shift has occurred to dynamic HCA, which uses real-time or near real-time data to reflect actual system conditions and GER behavior at specific substations or feeders, offering granular locational constraints. This dynamic HCA is used to support the flexible connections and dynamic operating envelopes concept.[63]

### 3.2.7 Integrated Resource Transmission and Distribution Planning

Integrated grid planning brings together traditionally siloed activities into a unified process to streamline analyses, reduce misalignment, and increase resource efficiency.[64] At high levels of GER adoption, the net load characteristics on the distribution system can have material impacts on the transmission system and bulk power system operation.

Integrated planning is a recurring process, updated regularly to reflect new technologies, policies, and system needs. The planning horizons commonly span 10 to 20 years, and refresh cycles vary by jurisdiction, often requiring updates every 1 to 5 years as forecasts, technologies, policies, and system conditions evolve.[65] For states with vertically integrated utilities, it is important to coordinate changes to distribution planning with integrated resource and transmission planning. Regulated utilities file integrated resource plans to assess optimal resource portfolio and to inform regulators and stakeholders with information on electric system demand, reliability, costs, risks, and uncertainties and other important issues that affect utility customers. To the extent GER is considered in resource and transmission planning, it is essential to align those GER growth patterns, timing and net load shape assumptions and plans for consistency across all planning domains. Further, to the extent distribution connected GER provides wholesale energy services, it is necessary to consider the deliverability of that GER across the distribution system to the wholesale transaction point.[66]

### 3.2.8 Interconnection Process

Interconnection refers to the process of integrating a GER at customer premises and operating it in parallel with the utility system while complying with the technical, legal, and contractual requirements established by a utility. Interconnection processes are designed to provide a non-discriminatory, transparent and timely evaluation of an interconnection request from a GER provider. Establishing a clear process and system interconnection rules, online application portals and analytics tools could streamline the interconnection process.[67]

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[63] NREL, Hosting Capacity Analysis for Utilities, August 2019. Available online: https://docs.nrel.gov/docs/fy19osti/74382.pdf

[64] LBNL, Interactive Decision Framework for Integrated Distribution System Planning. Available online: https://emp.lbl.gov/projects/integrated-distribution-system-planning

[65] LBNL and Synapse, Best Practices in Integrated Resource Planning. November 2024. Available online: https://www.energy.gov/sites/default/files/2024-12/best_practices_irp_nov_2024_final_optimized.pdf

[66] Definition developed from the following resources:

a) LBNL, Synapse Energy Economics, Best Practices in Integrated Resource Planning. November 2024. Available online: https://www.energy.gov/sites/default/files/2024-12/best_practices_irp_nov_2024_final_optimized.pdf
b) ICF, Integrated Distribution Planning, U.S. Department of Energy Office of Electricity, 2016, Page vi.

[67] LBNL, Interactive Decision Framework for Integrated Distribution System Planning. Available online: https://emp.lbl.gov/projects/integrated-distribution-system-planning

Feasibility and system impact studies are critical aspects of an interconnection application to assess potential grid impacts that would result if the proposed GER were interconnected without 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, including secondary-side voltage drop review for applicable customer-side interconnections.[68]

### 3.2.9 Locational Value Analysis

Locational value analysis is a structured process to quantify the location- and time-specific value of GERs on the distribution grid. GERs 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 GER 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 analysis estimates avoided or incremental system costs associated with local thermal, voltage, and reliability constraints, typically using area-specific avoided cost methods (also called the present worth method) or distribution marginal cost-of-service studies to produce $/kW or $/kW-year values at feeder or nodal levels.[69] The avoided cost of these investments forms the potential value that may be met by sourcing services from qualified GERs, as well as optimizing the location and timing of GER adoption on the distribution system to eliminate impacts and achieve least cost outcomes. The objective is to assess the costs and benefits of GERs to determine the net benefits for a given area of the distribution system (net of incremental platform costs to source GER) to compensate GER properly.[70]

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[68] Sheaffer, Paul. Interconnection of Distributed Generation to Utility Systems, RAP, September 2011. Available online: http://www.raponline.org/wp-content/uploads/2016/05/rap-sheafferinterconnectionofdistributedgeneration-2011 09.pdf

[69] LBNL, Locational Value of Distributed Energy Resources. February 2021. Available online: https://eta-publications.lbl.gov/sites/default/files/lbnl_locational_value_der_2021_02_08.pdf

[70] ICF, Integrated Distribution Planning, U.S. Department of Energy Office of Electricity, 2016, Page vi.

### 3.2.10 Open and Interoperable

Enable active participation by customers, and accommodate all forms of GER, 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.[71]

### 3.2.11 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.[72]

### 3.2.12 Resiliency by Design

A concept that emphasizes proactive planning and preparation for resiliency in the face of various distribution system challenges and uncertainties. This approach integrates risk-informed planning, high-resolution threat and vulnerability assessments, and solution portfolios that strengthen the system's ability to withstand, adapt to, and recover from disruptive events.[73] Key principles and components of resilience by design should include redundancy, adaptability, diversity, modularity, interoperability, etc. Depending on the hazards and local risk profile, relevant measures may include targeted undergrounding, sectionalizing switches and reclosers, FLISR, network redundancy, communications hardening, and vegetation management etc.

### 3.2.13 Reliability and Resiliency Criteria

Technical planning criteria are used to assess the operational performance of the distribution system in terms of availability, robustness and resiliency readiness. These criteria inform the identification and prioritization of infrastructure upgrades needed to improve performance to acceptable levels.

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[71] Definition developed from the following resources:

a) The Modern Grid Initiative Version 2.0, Conducted by the National Energy Technology Laboratory for the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, January 2007. Available online: http://www.netl.doe.gov/moderngrid/resources.html
b) Taft, JD and Becker-Dippmann, A. "Grid Architecture", January 2015.
c) Greentech Leadership Group and Caltech Resnick Institute. "More Than Smart – A Framework to Make the Distribution Grid More Open, Efficient and Resilient", Pages 12 & 13, August 2014. Available online: http://greentechleadership.org/wp-content/uploads/2014/08/More-Than-Smart-Report-by-GTLG-andCaltech.pdf
d) Minnesota Public Utilities Commission. "Staff Report on Grid Modernization", Page 17, March 2016. http://morethansmart.org/wpcontent/uploads/2015/06/MNPUC_Staff_Report_on_Grid_Modernization_March2016.pdf
e) New York Market Design and Platform Technology Working Group (MDPT). "Report of the Market Design and Platform Technology Working Group", Page 92, August 2015.

[72] De Martini, P, Fromer, N., Chandy, M. Grid 2020 Towards a Policy of Renewable and Distributed Energy Resources, Caltech Resnick Institute, 2012.

[73] De Martini, P, Taft, J. Distribution Resilience and Reliability Planning. January 2022. Available online: https://gridarchitecture.pnnl.gov/media/advanced/Resillience_Solution_Analysis_paper.pdf

Reliability planning criteria typically include:

- Voltage and thermal limits
- Performance metrics: SAIDI, SAIFI, CAIDI, and CEMI
- Rubrics for assessing utility resilience plans may include:[74]
- Preliminary Hazard Characterization: Identifies and ranks potential hazards (e.g., ice storms, flooding, extreme cold) using engineering judgment and qualitative assessments to guide where resilience investments are most needed.
- Attribute Metrics: Measures system features across four phases (anticipate, absorb, withstand, and recover).
- Performance Metrics: Tracks a utility's status in achieving its core objectives (e.g., affordability, safety, reliability, and resilience) like Major Event Day SAIDI to evaluate system behavior during extreme events.
- Threat Risk Analysis: Assesses the probability, consequence, and vulnerability of specific threats using historical data and forward-looking simulations.
- Investment Considerations: Take into account of various categories of investment types such as vegetation management, overhead hardening, network redundancy, and nonelectric grid physical infrastructure.
- Investment Prioritization: Identifies cost effectiveness of investment with respect to performance metrics, including stakeholder input to rank and justify resiliency projects.

### 3.2.14 Short-Term and Long-Term Distribution Investment Planning

Long term distribution investment planning establishes a utility's strategy, typically over a five- to ten-year or longer timeframe and provides a roadmap of capital and maintenance expenditures to address identified grid needs. This assessment is supported by multiple scenario-based assessment of distribution system needs, potential operational changes to system configuration, evaluations of asset plans and infrastructure replacement, modernization investments, and potential for non-wires alternatives.[75]

Short-term distribution investment planning provides greater specificity of proposed expenditures and investments needed to address priority grid needs within the next 1- to 5-year period. This includes identification of system needs, capital projects and costs estimated to accommodate customer load growth, grid reliability, resilience and safety, interconnected resources, and customer service connections.[76] These potential infrastructure upgrades are

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[74] NREL, Current Practices in Distribution Utility Resilience Planning for Winter Storms, August 2024. Available online: https://www.energy.gov/sites/default/files/2024-10/UtilityResiliencePlanningPracticesforHazards-WinterStorm.pdf

[75] Definition developed from the following resources:

a) LBNL, Interactive Decision Framework for Integrated Distribution System Planning. Available online: https://emp.lbl.gov/projects/integrated-distribution-system-planning
b) Case 14-M-0101 - Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, ("REV Proceeding"), Order Adopting Regulatory Policy Framework and Implementation Plan, Page 129, (issued February 26, 2015). Available online: http://energystorage.org/system/files/resources/0b599d87- 445b-4197-9815-24c27623a6a0_2.pdf

[76] NREL, Distribution Capacity Expansion Planning: Current Practice, Opportunities, and Decision Support, November 2022. Available online: https://docs.nrel.gov/docs/fy23osti/83892.pdf

defined into specific projects with estimated engineering, equipment and construction costs and need dates. These estimates are incorporated in budget forecasts and rate cases, used as a basis for avoided costs in a locational value analysis.

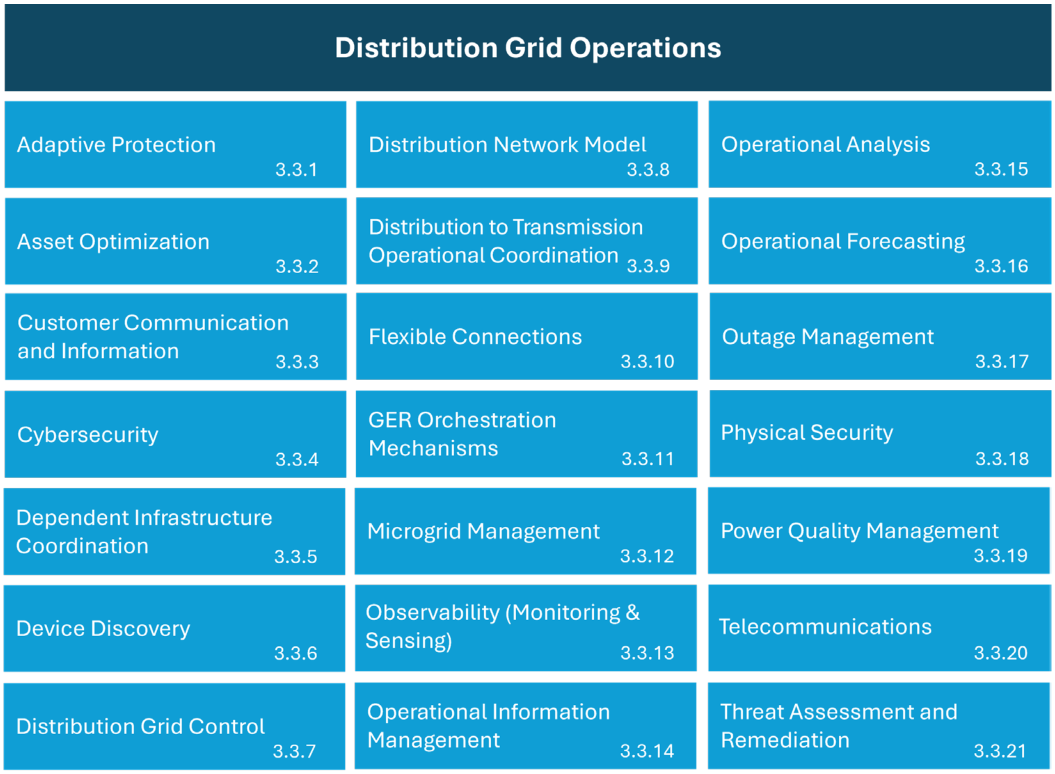
### 3.2.15 Short-Term and Long-Term Demand and GER Forecasting

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 GER growth and performance (including energy efficiency) and expected supply-side GER 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 GER adoption to capture evolving technology and policy environments.

Multiple GER forecast scenarios reflecting potential changes in GER and loads 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 GERs.[77]

## 3.3 Distribution Grid Operations

Figure 7 summarizes the revised functionalities under Distribution Grid Operations.



**Distribution Grid Operations**

| | | |
|---|---|---|
| Adaptive Protection 3.3.1 | Distribution Network Model 3.3.8 | Operational Analysis 3.3.15 |
| Asset Optimization 3.3.2 | Distribution to Transmission Operational Coordination 3.3.9 | Operational Forecasting 3.3.16 |
| Customer Communication and Information 3.3.3 | Flexible Connections 3.3.10 | Outage Management 3.3.17 |
| Cybersecurity 3.3.4 | GER Orchestration Mechanisms 3.3.11 | Physical Security 3.3.18 |
| Dependent Infrastructure Coordination 3.3.5 | Microgrid Management 3.3.12 | Power Quality Management 3.3.19 |
| Device Discovery 3.3.6 | Observability (Monitoring & Sensing) 3.3.13 | Telecommunications 3.3.20 |
| Distribution Grid Control 3.3.7 | Operational Information Management 3.3.14 | Threat Assessment and Remediation 3.3.21 |

Figure 7. Distribution grid operations functionalities.

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[77] Grid Modernization Laboratory Consortium U.S. Department of Energy, Electric Distribution System Planning with DERs – High-level Assessment of Tools and Methods, March 2020. Available online: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-28138.pdf

### 3.3.1 Adaptive Protection

Adaptive protection refers to a protection scheme that varies its logic based on system conditions.[78] An adaptive protection system is conventionally coordinated through a central management system, but there is research to explore distributed approaches. Adaptive protection relies upon communication infrastructure to monitor the latest status of the grid and send appropriate settings to protection devices within a specific coordination scheme.[79]

### 3.3.2 Asset Optimization

Asset optimization refers to the 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.[80,81,82]

### 3.3.3 Customer Communication and 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 a distribution services provider and/or retail energy services provider.

### 3.3.4 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, or other cyber-attacks.[83] 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

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[78] PNNL, Challenges, Industry Practice, and Research Opportunities for Protection of IBR-Rich Systems. Richland, WA: May 2024. Available online: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-36067.pdf.

[79] Sandia National Laboratories, Adaptive Protection and Control for High Penetration PV and Grid Resilience Final Technical Report. Albuquerque, NM: April 2024. Available online: https://www.osti.gov/servlets/purl/2382709.

[80] U.S. Department of Energy, NETL. The Modern Grid Strategy – A Vision for the Smart Grid, Page 9, June 2009. Available online: https://www.netl.doe.gov/File%20Library/research/energy%20efficiency/smart%20grid/whitepapers/Whitepa per_The-Modern-Grid-Vision_APPROVED_2009_06_18.pdf

[81] PNNL. Electric Distribution System Planning with DERs – High-Level Assessment of Tools and Methods. March 2020. PNNL-28138. Available online: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-28138.pdf.

[82] U.S. Department of Energy, NETL. Smart Grid Principal Characteristics: Optimizes Asset Utilization and Operates Efficiently. September 2009. Available online: https://netl.doe.gov/sites/default/files/Smartgrid/Optimizes-Assets--Operates-Efficiently_APPROVED_2009_09_09.pdf.

[83] “Core Sector: Critical Infrastructure and Cybersecurity”. Cybersecurity Glossary. NARUC. Retrieved 8 October 2025. Available online: https://www.naruc.org/core-sectors/critical-infrastructure-and-cybersecurity/cybersecurity-for-utility-regulators/cybersecurity-glossary/.

due to malpractice by operators, whether intentional, accidental or due to deviation from secure procedures.[84]

### 3.3.5 Dependent Infrastructure Coordination

Dependent infrastructure coordination involves identifying and incorporating the knowledge of dependencies of multiple entities (bulk power system, communication, transportation, gas, water), enabling coordinated decision-making in integrated planning.[85,86,87] This functionality supports coordination with affected entities during normal operations, contingencies, and service disruptions so that interdependent infrastructure conditions can be reflected in grid operations and response actions.

### 3.3.6 Device Discovery

Enable grid and edge devices to autonomously identify themselves (i.e., be discoverable), self-register, and automatically communicate their attributes and operating characteristics. Device discovery occurs across multi-tiered structures, heterogeneous communication protocols, and diverse technology platforms including legacy systems. The function involves the integration of technologies with distinct characteristics and supports the continued efficiency, reliability, and longevity of power distribution networks by facilitating streamlined coordination.[88]

### 3.3.7 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 GER in response to changes in load and injected power flows, and system disturbances.[89,90]

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[84] U.S. Department of Energy. Cybersecurity Considerations for Distributed Energy Resources on the U.S. Electric Grid. October 2022. Available online: https://www.energy.gov/sites/default/files/2022-10/Cybersecurity%20Considerations%20for%20Distributed%20Energy%20Resources%20on%20the%20U.S.%20Electric%20Grid.pdf.

[85] P. De Martini and J. Taft. The Emerging Interdependence of the Electric Power Grid & Information and Communication Technology. August 2015. PNNL-24643. Available online: https://www.pnnl.gov/main/publications/external/technical_reports/pnnl-24643.pdf.

[86] Cybersecurity & Infrastructure Security Agency (CISA). Learn: What are dependencies and why should I care? October 2025. Available online: https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/resilience-services/infrastructure-dependency-primer/learn.

[87] Electricity Advisory Committee (EAC). Natural Gas and Electric Critical Infrastructure Coordination. June 5, 2024. Available online: https://www.energy.gov/sites/default/files/2024-11/Natural%20Gas%20and%20Electric%20Critical%20Infrastructure%20Coordination%20June%202024.pdf.

[88] ScienceDirect. “Device Discovery”. Accessed October 2025. Available online: https://www.sciencedirect.com/topics/computer-science/device-discovery.

[89] New York Market Design and Platform Technology Working Group (MDPT). Report of the Market Design and Platform Technology Working Group, Pages 55, 56, August 2015.

[90] NREL. “Autonomous Energy Systems: Building Reliable, Resilient, and Secure Electrified Communities”. June 2024. Available online: https://docs.nrel.gov/docs/fy24osti/87629.pdf.

### 3.3.8 Distribution Network Model

A topological model of the physical distribution system, and customer and GER connectivity (including asset characteristics) that reflects dynamic changes to the state of the system.[91,92] In advanced implementations, the model may be updated to reflect switching and other changes in system state and may support real-time or near-real-time distribution operations and analysis.

### 3.3.9 Distribution to Transmission Operational Coordination

This function ensures reliability, resilience, security and assurance to the balancing authorities of the operational services of dispatched GERs, by efficiently coordinating, scheduling and managing GERs in real-time, including prioritization rules. T&D interface coordination functions are carried out across multiple entities and across timeframes (e.g., pre-event/registration, operational, and post-event) to avoid detrimental effects on local distribution systems and regional transmission systems by coordinating power flows between the transmission operator and DSOs due to GER dispatch.[93,94,95]

### 3.3.10 Flexible Connections

A control approach to enable GER interconnections and service connections based on dynamic operating parameters. Resources are provided with different options and approaches to interconnection to yield less costly interconnection requirements through increased control of GERs and interconnected devices. These methods involve shaping GER import and export limits to remain within distribution system operating parameters. Flexible connections can be implemented through customer-controlled solutions employing time-based import/export limits or in real-time via utility direct-controlled curtailment and derates of GERs or EV charging.[96]

### 3.3.11 Grid Orchestration Mechanisms

Grid orchestration mechanisms involve the coordinated management of GERs to meet the operational needs of the electric distribution grid. This functionality involves control mechanisms via centralized or decentralized dispatch signals, autonomous responses (either fixed parametric or via pre-set standards-based control), or behavior responses involving the use of information that influences energy consumption patterns (e.g., responsive demand and energy

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[91] Dirkman, John. Best Practices for Creating Your Smart Grid Network Model, Schneider Electric. Available online: http://cdn.iotwf.com/resources/8/Best-practices-for-creating-your-Smart-Grid-network-model_2013.pdf

[92] NREL. SMART-DS: Synthetic Models for Advanced, Realistic Testing: Distribution Systems and Scenarios. Accessed October 2025. Available online: https://www.nrel.gov/grid/smart-ds.

[93] New York Market Design and Platform Technology Working Group (MDPT). “Report of the Market Design and Platform Technology Working Group”, Page 18, August 2015.

[94] EPRI. Transmission Distribution and Aggregator Coordination. Accessed October 2025. Available online: https://msites.epri.com/der-vpp-ferc2222/Transmission-Distribution-and-Aggregator-Coordination.

[95] ESIG. “The Transition to a High-DER Electricity System: Creating a National Initiative on DER Integration for the United States”. August 2022. Available online: https://www.esig.energy/wp-content/uploads/2022/08/ESIG-DER-integration-US-initiative-report-2022.pdf.

[96] U.S. Department of Energy Office of Electricity. Flexible DER & EV Connections. July 2024. Available online: https://www.energy.gov/sites/default/files/2024-08/Flexible%20DER%20%20EV%20Connections%20July%202024.pdf.

conservation techniques). Successful orchestration depends on accurate data, interoperable systems, mature technologies, and robust communication networks.[97]

### 3.3.12 Microgrid Management

Coordination of interconnected microgrid operation with a distribution system in normal conditions, island mode, and safely synchronize a return to non-island distribution system operation. In operational modes, protection systems and distribution equipment are adjusted as needed to ensure the safe distribution of power within the microgrid boundary.[98]

### 3.3.13 Observability (Monitoring and Sensing)

The ability to provide actionable information on the operating state and condition of the distribution grid, grid and GER 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.[99,100]

### 3.3.14 Operational Information Management

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

### 3.3.15 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 GER dispatch.

### 3.3.16 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.

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[97] U.S. Department of Energy. Distribution Grid Orchestration. November 2024. Available online: https://www.energy.gov/sites/default/files/2024-12/2024-11-18%20Distribution%20Grid%20Orchestration_Clean.pdf.

[98] ORNL. Topic #5 – Advanced Microgrid Control and Protection. March 2021. Available online: https://www.energy.gov/sites/default/files/2022-09/5-Advanced%20Microgrid%20Control%20and%20Protection.pdf.

[99] NIST. NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 4.0. NIST Special Publication 1108r4. February 2021. Available online: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1108r4.pdf

[100] Tingting He, et al. Advanced sensing and holistic perception technologies for new-type power systems: A comprehensive review. Renewable and Sustainable Energy Reviews, Volume 223, 2025, 116023, ISSN 1364-0321. Available online: https://www.sciencedirect.com/science/article/pii/S1364032125006963?ref=pdf_download&fr=RR-2&rr=98efb6be0ecab086

### 3.3.17 Outage Management

Outage management involves a number of processes and systems that enable distribution operators to detect, locate, and resolve power outages in an informed, orderly, efficient, and timely manner. The outage 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.[101]

### 3.3.18 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.[102,103]

### 3.3.19 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.[104,105,106,107]

### 3.3.20 Telecommunications

Operational telecommunication consists of communication protocols, technologies, and assets that are present between operating centers and substations and extend into the field to connect grid sensors and controllable grid devices (e.g., switches, capacitor banks, protective devices, etc.) on 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.

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[101] Stewart, Emma. Distribution System Components, Systems and Operators: Distribution-level Management Systems. October 2020. Available online: https://eta-publications.lbl.gov/sites/default/files/1b._distribution_components_systems_and_operations.pdf

[102] U.S. Department of Energy, Quadrennial Technology Review – An Assessment of Energy Technologies and Research Opportunities, Chapter 3, Section 3A. Page 9-10, September 2015.

[103] NERC. Physical Security Guideline for the Electricity Sector: Assessments and Resiliency Measures for Extreme Events. June 2019. Available online: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Physical_Security_Guideline_%20Assessments_and_Resiliency_Measures_for_Extreme_Events_June_2019.pdf.

[104] CA Working Group, Overview of Discussions Q3 2014 thru Q1 2015 Volume 2, More Than Smart-Caltech, 2015.

[105] Los Angeles Department of Water & Power (LADWP). Power Quality. Accessed October 2025. Available online: https://www.ladwp.com/who-we-are/power-system/power-quality.

[106] Gerber, et al. Energy and Power Quality Measurement for Electrical Distribution in AC and DC Microgrid Buildings. Applied Energy, Volume 308, 2022, 118308, ISSN 0306-2619. Available online: https://doi.org/10.1016/j.apenergy.2021.118308.

[107] Dehaghani, et al. Power quality improvement in DG based distribution systems: A review. Renewable and Sustainable Energy Reviews, Volume 225, 2026, 116184, ISSN 1364-0321. Available online: https://www.sciencedirect.com/science/article/pii/S1364032125008573#bib0035.

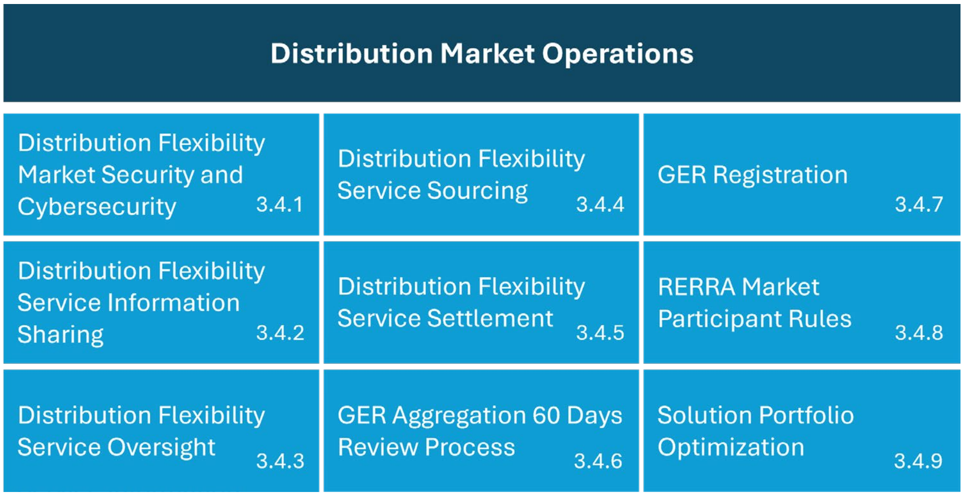
Operational telecommunications are intended to maintain highly reliable connectivity under both normal and degraded system operating conditions (e.g., electrical noise, equipment failure, and physical attacks).[108] However, no communication system is invulnerable to failure, making it a key modern grid design requirement for systems to operate safely and reliably in the event of loss of telecommunication infrastructure connectivity.

### 3.3.21 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. Assessments of threat vectors and countermeasures may be defined using quantitative and/or qualitative metrics and can incorporate historic event data and forward-looking projections on how threat probabilities may change in future.[109,110,111]

## 3.4 Distribution Market Operations

Figure 8 summarizes the revised functionalities under Distribution Market Operations.



| Distribution Market Operations | | |
|---|---|---|
| Distribution Flexibility Market Security and Cybersecurity 3.4.1 | Distribution Flexibility Service Sourcing 3.4.4 | GER Registration 3.4.7 |
| Distribution Flexibility Service Information Sharing 3.4.2 | Distribution Flexibility Service Settlement 3.4.5 | RERRA Market Participant Rules 3.4.8 |
| Distribution Flexibility Service Oversight 3.4.3 | GER Aggregation 60 Days Review Process 3.4.6 | Solution Portfolio Optimization 3.4.9 |

Figure 8. Distribution market operations functionalities.

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[108] Definition developed from the following resources:

a) U.S. Department of Energy. Quadrennial Technology Review – An Assessment of Energy Technologies and Research Opportunities, Chapter 3, Section 3E. Page 11, September 2015.
b) New York Market Design and Platform Technology Working Group (MDPT). Report of the Market Design and Platform Technology Working Group, Pages 100-101, August 2015.

[109] U.S. Department of Energy. "Risk Assessment Essentials for State Energy Security Plans". April 2024. Available online: https://www.energy.gov/sites/default/files/2024-05/DOE%20CESER-Risk%20Assessment%20Essentials%20Guide%20for%20State%20Energy%20Security%20Plans.pdf.

[110] National Academies Press (NAP). Terrorism and the Electric Power Delivery System. Chapter 6: Mitigating the Impact of Attacks on the Power System. 2012.

[111] Wynn, Jackson. Threat Assessment and Remediation Analysis (TARA) Workbook for Industrial Control Systems / Supervisory Control and Data Acquisition (ICS/SCADA). Version 1.4. The MITRE Corporation. May 2018.

### 3.4.1 Distribution Flexibility Market Security and Cybersecurity

Capabilities put in place to ensure that all information communications networks from many different actors 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 GER providers and utilities, mechanisms to ensure that data provided does not enable market gaming and respects privacy and cybersecurity concerns must be established.[112] The implementation of FERC Order No. 2222 will bring significant organizational and operational changes, making it essential to establish robust cybersecurity and data governance frameworks to manage the increased data sharing among stakeholders.

### 3.4.2 Distribution Flexibility Service Information Sharing

This function encompasses the use of communication technologies and exchange of market information between the ISO, DSO, GER aggregators, and participating GER customers for greater transparency and interoperability. This includes information on net distribution system demand, net interchanged supply, GER services scheduled by the distribution operator, GER forecasts, aggregate output of GERs, and GER 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 distribution system operator is involved in other market functions (e.g., retail supply).[113]

FERC Order No. 2222 requires secure and standardized protocols for data exchange among aggregators, EDCs, RERRAs, and market operators (RTOs/ISOs) and data requirements for GER aggregations. Aggregators may require access to system data to identify eligible GERs for aggregation participation and to complete registration in RTO/ISO markets. This information is likely to be subject to data privacy regulations, cybersecurity measures, and may be considered critical infrastructure. Similarly, EDCs will need to retain records of GERs and their aggregations within their respective service areas. A coordinated effort among key stakeholders is essential to establish what data types and functionalities are required to align with relevant RTO/ISO implementation plans and state-level requirements.[114]

### 3.4.3 Distribution Flexibility Service Oversight

The oversight process includes functions to monitor distribution flexibility markets and to assess potential market manipulation, ensure market security, legitimacy, and performance. This function also includes the related market participant rules in terms of the responsibilities and associated requirements.

Additionally, in accordance with FERC Order No. 2222, RERRAs will play a key role in establishing frameworks to oversight GERs that participate in both retail and wholesale markets to prevent dual participation. Additionally, RERRAs are responsible for establishing clear

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[112] New York Market Design and Platform Technology Working Group (MDPT), Report of the Market Design and Platform Technology Working Group, Pages 69, 70, August 2015.

[113] New York MDPT. Report of the Market Design and Platform Technology Working Group, Page 65, August 2015.

[114] FERC, Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators [Docket No. RM18-9-000; Order No. 2222], September 2020. Available online: https://www.ferc.gov/sites/default/files/2020-09/E-1_0.pdf

processes for resolving disputes between aggregators, EDCs, and other stakeholders. Disputes may include distribution system override decisions by EDCs, curtailment and derating of GERs by EDCs.[115]

### 3.4.4 Distribution Flexibility Service Sourcing

Distribution operational markets would enable GER to provide services as an alternative to certain utility distribution capital investments and/or operational expenses. The potential types of services may include distribution capacity, energy, reactive power support, reliability and resiliency, and power quality.[116] The distribution planning process defines the need for these grid operational services.[117,118]

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

- Pricing: GER response through time-varying rates, tariff-based prices or cost-based distribution marginal values
- Programs: GER 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: GER services sourced through competitive procurements such as requests for proposals/offers, auctions, etc.
- Local Flexibility Markets: GER services sourced through market platform where distribution system operators buy and sell grid services through an over-the-counter forward and day-ahead local distribution level market.

GER portfolio management consists of managing a mix of GER sourced through various mechanisms involving prices, programs, procurements, and flexibility markets, as well as grid infrastructure investments. Distribution sourcing methods evaluation is the assessment of the sourcing mechanisms by which a distribution utility procures, incentivizes or contracts with GERs to deliver services that meet local distribution-grid needs. 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 GERs into grid operations) and offering value certainty for ratepayers in terms of cost-effectiveness and for GER customers and service providers in terms of financial risk and certainty.[119]

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[115] LBNL, State regulatory opportunities to advance distributed energy resource aggregations in wholesale markets, January 2025. Available online: https://eta-publications.lbl.gov/sites/default/files/2025-01/final_der_participation_in_wholesale_market.pdf

[116] U.S. Department of Energy, Bulk Power, Distribution, and Grid Edge Services Definitions, November 2023. Available online: https://www.energy.gov/sites/default/files/2023-11/2023-11-01%20Grid%20Services%20Definitions%20nov%202023_optimized_0.pdf

[117] California Public Utility Commission, Docket R.14-08-013, Distribution Resources Plan.

[118] Consolidated Edison, Brooklyn Queens Demand Management program. More information available online: https://www.coned.com/energyefficiency/pdf/BQDM-program-update-briefing-08-27-2015-final.pdf

[119] De Martini, Paul and Kristov, Lorenzo, Distribution Systems in a High Distributed Energy Resources Future – Planning, Market Design Operation and Oversight, LBNL, Page 42, October 2015. Available online: https://emp.lbl.gov/sites/all/files/FEUR_2%20distribution%20systems%2020151023_1.pdf

### 3.4.5 Distribution Flexibility Service 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.[120] This serves as the basis of financial settlements for services supplied, identifying their quantity, quality, and timing. The settlement process includes calculating credits and charges for the grid services provided by GERs and other market activity. To ensure settlement is based on verifiable data, metering and telemetry are essential to provide the accurate, time-stamped records needed for audits, dispute resolution, and compliance checks, helping to prevent both over- and under-payment for GER services.[121]

### 3.4.6 GER Aggregation 60-Day Review Process

FERC Order No. 2222 requires each RTO/ISO to revise its tariff so that EDCs have up to 60 calendar days to review proposed GER aggregations. This review period allows EDCs to determine whether the proposed aggregation can safely and reliably operate on the distribution system and participate in wholesale markets and provides an opportunity to report any identified concerns and recommendations to the RTO/ISO. There are two main review functions:[122]

- Capability Review: This process verifies that each constituent GER within an aggregation has a valid interconnection agreement and ensures that participation in retail tariffs or programs does not prevent participation in the aggregation or wholesale markets (i.e., to confirm that GERs are not receiving dual compensation for the same service).
- Safety and Reliability Review: This review assesses any risks that the aggregation’s operation could pose to the safety and reliability of the distribution system resulting from the operation of GER aggregations (and individual GERs within an aggregation) in a RTO/ISO's energy and ancillary services markets. EDCs will review the expected dispatch and any limitations set in interconnection agreements. EDCs may also consider the impact of different GER technologies, participation models, and penetration levels.

### 3.4.7 GER Registration

In accordance with FERC Order No. 2222, each RTO/ISO is required to create a framework that recognizes GER aggregators as a market participant, enabling them to register and allow GER aggregations to participate directly in RTO/ISO markets. A GER registry serves as a master record database that provides stakeholders key information on GER aggregations and

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[120] Definition developed from the following resources:
  a) The GridWise Architecture Council. GridWise Transactive Energy Framework Version 1.0, Page 25, January 2015. http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf
  b) De Martini, Paul and Kristov, Lorenzo, Distribution Systems in a High Distributed Energy Resources Future – Planning, Market Design, Operation and Oversight, LBNL, Pages 25, 28, October 2015. Available online: https://emp.lbl.gov/sites/all/files/FEUR_2%20distribution%20systems%2020151023_1.pdf
  c) New York Market Design and Platform Technology Working Group (MDPT). Report of the Market Design and Platform Technology Working Group, Page 67, August 2015.

[121] CAISO, Metering and Telemetry. Available online: https://www.caiso.com/generation-transmission/metering-telemetry

[122] FERC, Order No. 2222, Docket No. RM18-9-002, Marh 2021. Available online: https://www.ferc.gov/sites/default/files/2021-03/E-1.pdf

underlying participatory GERs, managing and cataloging GER data in a standardized manner. The types of data include asset registration, operating parameters and characteristics, interconnection and operational constraints, GER aggregation information, GER aggregator and owner information, aggregation rules, and market participation rules and pre-qualifications.[123]

EDCs will be positioned to review GER enrollments for compatibility with both retail and wholesale market rules, and to support GER aggregation registration with an ISO by providing detailed data on GER location, configuration, telemetry, performance characteristics, and operational status. This dynamic GER dataset is essential for RTOs/ISOs, DSOs, and aggregators for planning, operation, and settlement. As such, it needs to be secure and interface seamlessly with existing systems. Access to registration information to ensure data privacy is governed by specific privileges and rules established by FERC and/or the RERRA, as applicable.

### 3.4.8 RERRA Market Participant Rules

This set of rules defines the requirements and responsibilities of market participants regarding service delivery and compliance standards, including eligibility criteria, interconnection requirements, and dual participation policies. RERRAs will play an important role in shaping the rules that govern how GER aggregators and other market participants operate within their jurisdictions under FERC Order No. 2222.

### 3.4.9 Solution Portfolio Optimization

Solution portfolio optimization is the iterative process of selecting, structuring, and managing a mix of solutions (resources, programs, investments, and operational controls) in a portfolio to achieve the best trade-off between performance, cost, and risk. This iterative optimization process refines the grid solutions portfolio through repeated evaluation and adjustment, giving confidence that the chosen portfolio is optimal given the specified goals and constraints.[124]

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[123] U.S. Department of Energy, TSO-DSO-Aggregator Market and Operational Coordination Requirements, April 2024. Available online: https://www.energy.gov/sites/default/files/2024-07/47990_DOE_OE_TDC_Project_Coordination_Platform_v9_RELEASE_508.pdf

[124] GridLab, Iterative Portfolio Optimization: An essential tool for reliable and clean electricity planning, December 2024. Available online: https://gridlab.org/wp-content/uploads/2024/12/GridLab-Sylvan_Iterative-Portfolio-Optimization.pdf

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