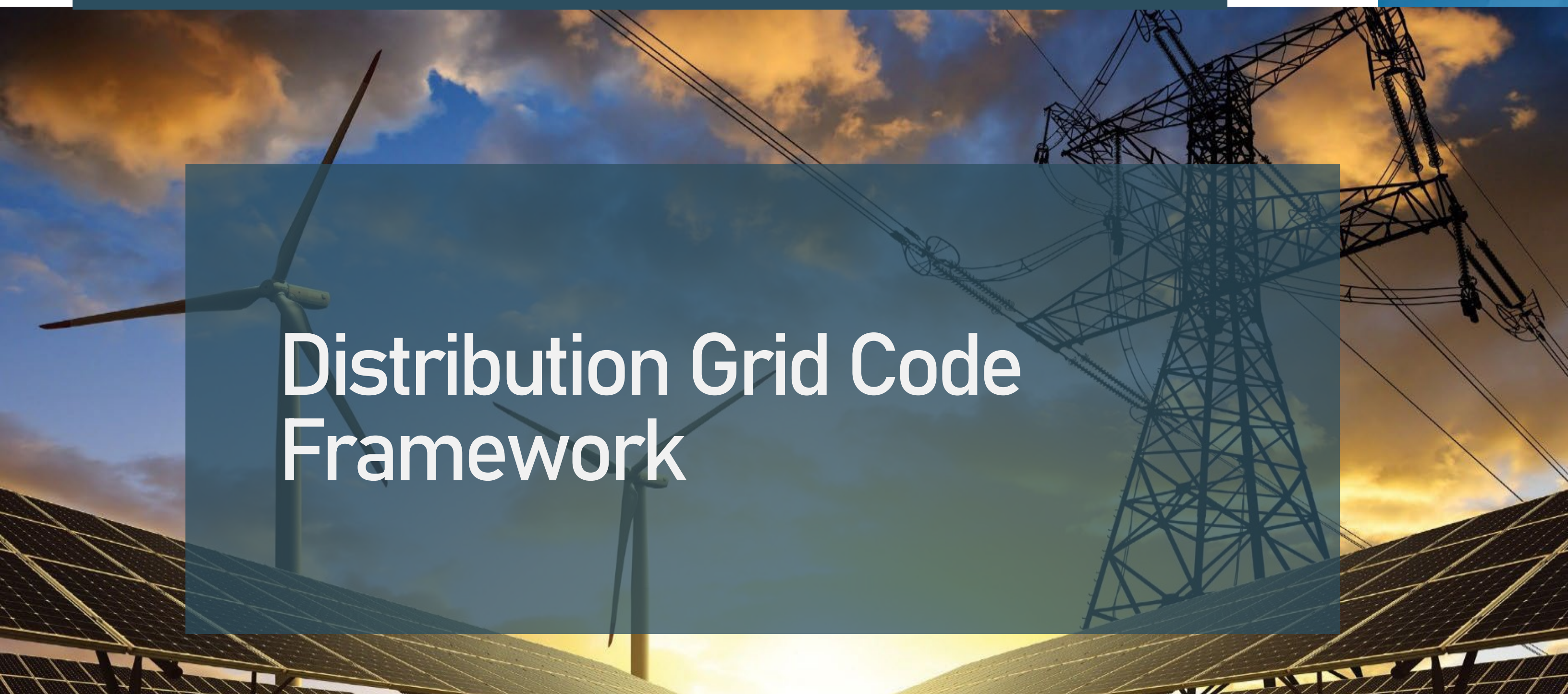

Distribution Grid Code Framework

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U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

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DOE Office of Electricity Program Manager Joseph Paladino oversees this work.

Contents

Acknowledgements 1

Disclaimer 1

Introduction 3

Distribution Grid Code Framework 4

- Distribution Grid Code Families and Elements 4
  - Grid Engineering 5
  - DER and Microgrid Integration 5
  - Virtual Power Plants and Microgrid Services 6
  - DER and Microgrid Operation 7
  - Information Sharing and Security 8
  - Governance and Oversight 9
- Institutional, Business, and Technical Components 9
- Best Practices and Technical Standards 18
  - Transportation Electrification 18
  - Hosting Capacity Analysis 20

Pathways for the Adoption of Distribution Grid Codes 22

Conclusion 26

Introduction

In recent years, several interrelated trends have arisen in the U.S. electricity sector related to the evolving role of the distribution system. These include (but are not limited to) rapid technological advancements, the growing roles of both customers and independent energy services providers in the generation and management of electricity, and the convergence of transmission - distribution system markets and operations. These trends are set against a broader backdrop of rising distributed energy resource (DER)[1] growth, carbon-focused public policies, electrification of vehicles and buildings, an interest in microgrids, and a desire to use these resources to maintain the security and resilience of the grid. Consequently, those who seek to act on these shifts to advance related objectives need a logical framework that aids in clearly parsing the intertwined considerations associated with the trends. This paper presents that framework, aiming to create alignment between an entity's goals and objectives and the practical considerations required to achieve those objectives.

This report presents a framework for regulators and industry stakeholders to understand, develop, and implement distribution grid codes required to integrate and utilize DER within power systems. The paper broadens the traditional purview of electric distribution system grid codes to institutional and business processes and engineering practices for DER integration and utilization. This is in addition to traditional grid codes that focus, for example, on technical standards for generation interconnection. Adherence to a standard set of grid codes creates a common set of expected methods and outcomes that provide all stakeholders confidence that system elements will behave as intended. Hence, the use of grid codes helps facilitate the building of trust between power system participants, aiding in achieving the desired scale of DER integration and utilization.[2]

This report introduces a distribution grid code framework. The framework encompasses the various activities associated with the integration and utilization of DER, microgrids, and electrification into a structured set of best practices and associated technical standards. The resulting taxonomy will enable regulators and other stakeholders to consider the scope of implementation issues to address and the respective best practices for each aspect necessary to achieve jurisdictional goals. This report also recognizes that each state and utility will have a unique set of factors that will shape their public policy objectives and the pathways to achieve those objectives. Subsequent companion reports will a) examine various pathways that states and utilities may pursue and b) provide a comprehensive catalog of regulatory, business, and engineering best practices.

This report is organized in the following fashion. The "Distribution Grid Code Framework" section introduces the key concepts and features of the distribution grid code framework. This section also describes the details of the framework and includes an illustrative example. The "Pathways for the Adoption of Distribution Grid Codes" section presents the steps required to develop an implementation plan for adopting distribution grid codes. The "Conclusion" section summarizes this report and its key takeaways for the reader.

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[1] In addition to "traditional" DERs, such as solar PV, battery energy storage, energy efficiency, demand response, and electric vehicles, this distribution grid code framework includes concepts and components relevant to microgrids.

[2] High DER penetration is often synonymous with clean energy goals. The federal government has a goal of 100% clean electricity by 2035, and a target of net-zero emissions by 2050 (https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf). Twenty-two states, Washington DC, and Puerto Rico have 100% clean energy goals (https://www.cesa.org/projects/100-clean-energy-collaborative/guide/table-of-100-clean-energy-states/).

Distribution Grid Code Framework

This distribution grid code framework uses a business process engineering approach to consider the interrelated regulatory, business, and technical aspects required to transform distribution system functions as desired. The distribution grid code framework is shown below in Figure 1. The components of the framework include:

- **Grid Code Families:** Families are the broad functional categories relevant to the integration and utilization of DER and electrification in distribution systems.
- **Grid Code Elements:** Elements are a more detailed breakdown of the functions within a code family.
- **Institutional, Business, and Technical Components:** Components are the interrelated legislative, business, and technical processes, procedures, and design criteria associated with each code element.
- **Institutional, Business, and Technical Best Practices and Standards:** The best practices and standards are associated with each component. These include regulatory rulemakings, leading business processes and engineering practices, and recognized technical standards.

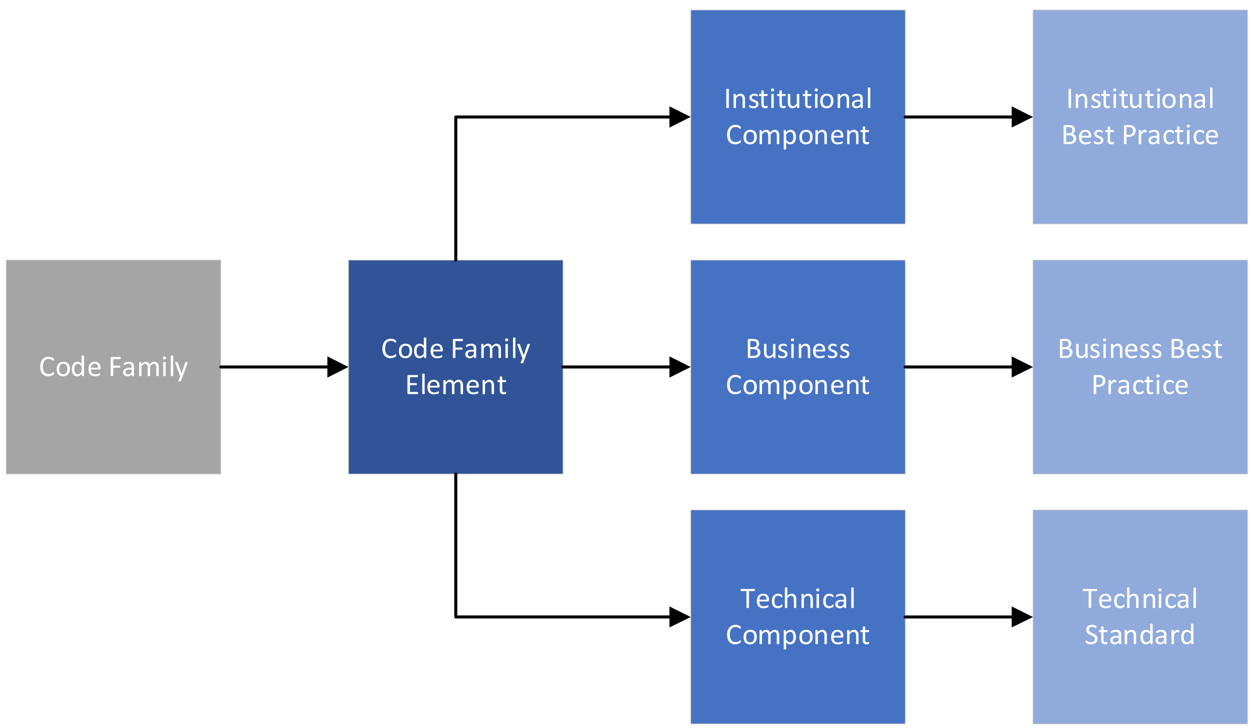

Figure 1. Distribution Grid Code Taxonomy Framework

This taxonomy is intended to provide regulators and stakeholders with insight into the capabilities and interrelated considerations required to facilitate DER integration and utilization within distribution systems.

Distribution Grid Code Families and Elements

The grid code families address six critical areas pertinent to integrating and utilizing DERs on the distribution system. The six families are:

- Grid Engineering
- DER and Microgrid Integration
- Virtual Power Plants and Microgrid Services
- DER and Microgrid Operation
- Information Sharing and Security
- Governance and Oversight

Each code family is further parsed into its respective constituent code family elements. The objective of summarizing these code families and elements is to capture a holistic set of considerations for DER integration and utilization. These code families and elements were distilled from industry documents, peer reviews, and conversations with industry experts. The code families and elements are described below.

Grid Engineering

This code family includes various DER integration analyses, with a particular emphasis on analyses undertaken as part of a utility's distribution system planning process. As increasing numbers of DERs are integrated into utility distribution systems, detailed studies can be undertaken to investigate the impact of these resources on the grid.

Table 1. Grid Engineering Code Family Elements

Code Elements	Description
Hosting Capacity Analysis	Planning studies that estimate the amount of generation, storage, and electric vehicles that can be added to the electric distribution system at a given time and location under existing or future grid conditions without system upgrades.
Short- and Long-Term DER Adoption Forecasting	Planning analysis to estimate the growth of distributed resource types, such a solar PV, and other distributed generation, storage, and electric vehicles over various time horizons across a distribution system. This includes forecasting the associated net load.
Locational Value Analysis	Studies to determine the potential value (generation, capacity, frequency response, ramping, etc.) that DERs can provide at a specific location on the distribution system.
Transportation Electrification	Analyses to determine the impacts of increased electrification of transportation, such as the addition of light, medium, and heavy-duty electric vehicles. Outputs of these analyses typically include a quantification of the incremental energy required to serve new load and an assessment of change in system peak loads.

DER and Microgrid Integration

The "DER and Microgrid Integration" code family captures functions and technologies required to support grid resilience and practices to enable system safety and reliability at all levels of DER penetration. These practices include consideration of the appropriate communication and cyber-physical security protocols.

Energy storage systems, including batteries and other innovative technologies, will be widespread. The adoption of residential and commercial energy storage solutions will be driven by a desire for energy independence, resilience against power outages, and the potential for cost savings by optimizing energy consumption. This is enabled by continued cost reductions in battery storage technologies, driven by advancements in materials, manufacturing processes, and economies of scale. In addition, energy density and duration are expected to improve, allowing batteries to store more energy within the same or smaller physical footprint. This will result in storage systems (including hybrid systems) capable of storing more energy for multiple hours or even days becoming more common.

Table 2. DER and Microgrid Integration Code Family Elements

Code Elements	Description
Inverter-Based Resources (IBRs)	IBRs are assets that require a power electronic device (an inverter) to convert their direct current (DC) electric output to an alternating current (AC) output. Common examples of IBRs on the distribution system include solar PV and battery energy storage.
DER Monitoring and Control	DER monitoring and control capabilities include the observation of distribution grid and DER parameters (including factors that affect DER performance such as temperature and irradiation) and ability to control and/or adjust DER output.
DER Interconnection Procedures	Engineering analysis and study procedures that govern interconnection studies for DERs applying to interconnect and operate in parallel with the utility distribution system.
Community-Based Renewable Energy	Refers to installations such as community solar gardens and solar farms that operate under a virtual net metering (Virtual NEM) or virtual PPA (VPPA) regime and community microgrids operating under a microgrid tariff.
Microgrids	Microgrids consist of groups of controllable DERs that are designed to serve loads within a discrete geographical boundary. Microgrids can connect and disconnect (island) from the broader electric distribution system.

Virtual Power Plants and Microgrid Services

This code family includes aspects relevant to the provision of DER distribution grid services and microgrid resilience services. This code family also includes aspects related to the participation of DERs and DER aggregations in wholesale electricity markets (as envisioned by FERC Order 2222, for example).

Table 3. Virtual Power Plants and Microgrid Services Code Family Elements

Code Elements	Description
Retail Energy and Distribution Grid Services	Distribution grid services include retail energy, capacity, voltage, and reactive power support on the distribution system as well as improvements in flexibility, resilience, reliability, and increases in hosting capacity.
Distribution Resilience Services	Distribution resilience services are provided by microgrids and DERs that are compensated by electric utilities. These services are intended to

Code Elements	Description
	mitigate the impact of high-impact, low-probability events that adversely impact the electric grid.
DER Aggregation	A collection of DERs located behind or in front of the customer meter that is orchestrated by an entity (known as a DER aggregator) for participation in retail (distribution level) and wholesale (ISO/ RTO) markets.
DER Aggregator (DERA) Wholesale Market Services	Utility tariffs and agreements that define the rules and regulations for distribution-connected DERs that wish to participate in wholesale electricity markets (standalone or through an aggregation). This code element also includes an administrative workflow and process that guides DER aggregators in the submission of information for an electric utility 60-day technical study of DER aggregation impacts (as mandated under FERC Order 2222).

DER and Microgrid Operation

This code family includes broad considerations relevant to the accommodation of DER, multidirectional power flows, and active grid management to maintain grid safety, reliability, and efficiency. This code family also includes the operational practices associated with the formation of microgrids. Code elements in this family include timing decisions for significant information/operational technology (IT/OT) investments and utility processes to validate market participation rules for DERs wishing to provide grid services (either in retail or wholesale markets).

Table 4. DER and Microgrid Operations Code Family – Code Elements

Code Elements	Description
Distributed Resource Management – Utility	The management and dispatch of DERs by utilities, based on the use of optimization tools, control systems and architectures, and DER analytics.
Distributed Resource Management – Aggregator	The management and dispatch of DERs by DER aggregators, based on optimization tools, control systems and architectures, and DER analytics.
Operating Agreements	Documents that govern project development, testing, and commercial operations. Agreements will include operational coordination requirements applicable to the unique characteristics of the project and general requirements to conform with utility operations (e.g., microgrid operating agreements).
Common Information Sharing Model/Framework/Capability between System Operators, Utilities, Market Participants	The Common Information Sharing Model (CIM) contains a set of standards for representing the major power system components within a utility's operational environment. The goal of the CIM is to assist in exchange of power system network data between companies, exchange of data between applications within a company, and exchange market data between market participants.

Code Elements	Description
Utility Investments in Operational Technology (ADMS/DERMS/SCADA)	Operational technologies use grid devices to capture and analyze information on grid parameters and behavior to help improve visibility and situational awareness, which in turn helps inform operational coordination and grid planning practices.
Registration of DERs and DER Aggregations for Market Services	Registration of DERs and aggregations by DER aggregators and customers for participation in retail and wholesale markets.
Market Participation Rules Validation for DER Aggregations	The ability of ISOs/RTOs and utilities to validate the proposed market participation strategies of DERs and DER aggregations against established retail and wholesale market rules.
Net Load Baselining and Performance Analytics for DERs and DER Aggregations	Baselines establish a customer's net load in the absence of DER. Hence, accurate net load baselining helps assess the performance of a customer DER (injection or load reduction) in response to dispatch instructions. Verifying DER performance helps generate accurate settlement and audit data for DER and DER aggregator services.

Information Sharing and Security

This code family relates to data dissemination and protection practices relevant to distribution system and market data. Distribution system data are intended to support DER integration use cases, with the sharing of information between customers, third parties, and utilities. Market information sharing relates to the sharing of data between the ISOs/RTOs, utilities, customers, and DER aggregators participating in wholesale and retail electricity markets.

Table 5. Information Sharing and Security Code Family – Code Elements

Code Elements	Description
Customer Data Access and Privacy	This code element refers to tools that provide customers with the means to access their energy usage data, with data being protected by the appropriate privacy and cybersecurity controls.
Distribution System Data	This code element refers to external facing data portals that provide utility information such as electric reliability reports, hosting capacity maps, historical and forecasted load data, and queued and installed DERs, among other items.
Information Sharing – Aggregators	This code element refers to the sharing of customer data (including historical energy usage data) with aggregators.
Cybersecurity	In the context of information and data sharing, cybersecurity refers to periodic cyber risk assessments; adherence to cyber requirements; monitoring, reporting, and management of incidents; and ensuring the privacy of customer data.

Governance and Oversight

This code family includes elements relevant to the monitoring of market activity to prevent market manipulation and ensure market security, legitimacy, and performance. This code family also includes elements related to the roles and responsibilities of various parties (utilities, DER aggregators etc.) and guidance of market behavior.

Table 6. Governance and Oversight Code Family – Code Elements

Code Elements	Description
Distribution Open Access	A distribution tariff/provision that requires distribution utilities to provide third parties (DER developers and aggregators, customers) with non-discriminating services comparable to the services provided by distribution utilities to themselves.
DER Aggregator Oversight	Regulatory oversight of DER aggregator operations by state-level regulatory authorities.
DER and Microgrid Value Determination and Cost Allocation	Evaluation of the benefits of DERs and/or microgrids via usage of a cost-benefit framework and determination of appropriate cost allocation and recovery mechanisms to finance the construction and operation of the DERs or microgrids.
Governance and Oversight of Wholesale Market Participating DER	The enactment of rules and policies by state-level regulators and commission members to govern and guide the behavior of DERs and DER aggregators participating in wholesale markets.

Institutional, Business, and Technical Components

The second layer of the grid code framework includes institutional, business, and technical components. Each of the code family elements is parsed into its various institutional, business, and technical components as illustrated in Figure 2. The identification of these three categories of components provides a line of sight into the end-to-end actions necessary to achieve specific objectives.

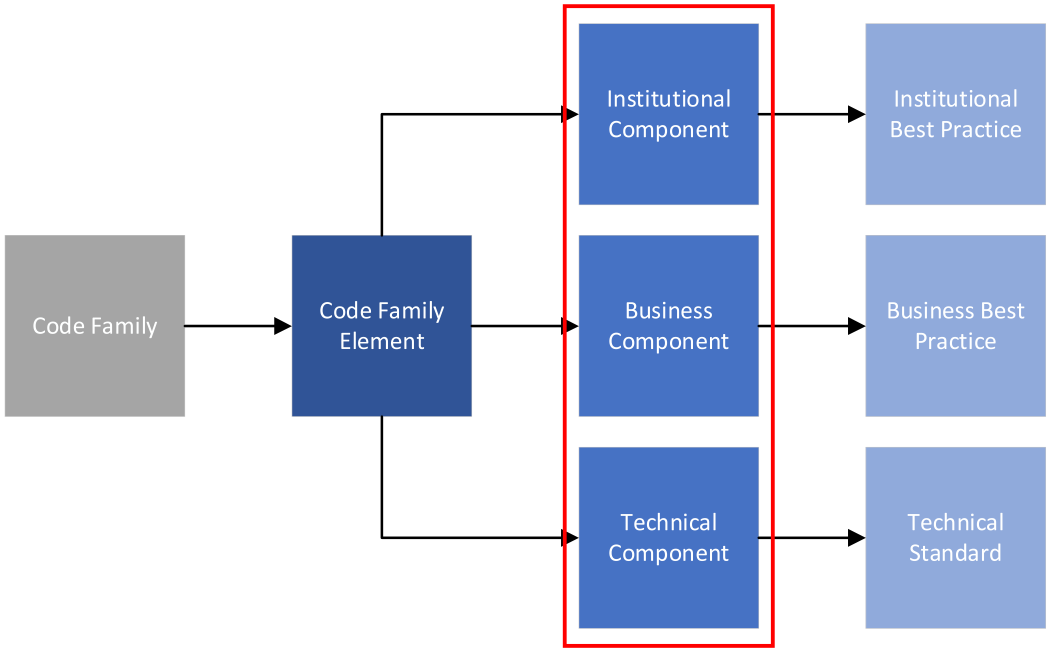

Figure 2. Relationship between Code Families, Elements, Components, and Best Practices

Institutional Component: The institutional component defines the rationale, requirements, and objectives for a grid code element. The institutional component is based on policy objectives, statutory requirements, and regulatory decisions for desired capabilities and enhanced functionality of the distribution system.

Business Component: The business component of a grid code defines the process and practices that enable desired utility and energy services provider business functions and commercial activities related to elements of a grid code.

Technical Component: The technical component of a grid code element identifies the relevant technologies, engineering methods, and technical standards required to implement a functionality or achieve an institutional or business objective.

The institutional, business, and technical components associated with each of the code family elements are described in the tables below.

Table 7. Grid Engineering Code Family – Institutional, Business, Technical Components

Code Element	Institutional Component	Business Component	Technical Component
Hosting Capacity Analysis	Establish hosting capacity analysis requirements regarding the scope of the DERs to be studied, system granularity, analytic methodology, update frequency, and information sharing means for external parties.	Develop and implement organizational practices (people, processes) to conduct hosting capacity analyses and enable related information sharing.	Application of best practice hosting capacity analysis methodologies as appropriate, based on the relevant work stages.
Short- and Long-Term DER Adoption Forecasting	Establish DER forecasting requirements, including DERs to be considered, forecast period, the level of system granularity required (service territory, substation, circuit, etc.), and update frequency.	Develop and implement a DER forecasting methodology and include it in the distribution system planning process.	Application of best practice forecasting and scenario methodologies (e.g., probabilistic) and software tools.
Locational Value Analysis	Create requirements for electric utility distribution planning processes to include locational value analyses and evaluation of non-wires alternatives (NWA).	Develop a transparent solution identification workflow including DER tariffs/programs and third-party NWA for inclusion in distribution system planning process.	Application of best practice DER solution screening and evaluation methodologies to procure DER services aligned with grid needs.
Transportation Electrification	Establishment of rules aimed at facilitating EV charging infrastructure deployment, electrification of transit, and creation of new EV rates and programs for customers.	Develop new rates, incentives, and programs for customers with the goal of facilitating transportation electrification.	Application of best practice methods, as appropriate, based on the implementation stages and level of EV penetration.

Table 8. DER and Microgrid Integration Code Family – Institutional, Business, Technical Components

Code Element	Institutional Component	Business Component	Technical Component
Inverter-Based Resources	Establish requirement to explore smart/advanced inverter functionality, aligned with state policy and goals.	Create a roadmap for phased implementation of smart inverter functionality to support safety and reliability of the distribution system.	Implement relevant technical standards, communication protocols, and architectures for maximizing the benefit of smart inverters.
Microgrids	Establish rules to facilitate customer and community microgrid development, including development of a microgrid tariff and enablement program.	Create a standardized microgrid development and engineering study process and operating requirements.	Create a standard microgrid island engineering study and operating agreement and test microgrid functionality (such as microgrid controllers).
Monitoring and Control (M&C) of DERs	Establish a requirement for utilities to develop and implement DER monitoring and control criteria.	Create technical and business processes to obtain and utilize data from field assets using appropriate communications protocols.	Develop monitoring and control criteria for DERs based on asset sizes.
DER Interconnection Procedures	Establish a requirement for utilities to develop and implement DER interconnection study processes and a pro forma interconnection agreement.	Create a DER interconnection process that describes milestones from application submittal to permission to operate. Create a standardized interconnection agreement describing aspects such as responsibilities of parties, inspection and testing, effective date and term, cost responsibility, etc.	Develop and document the technical study practices and procedures for DER interconnection.
Community-Based Renewable Energy (CBRE)	Establish a requirement for utilities to implement CBRE	Develop and implement CBRE programs. Provide customers and third parties with information on financial incentives and	Develop and document the technical study practices and

Code Element	Institutional Component	Business Component	Technical Component
	programs, such as community solar and community microgrids.	allowances, eligibility criteria, application process overview, etc.	procedures for community energy facility interconnection.
Microgrid Interconnection Procedures	Establish a requirement for utilities to implement interconnection and islanding study processes for customer microgrids.	Define the interconnection study practices and methods for customer microgrids.	Develop and document the technical study practices and procedures for microgrid interconnection.

Table 9. Virtual Power Plants and Microgrid Services Code Family – Institutional, Business, Technical Component

Code Element	Institutional Component	Business Component	Technical Component
Retail Energy & Distribution Grid Services	Establish a set of defined retail energy and distribution grid services and market designs (e.g., rates, programs and procurement) for the provision of DER/microgrid services.	Develop and implement retail and distribution grid market mechanisms, including the related performance requirements to facilitate DER and microgrid service provision and settlement.	Develop a standard retail energy and distribution grid services agreement for the provision of DER and microgrid services.
Distribution Resilience Service	Establish distribution resilience service and compensation structures for the provision of resilience services from microgrids and DERs.	Develop microgrid and DER rules and tariffs to instantiate distribution resilience services and related business processes.	Develop a standard microgrid island engineering study, design of microgrid controllers, and testing procedures for black start and islanding.
DER Aggregation	Establish the role of independent DER aggregators and procedures and requirements to enable the provision of retail energy and	Develop contracts, tariffs, and rules and processes to enable the activities of DER aggregations.	Develop a code of conduct for aggregators, standards for information sharing, and guidelines for aggregator interactions with utility customers.

Code Element	Institutional Component	Business Component	Technical Component
	distribution grid services by aggregators.		
DERA Wholesale Market Services	Establish and approve rules relevant to resources interconnecting to the distribution system and providing services into wholesale markets (such as cost recovery from aggregators, wholesale distribution tariffs, utility-aggregator agreements).	Comply with requirements of FERC Order 2222 and requirements of individual ISO/RTO compliance filings.	Creation of rules, processes, and documents relevant to participation of distribution-connected resources providing services into wholesale markets (such as cost recovery from aggregators, wholesale distribution tariffs, utility-aggregator agreements).

Table 10. DER and Microgrid Operations Code Family – Institutional, Business, Technical Components

Code Element	Institutional Component	Business Component	Technical Component
Distributed Resource Management – Utility	Establish requirements for creation of fair and non-discriminatory procedures in operational control of DERs by the utility.	Develop utility processes to monitor and control utility and third-party DERs and aggregations through bi-directional communications.	Utility dispatch of DERs on a fair and equitable basis to meet grid needs, without providing preferential treatment to DERs owned by the utility.
Distributed Resource Management – Aggregator	Establish requirements for creation of fair and non-discriminatory procedures that provide aggregators the opportunity to provide grid services.	Develop processes to monitor and control DERs through bi-directional communications.	Aggregator dispatch of DERs while respecting utility-imposed constraints and restrictions to maintain system safety and reliability.

Code Element	Institutional Component	Business Component	Technical Component
Common Information Sharing Model/Framework/Capability between System Operators, Utilities, and Market Participants	Establish rules, regulations, legal agreements, and responsibilities for data sharing between entities.	Develop specifications and use cases for data sharing.	Develop data architectures for data collection, storage, and data sharing mechanisms.
Operating Agreements	Provide directives to utilities to create various types of operating agreements (microgrid operating agreement, DER aggregation operating agreement).	Create pro forma operating agreements for various applications.	Agreements should provide details on items such as applicability, eligibility criteria, services and fees, termination, special conditions, etc.
Utility Investments in Operational Technology (ADMS/DERMS/SCADA)	Establish guidelines for cost-benefit analyses and business cases in utility regulatory filings for investments in large, complex operational technology systems.	Develop process to identify the justification and implementation plans for IT/OT technologies.	Develop robust technology identification process (including definition of use cases for technology, issuance of requests for information (RFIs), vendor selection process) through final implementation of technology solution.
Registration/Enrollment of DERs and DER Aggregations Participating in Market Services	Establish requirements applicable to DERs and DERAs that have registered to participate in wholesale markets.	Implement tools and systems to track the registration of DERs and DERAs and any future changes (size, resource mix, location, etc.).	Application of best practice methods as appropriate for the relevant activities.
Market Participation Rules Validation for DER Aggregations	Establish procedures, documentation requirements, checklists, etc. to validate the proposed participation strategies of DERAs to prevent dual compensation, inaccurate information at time of registration, etc.	Develop processes to validate registration and market participation information of DERs and DERAs against established distribution tariffs and rules.	Implementation of rules and processes to validate registration and market participation information of DERs and DERAs against established distribution tariffs and rules.

Code Element	Institutional Component	Business Component	Technical Component
Net Load Baselining and Performance Analytics for DERs and DER Aggregations	Establish requirement for utilities to determine baselining and settlement methodologies to ensure generation of accurate settlement and audit data from DER and DER aggregator services.	Develop processes to determine customer baselines and separate wholesale and retail loads and injections from DERs.	Implementation of systems to distinguish between wholesale and retail load and injections/withdrawals from DERs participating in both wholesale and retail markets.

Table 11. Information Sharing and Security Code Family – Institutional, Business, Technical Components

Code Element	Institutional Component	Business Component	Technical Component
Customer Data Access & Privacy	Establish requirements for utilities to enable customers to access their energy usage data and securely share with third parties.	Develop and implement processes to aid customers in accessing and sharing their data.	Development of tools and platforms to provide customers and their designees access to data while ensuring proper customer data privacy.
Distribution System Data	Establish requirements for utilities regarding distribution system data sharing (including level of access, scope, and frequency of data sharing).	Development and implement processes to facilitate sharing of distribution system data with external parties.	Development of system data portals or websites to provide information such as load profiles, projected load, hosting capacity, NWA opportunities, etc.
Information Sharing – Aggregators	Establish guidance and requirements for utilities on providing aggregators access to system data for DER registration and market operations.	Develop utility processes to fulfill aggregator data sharing needs based on business use cases as conveyed by aggregators.	Development of tools or file sharing mechanisms to provide data to aggregators.
Cybersecurity	Establish cybersecurity requirements for utility grid-facing systems and DER, microgrid, and aggregation systems.	Develop utility process to build cyber hygiene, awareness, and security capabilities within the company.	Implementation of best practices and NIST cybersecurity standards and other applicable industry standards (e.g., NERC CIP).

Table 12. Governance and Oversight Code Family – Institutional, Business, Technical Components

Code Element	Institutional Component	Business Component	Technical Component
Distribution Open Access	Establish requirements for utilities to provide third parties with open access to the distribution system.	Develop processes to provide third parties fair and open access to distribution systems, descriptions of their rights and responsibilities, and the relevant cost recovery and allocation mechanisms.	Implementation of ongoing checks to ensure distribution open access service is being provided.
DER Aggregator Oversight	Establish rules to ensure that customers participating in DER markets and programs are protected from confusion, fraud, and abusive marketing practices.	Develop processes to communicate and enforce rules to prevent exploitive pricing, deceptive marketing practices, etc. Develop complaint resolution procedures.	Implementation and enforcement of rules as communicated in tariffs, agreements, etc. to ensure oversight of DER aggregator activities.
DER and Microgrid Value Determination & Cost Allocation	Establish guidance on key principles for DER and microgrid benefit-cost analysis (BCA) frameworks and methodologies for comparison of costs and benefits to traditional alternatives.	Develop DER and microgrid sourcing process to inform utility cost-effectiveness tests and procurement strategies for DERs and associated investments.	Source DER and microgrid services by implementing microgrid tariffs, DER programs, etc.
Governance and Oversight of Wholesale Market Participating DERs	Creation of new rules, tariffs, and agreements that guide the participation of DERs in wholesale markets.	Develop oversight and governance capabilities to guide the ability of aggregators to create DER aggregations that can participate in wholesale markets.	Implement processes and tools to actively monitor and track the performance and obligations of DERs and aggregators.

Best Practices and Technical Standards

The third layer of the grid code framework identifies the best practices and technical standards associated with each component of the grid code elements (Figure 3). The best practices will be identified from existing literature and input from industry experts. Technical standards will involve references to specifications and certification requirements identified by industry organizations (such as IEEE) for the integration, operation, and utilization of DER. This catalog of best practices and standards is intended to reflect the state of the art regarding the implementation considerations for each grid code.

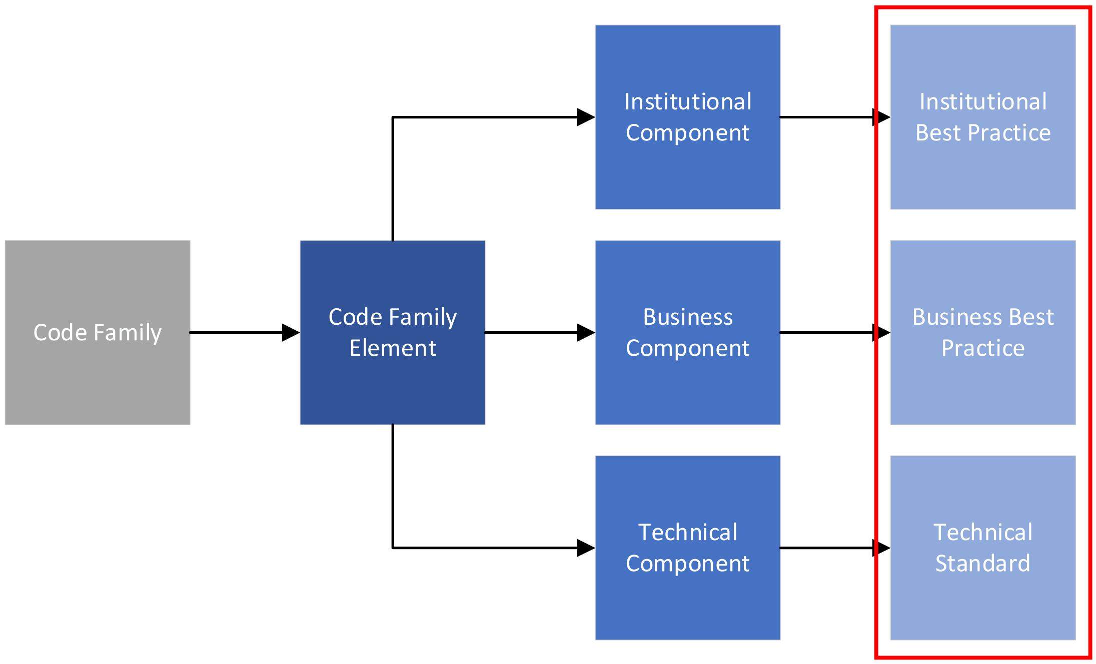

Figure 3. Relationship between Code Families, Code Family Elements, Components, and Best Practices

The following examples for transportation electrification and hosting capacity analysis illustrate the layers of the grid code taxonomy, from code family and element to institutional and business components and best practices and technical standards.

Transportation Electrification

Transportation electrification is a predominantly consumer-driven activity. Recently, regulators have begun to establish requirements for utilities to offer EV rates and rebates for charging equipment and to explore initiatives to facilitate transportation electrification for underserved communities. In response, utilities have begun to create new programs, rebates, and incentive structures to spur electrification. Some utilities are also creating hosting capacity maps for EVs and conducting transportation electrification analyses. These studies quantify the impacts of increased electrification of transportation, such as the addition of light, medium, and heavy-duty electric vehicles. Outputs of these analyses typically include a quantification of the incremental energy required to serve new load and an assessment of change in system peak loads.

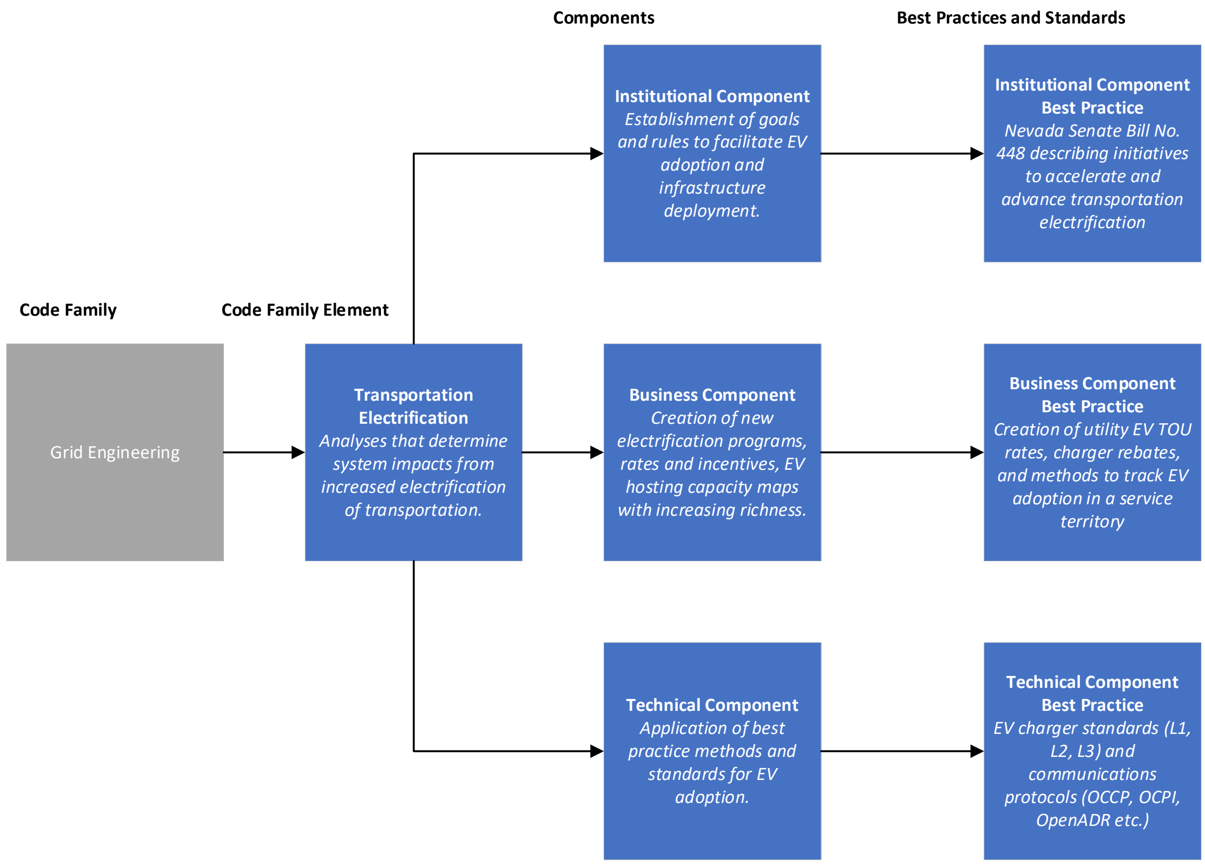

Figure 4. Distribution Grid Code Taxonomy Framework Example – Transportation Electrification

The best practices and standards associated with the "Electrification" code element include the following:

- Institutional Best Practices: An example of a best practice in this regard is Nevada Senate Bill Number 448, which provides electric utilities clear direction to implement transportation electrification programs in the state.
- Business Best Practices: Examples of leading practices related to transportation electrification can be found in utility programs that have aided in increased EV adoption and provided customers with rebates and clear price signals to manage EV charging behavior. Some examples include SCE's EV rate offerings for business customers, Holy Cross Energy's charger rebates for residential customers, and Salt River Project's EV Community initiative.
- Technical Standards: The technical standards associated with transportation electrification are primarily related to EV charger standards and communication protocols to interact with EV supply equipment (EVSE). Examples of EV charging standards include the SAE J1772-2017 standard for L1 and L2 chargers, SAE J4300, and the CHAdeMO standard.[3,4,5,6] Examples of communication standards include the OpenADR protocol (for V1G applications), ISO 15118 (for exchanging messages between EVs and EV charging stations), and Open Charge Point Protocol (OCCP) for bi-

[3] SAE J1772 Standard. Available online: https://www.sae.org/standards/content/j1772_201710/

[4] SAE, SAE International Announces Standard for NACS Connector, Charging PKI and Infrastructure Reliability, June 27, 2023. Available online: https://www.sae.org/site/news/press-room/2023/06/sae-international-announces-standard-for-nacs-connector

[5] SAE J3400 Standard (In Development). Available online: https://www.sae.org/standards/content/j3400/

[6] CHAdeMO Standard. Available online: https://www.chademo.com/about-us/what-is-chademo

directional charging.[7,8,9]

Hosting Capacity Analysis

Hosting capacity indicates the amount of DER that can be added to a distribution system based on existing and future grid conditions and without equipment upgrades. In recent years, regulators from across the United States have ordered electric utilities to calculate hosting capacity on their systems and provide the results to external parties. Accordingly, utilities have developed roadmaps and tools to share hosting capacity information publicly. The information shared by utilities typically increases in its granularity and richness over time, as companies gain experience with hosting capacity tools.

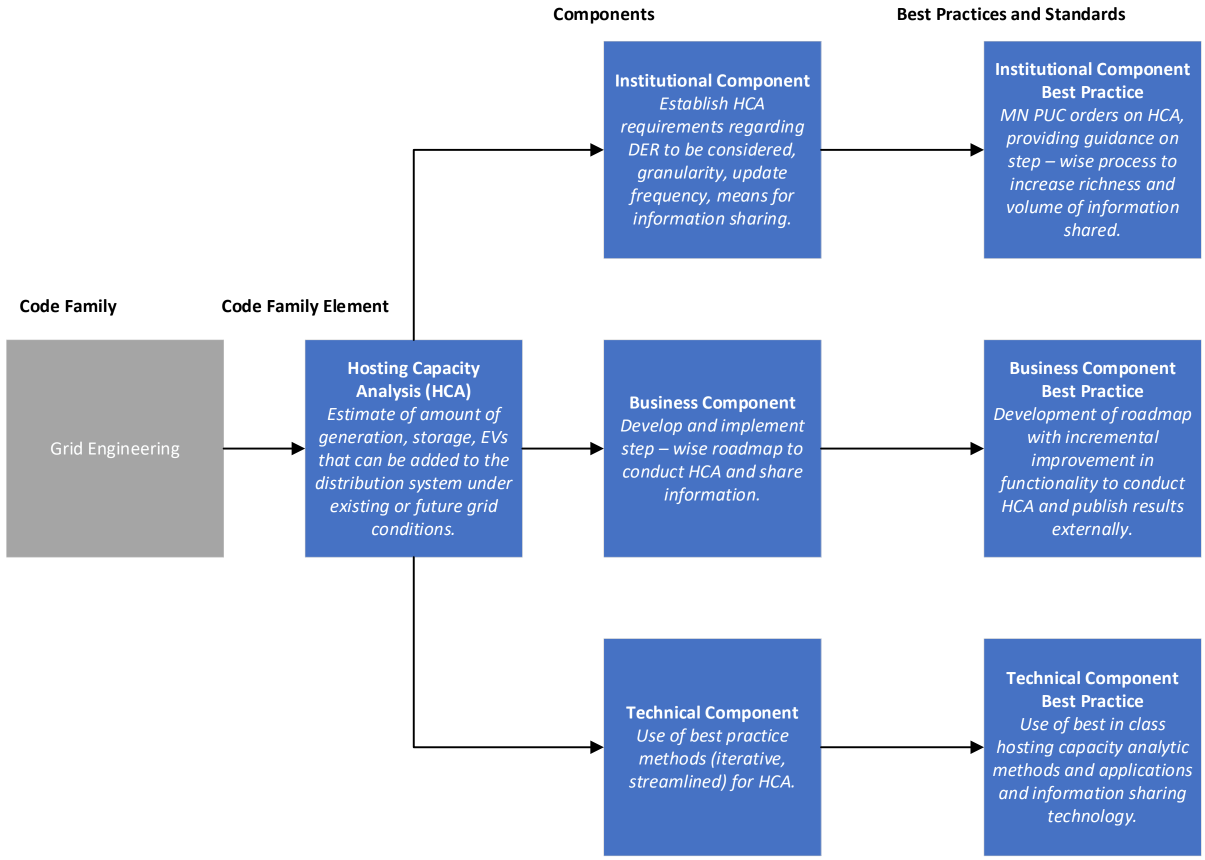

Figure 5. Distribution Grid Code Framework Example – Hosting Capacity Analysis (HCA)

The best practices and standards associated with the "Hosting Capacity Analysis" code element include the following.

- Institutional Best Practices: An example of a best practice in this regard is the Order issued by the Minnesota Public Utilities Commission in Docket No. E-002/ M-19-685 on July 31, 2020. The Order provides guidance to Xcel Energy on the information to be included on HCA maps and mentions how the HCA information should fulfill multiple use cases. The Order also describes how frequently HCA maps should be updated.[10]

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[7] OpenADR. Available online: https://www.openadr.org/

[8] ISO 15118-1:2019. Available online: https://www.iso.org/standard/69113.html

[9] OCCP 2.0.1. Available online: https://www.openchargealliance.org/protocols/ocpp-201/

[10] Before the Minnesota Public Utilities Commission, Order Accepting Report and Setting Further Requirements, Docket No. E-002/M-19-685. Available online:

- Business Best Practices: NREL and IREC collaborated to publish a report documenting the best practices for utility HCA processes.[11] The report's recommendations included: building a well-resourced HCA team to track key metrics, a well-documented process for data validation that ensures software tools reflect grid conditions, and transparent and collaborative information sharing.
- Technical Standards: An example of a best practice in this regard is the creation of a hosting capacity data validation plan by each of the large Californian investor-owned utilities. In response to a requirement issued by the California Public Utilities Commission (CPUC), each utility had to file and implement a data validation plan. The goal of the data validation exercise is to remove erroneous hosting capacity data from being published. The data validation process has five stages: input data validation, model validation, engineering analysis, results validation, and results publication.[12]

In summary, the sequential identification of institutional components, followed by business and technical components associated with a grid code element, provides a line of sight into the functions and activities required to enable that grid code element. The best practices and standards illustrate how a particular grid code element should be implemented.

A detailed compendium of the applicable best practices and technical standards will be prepared by DOE and made available in 2024. This forthcoming work product will also describe instances wherein technical standards are absent or in development for a particular grid code element or code family. The intention is to update the list of standards and best practices on a periodic basis as new information becomes available.

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https://www.edockets.state.mn.us/edockets/searchDocuments.do?method=showPoup&documentId=%7bC06CA673-0000-C714-93E9-DFED768388A6%7d&documentTitle=20207-165472-01

[11] Nagarajan, Adarsh and Yochi Zakai. 2022. Data Validation for Hosting Capacity Analyses. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-81811. https://www.nrel.gov/docs/fy22osti/81811.pdf

[12] Stephen Teran and Vic Romero, SCE Integration Capacity Analysis Data Validation Plan Assessment, Quanta Technology (June 24, 2021) (Quanta SCE Assessment), https://publicadvocatesprodtemp.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/infrastructure/distribution-planning/qtech-sce-ica-data-validation-plan-assessment-report.pdf

Pathways for the Adoption of Distribution Grid Codes

A key element that drives adoption of grid codes is the evolution of the distribution system within the context of the jurisdiction being considered. Figure 6 indicates a conceptual three-stage evolutionary framework for the distribution system, from low to very high levels of DER penetration.

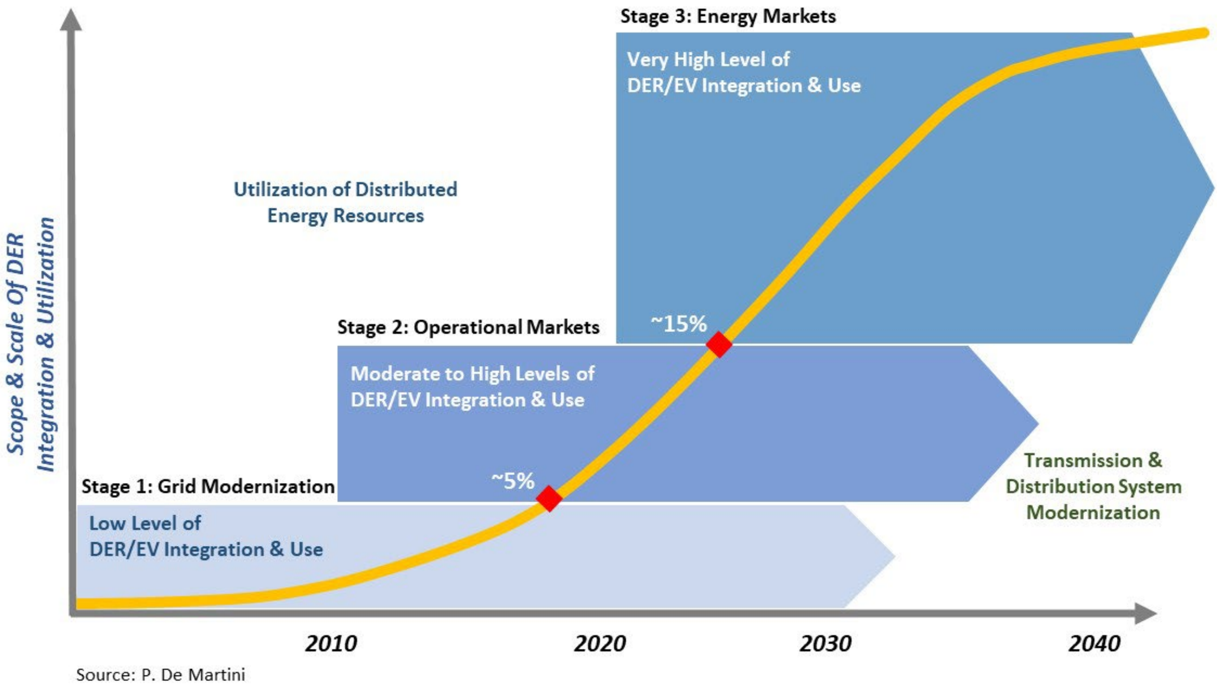

Figure 6. Distribution System Evolution

Stage 1 (Grid Modernization) encompasses scenarios wherein DER penetration within a utility's service territory as a fraction of the peak load is less than 5%. DER levels can be accommodated within existing distribution systems without material changes to infrastructure, planning, and operations. Grid modernization[13] is undertaken to address reliability, resilience, safety, and operational efficiency and to enable forecasted requirements for DER integration and utilization.

Stage 2 (Operational Markets) includes scenarios wherein DER adoption has increased to between 5% and 15% of the utility's peak load. This stage is characterized by the increased use of onsite DER and electric vehicles by customers for energy management and resilience purposes. DERs—individually and in aggregations—are increasingly used as load-modifying resources for both distribution non-wire alternatives (NWAs) and wholesale capacity and ancillary services. Integrated distribution system planning and grid modernization are needed to enable real-time observability and operational use of DERs.

Stage 3 (Energy Markets) denotes scenarios wherein DER penetration exceeds 15% of the utility's peak load. DERs and electric vehicles are actively utilized to provide both distribution/retail and wholesale market services and are also used in the context of community microgrids. Individual DERs and DER aggregations are optimized and orchestrated to support grid service requirements for distribution and transmission systems. Multi-use/community microgrids help support local energy supply and resilience. Ultimately, distribution system-level energy transactions are enabled. This third stage of DER utilization requires coordination across jurisdictions (e.g., Federal Energy Regulatory Commission (FERC) Order

[13] Grid modernization is associated with the deployment of digital information and operational technologies (IT/OT) that provide sensing, communication, control, and computing capabilities to deliver advanced functionality to the electric grid.

2222[14]) and infrastructure to support both grid and market operations.

The pace and scale of DER integration and utilization will shape the evolution of the distribution system and when new grid codes are needed. For example, the integration and adoption of DERs into distribution systems is spatially dispersed and depends on technology costs, grid integration considerations, customer interest, and other local factors. Also, the ability to utilize DERs for grid services depends on factors like size thresholds for DER participation, DER aggregation participation in wholesale markets, the scope of eligible DER services, and wholesale and retail market rules for DER services. As such, the pathway toward an electric system with a higher penetration of DER will vary by state and utility service area. In this context, it is helpful to consider the level of expected DER adoption and use, as well as the size of the utility (and its capabilities), to chart a specific path forward. The conceptual matrix below in Figure 7 references the scale of DER adoption and use discussed above, combined with consideration of utility size and the associated organizational capacity.

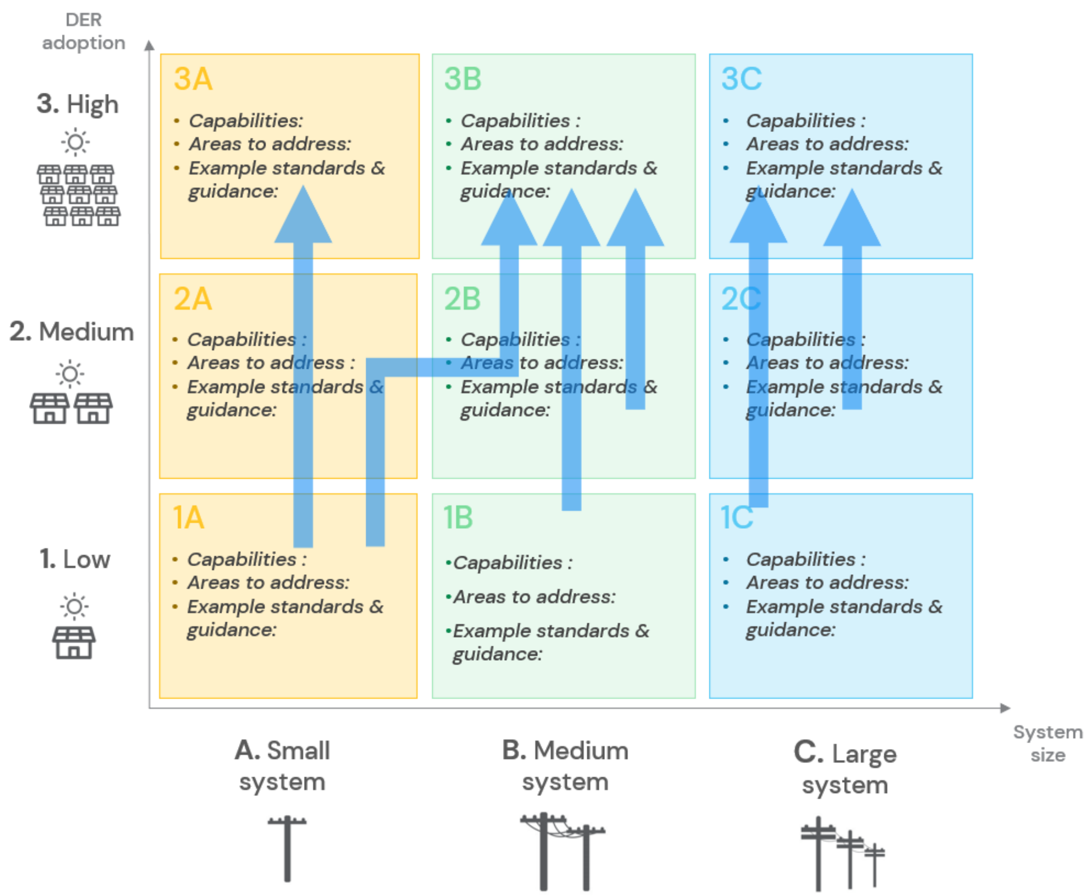

Figure 7. Distribution Grid Codes Adoption Matrix

The relative size of the distribution system is classified into three types based on the number of customers. The metric of the number of customers served acts as a surrogate to determine the organizational capacity of a utility. The organizational capacity of a utility, in turn, sheds light on the company's capability to increase roles and responsibilities and adopt new technologies. Utilities are categorized as small systems ($\leq$500,000 customers), medium systems (>500,000 and <1,000,000 customers), and large systems ($\geq$1,000,000 customers). Small utility systems often have a small number of employees, relatively small

[14] FERC Order 2222, Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators, 2020.

budgets, and limited technical capabilities. Medium utility systems have a higher number of employees when compared to small systems but often have relatively constrained resources. Relative to small- and medium-sized systems, large companies employ a significantly higher number of personnel, have greater resources available, and frequently execute large and complex infrastructure and IT projects. The set of technology vendors that serves small, medium, and large utilities and their respective product/service offerings is typically also different. These factors shape the organizational changes that utilities undertake and should be considered when planning transformational roadmaps.

Therefore, multiple pathways for DER integration can exist for the various permutations of system size and DER penetration. For example, consider a utility with a small system with low DER penetration. The utility is projecting rapid growth in DER adoption, with DER penetration rising to medium levels in the near term. The utility will need to evolve its internal tools and processes accordingly to maintain system safety and reliability with the rise in DER penetration. This evolution corresponds to an increasing level of minimum capability sophistication and maturity as illustrated in Figure 8.

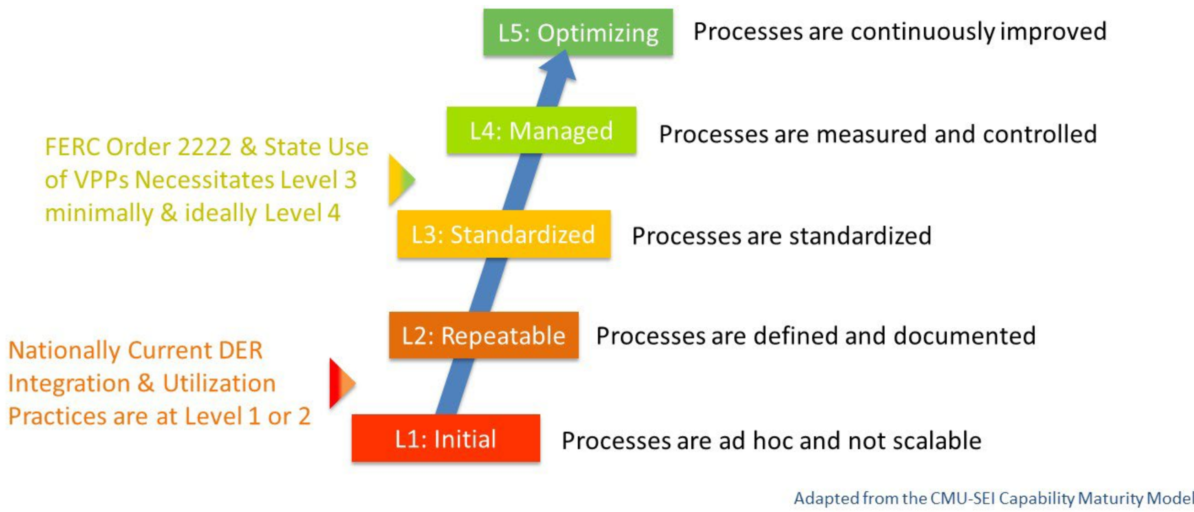

Figure 8. Capability Maturity Model

The objective in this approach is to achieve a consistent level of standardization for each distribution grid code component and then proactively manage the associated activities for corrective action and potential improvement. As such, this capability maturity model (CMM) can provide a framework for identifying the relevant grid codes to adopt at each stage of DER evolution across the grid code family elements.

Below is an illustrative example (Figure 9) of the increasing maturity for distribution processes, practices, and standards adoption that will likely be required for FERC Order 2222 implementation and greater use of DER services by distribution utilities.

Maturity	Institutional	Business	Technical	Standards
5. Optimizing	Evaluation of outcomes to identify areas for improvement and address continuing DER evolution	DER services and market evaluation and improvements	Distribution grid performance metrics evaluated for improvements to service quality and to achieve public policy outcomes	Advanced inverter functionality adjusted based on measured performance & grid needs
4. Managed	Policy & Process Outcome Metrics for Governance Roles	DER performance metrics established, measured and evaluated ex-post	Integrated distribution planning and grid architectural metrics established and measured	Advanced inverter performance measured in relation to grid need
3. Standardized	Standardized Cost-Effectiveness Methodology for DER Services, Distribution Standard of Conduct, DERA Rules, Market Eligibility & Participation Rules	Standard Flexibility Services & Performance Attributes and Standard Pro Forma Services Agreement, Standardized Operational Coordination processes	Best practice integrated distribution planning processes widely adopted, Grid architectural methods widely adopted, standardized market and operational coordination architecture for FERC 2222	1547-2018 and cybersecurity and information (IEEE 2030.5) requirements incorporated into Interconnection Rules & DER Services Agreements
2. Repeatable	Requirements for Hosting Capacity, DER Services Sourcing Integrated Distribution Planning	Non-wires evaluation methodology & sourcing approach	Incorporating DER and resilience considerations into distribution planning	IEEE 1547-2018 Released
1. Initial	Various traditional processes	Various traditional processes unique to each utility	Traditional engineering-economic practices	Basic service quality and reliability related standards

Figure 9. FERC Order 2222 Distribution CMM Example

As a next step in the development of distribution grid codes, the several logical distribution transformation pathways will be explored, and the relevant best practices for a given scale of DER integration and utilization in relation to utility size will be identified. The goal of this ongoing effort is to enable decision makers to design bespoke pathways for DER integration and utilization based on their unique needs and local context. The considerations and details (such as the capabilities and example standards and guidance) incorporated into the 3 × 3 matrix and capability maturity model above will help facilitate the creation of these pathways. A detailed reference document that provides guidance on how to build unique pathways for DER integration and utilization will be developed in FY 2024. The goal of this guidebook will be to provide a diverse set of practitioners with a logical and stepwise approach for the adoption of distribution grid codes introduced in this report.

Conclusion

Achieving the goal of integrating and accruing the benefits of DER at scale requires that industry practitioners (regulators, utilities, DER aggregators, developers, and device manufacturers) have a shared understanding of the incremental capabilities necessary for this transformation. In addition, it is necessary to recognize that an entity's DER integration goals are based on the unique circumstances and policy objectives of the jurisdiction in which it operates. The distribution grid code framework introduced in this paper is rooted in these realities and acknowledges the importance of the intertwined institutional, business, and technical aspects of DER services and markets. The concept of distribution grid codes and the framework proposed in this paper aim to provide information that entities can use to build logical pathways for DER integration and utilization. The goal of the framework is to remain flexible, such that entities can select and employ the grid codes that are most applicable to their unique circumstances.

This paper also recognizes that the set of distribution grid codes cannot remain static or be based on a single snapshot in time. As mentioned previously, electric distribution systems in the United States are poised for rapid evolution. In recognition of this change, regulators, technical organizations, and standards bodies continue to issue guidance and direction to facilitate system transformation. As this body of knowledge expands and is constantly updated over time, resources will be required that track the most applicable standards and best practices. These resources must provide practitioners with a practical guide to help assess the most pertinent issue(s) for their individual circumstances. Additionally, these resources must be framed within the broader context of the three stages of distribution evolution described in Figure 6 above. Accordingly, DOE will prepare and disseminate the following work products in the near future to address these issues. Together, these resources will provide practitioners with a holistic guide for distribution grid code implementation.

- Pathways Guidebook for Implementing Distribution Grid Codes: The goal of this paper is to provide practitioners with the outline of a logical, stepwise approach for the adoption of grid codes. The paper will include a detailed description of the 3 × 3 matrix, capability maturity-based grid code adoption framework, and resulting logical pathways. The paper will focus on how this grid code framework can be used by entities to identify specific grid codes to enable their unique pathways for DER integration and utilization, based on their current state and social and policy objectives.
- Compendium of Best Practices and Technical Standards: This document will be a "living repository" of information, identifying the various institutional and technical best practices associated with various distribution grid code families and elements. This document will be updated on a periodic basis. The goal of this resource is to provide a single location for practitioners to access industry standards and best practices relevant to DER integration and utilization.