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Common Grid Services

Terms and Definitions Report

July 2023

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GMLC 2.5.2 project report

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Abstract

This document is prepared as part of the Department of Energy's Grid Modernization Laboratory Consortium (GMLC) 2.5.2 project, whose goal is to develop and socialize a common set of grid service definitions relevant to grid-related interactions with distributed energy resources (DER: responsive generation, storage, and loads) and to advance the concept and requirements of the Energy Services Interface (ESI) to the point of launching related interface standards and guides that can be implemented in communication protocols and business process definitions. The notion of grid services is associated with the definition of an ESI because a key principle of the ESI is that it permits coordination between grid operators and DER facilities in a way that is service-oriented with an understanding of performance expectations.

The project investigated the current state of North American grid service definitions from various market operators and utilities, as well as the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation, actively used today (Liu et al. 2022). This document builds on that work to propose terms and definitions for a set of grid service types that address operational objectives commonly found in power system operations. These grid service types derive from existing grid services used in bulk electric market operations, recognizing that each operational authority uses somewhat different names with variations on service performance parameters. Finding commonality at the wholesale or bulk system operation level will hopefully engender progress in seeking agreement on grid services for DER engagement at the distribution level in the emerging retail marketplace.

Acknowledgments

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Acronyms and Abbreviations

ACE	area control error
AS	ancillary service
CAISO	California Independent System Operator
CSP	Curtailment service provider
DER	distributed energy resources
DOE	Department of Energy
EDC	electric distribution company
ENodes	electric nodes
ERCOT	Electric Reliability Council of Texas
ESI	Energy Services Interface
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
GMLC	Grid Modernization Laboratory Consortium
ISO	Independent System Operator
ISO-NE	ISO New England Inc.
LMP	Locational marginal pricing
MISO	Midcontinent Independent System Operator
MW	megawatt
NERC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory
NYISO	New York Independent System Operator
PNNL	Pacific Northwest National Laboratory
PNodes	pricing nodes
RMS	root mean square
RTBM	real-time balancing
SPP	Southwest Power Pool

The following terms are described for their use in the GMLC 2.5.2 Project.

DER	Distributed energy resources (DER) include responsive generation, storage, or load connected at the distribution system level. Responsive means that the operation of the assets can be managed to provide one or more grid services.
DER facility	A site that includes one or more DER and has a single point of connection with the electric distribution system.
ESI	An energy services interface (ESI) is a bi-directional, service-oriented, logical interface that supports the secure communication of

	information between entities inside and outside of a customer boundary to facilitate various energy interactions between electrical loads, storage, and generation within customer facilities and external entities (Hardin 2011).
facility management function	Manages the operation of the electrical devices and systems at a customer site (a facility). In the ESI concept, this function interacts with outside parties through the ESI.
Grid-DER service	A service provided between a DER facility and an external interacting party (usually a grid entity) as coordinated by ESI interactions. The service definition describes what is expected to be provided but does not specify how it is accomplished or how it will be used. Managing the quantity of energy consumption over a period is an example of a grid-DER service.
Grid service agreement	Specifies what a service provider will accomplish for a service requester, how it will be measured, and any compensation (monetary or otherwise) from the service requester for performing that service.
Grid-side entity	An externally interacting party that interacts with a DER facility using the ESI.
Layered decomposition	Hierarchical disaggregation of a complex problem into a series of simpler subproblems with clear and relatively simple interfaces between them. These subproblems are solved locally with interaction links to larger coordination domains and internally with subdomains.
Service-oriented	A style of software interface where services are provided to other system components (service requesters) by service provider components through a network communication protocol. Its principles are independent of vendors and other technologies.

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1.0 The Need for Common Grid Service Definitions

The notions about grid services come from the operational paradigm for managing the electric power system. The terms and definitions for these services are formalized for transmission and wholesale electricity markets, where market participants can compete to provide the service with various types of equipment. Each wholesale market has evolved unique grid service names and definitions, even though there is significant alignment in the types of services being exchanged because of similar operational paradigms. Different names can cause confusion in discussions among various markets, but the terms and definitions within a market's jurisdiction work well for the interactions of their participants.

Common terms and definitions of grid services become more critical to supporting interactions among much greater numbers of participants as coordination extends into electricity distribution systems. There, renewable generation, electric vehicle (EV) charging, and other customer-side assets with operational flexibility are becoming viable grid service providers.

Semantics will be critical to both business and cyber-physical transactions between the various systems, jurisdictions, and their participants. The intent of the common grid service terms and definitions is to accommodate diverse grid and customer needs in a clear and broadly acceptable manner for improved communications between interested parties and to provide a common starting place for specialization to satisfy different regional jurisdictional requirements.

A grid service uses performance attributes to describe the physical and temporal characteristics of the service. A review of the state of electricity transmission and distribution system grid services (Liu 2022) indicates that existing grid service names often derive from operational objectives (i.e., why a service is used) rather than the performance desired from the service provider. While the objective is important to the requestor, the service provider only needs to understand what is expected of their resource(s). For example, the term "peak load management" contains little information of value to a generator or a distributed energy resource (DER) like an EV charging system, but scheduling energy production or consumption during specific time periods (that might correspond with the service requestor's peak periods) is understood. In other words, the grid service is the means to achieve the operational objective, as shown in Figure 1. By developing clear, concise, service-oriented, and performance-based grid service definitions, the requested service and the performance expectations are clear to both the provider and the requestor.

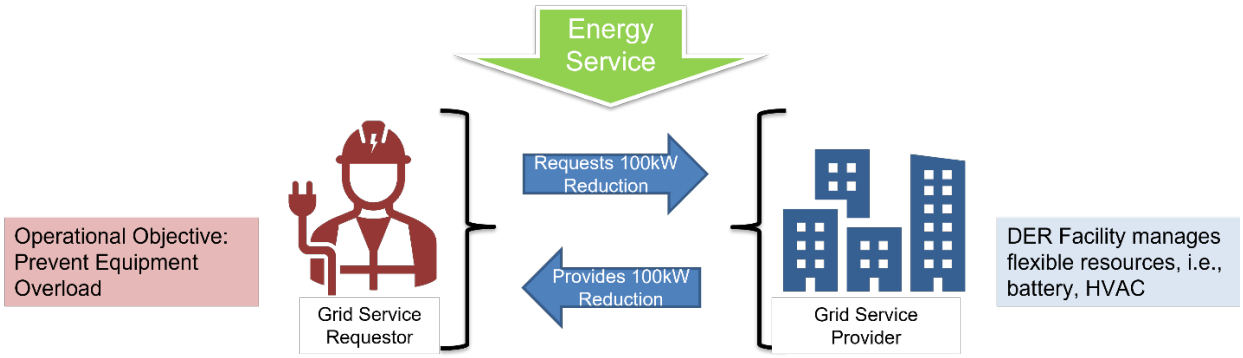

Figure 1: Objectives are met through the request and provision of grid services rather than direct control.

1.1 Smart Grid Considerations

The electric grid is going through a transformational period marked by greater numbers of DER with automated controls and communications to coordinate the operational flexibility of generation, storage, and load. Though the connections to the electric system largely remain the same, the power flows are changing, sometimes becoming bi-directional. Managing these flows will require communication across many interfaces and coordination among multiple stakeholders. This mix of widely distributed resources will require a high level of interoperability to support coordination between participants' systems. Shared definitions for the common types of grid services will facilitate interoperability through semantic understanding of grid services between these systems.

A distributed electrical system provides opportunities for more grid service providers. Participants will include distribution and transmission operators, aggregators, prosumers, regulators, integrators, and others. Agreements to define the roles and responsibilities associated with the service will proliferate. Third-party energy market participants, such as aggregators aiding in energy transactions between the grid operator and the resources providing grid services, will be included in many of the agreements. Common definitions for performance-based grid services will improve contracts and negotiations through an understanding of grid services, roles, and responsibilities between these actors.

The intelligence and connectivity of intelligent devices such as thermostats and water heaters have already made them popular resources in various direct load control programs. Common grid service definitions can provide a path to qualifying assets for their capability to provide grid service. By understanding the physical operating characteristics required by the provider of the service, one could determine a test to determine if the DER qualifies for the service. For example, if a service requires that a resource be available within two seconds of being requested, this metric could be used to determine if the resource is a viable candidate to provide the service.

1.2 Jurisdictional Considerations

As more flexibility at the distribution level is introduced in the electric system, coordination across operating jurisdictions and among participants becomes increasingly important. While there are several operational jurisdictions at the bulk electricity system level, there are orders of magnitude more at the distribution level. As the number of participants increases, the specialization of grid service terms and definitions becomes even more important for clear communications and expectations. Common definitions improve processes such as establishing agreements or contracts between interacting parties. They can also be beneficial for standardizing things like energy market interactions and exchanging information that characterizes a DER or DER facility's capability to provide grid services.

In addition, technology solutions providers will be able to offer more affordable products, requiring less customization, as grid service terms and definitions become consistent across distribution system operations jurisdictions. While jurisdictional differences may be necessary, common terminology and definitions reduce the cost of DER integration and coordinated operations.

A common vocabulary and understanding of grid services, including the requirements and characteristics associated with them, can provide a basis for grid-DER service agreements at the retail level that look more similar across jurisdictions.

2.0 Categorization of Grid Services

An operational objective (Pratt et al. 2021) refers to “the fundamental underlying physical needs, stated as objectives, of the grid for safe, reliable, robust, and economically efficient operation. These are often in the form of balancing supply and demand at various time scales and for various purposes.” Operational objectives may include things like peak load management, the need to move controllable generation (or load) up or down to follow load (or generation) changes, manage area control error, and call on extra generation capacity during an unplanned equipment outage.

A grid-DER service, on the other hand, describes a DER facility’s expected performance in response to a service request. These service requests are issued to meet an operational objective but are based on performance, and the same set of performance requirements, i.e., service, could address a wide range of objectives. The performance expectation should describe what needs to be done at the connection point to the grid and how it will be measured. The service provider clearly understands what is expected, not why or how the service is being used. In this way, the service requestor’s operational objective for reliably managing the operation of the power system does not need to be communicated to or understood by the service provider, as it is cleanly separated from the grid service performance expectation of operating the DER facility.

Existing grid service terms used by system operators can derive from a limited operational objective (like peak load management) instead of the more general service to be performed (schedule energy) during peak periods. Examples of performance attributes include providing energy within a given response time for a specified duration. Performance attributes can be used to quantify the capability of a DER to meet a performance expectation required by a service. For example, a service defined by a performance expectation might be defined as the ability of a service provider to respond in less than a minute to supply a certain amount of energy according to an agreed-upon schedule.

The following sections present the proposed types of grid service terms and definitions. To clarify these definitions, performance expectations are described, along with potential ways to measure adequate performance relative to expectations. A subsequent section uses examples of operational objectives to demonstrate how these grid services can be applied by a service requester to reliably operate a power system.

2.1 Grid Service Identification

To separate out the service being requested from the operational objective (how or why it is used), one must focus on the information the service provider needs to understand what physically needs to be delivered. After comparing the performance expectations required to achieve the broad range of operational objectives shown in Figure 2, such as magnitude, capacity, response time, and service duration, the following grid service categories are proposed:

- **Energy service:** A scheduled production or consumption of energy at an electrical location over a committed period.
- **Reserve service:** Reserves a specified capacity to produce or consume energy at an electrical location when called upon over a committed period.

- **Regulation service:** Continuously provides an increase or decrease in real power from an electrical location over a specified scheduled period against a predefined real-power basepoint following a service requestor's signal. The signal interval is typically one to several seconds, and the associated performance period is significantly shorter than the typical energy service performance period.
- **Frequency response service:** Responds to a change in system frequency nearly instantaneously by consuming or producing power over a committed period.
- **Voltage management service:** Provides voltage support (raising or lowering) within a specified upper and lower voltage range at an electrical location over a committed period.
- **Blackstart service:** Energize or remain available without grid electrical supply to energize part of the electric system over a committed period.

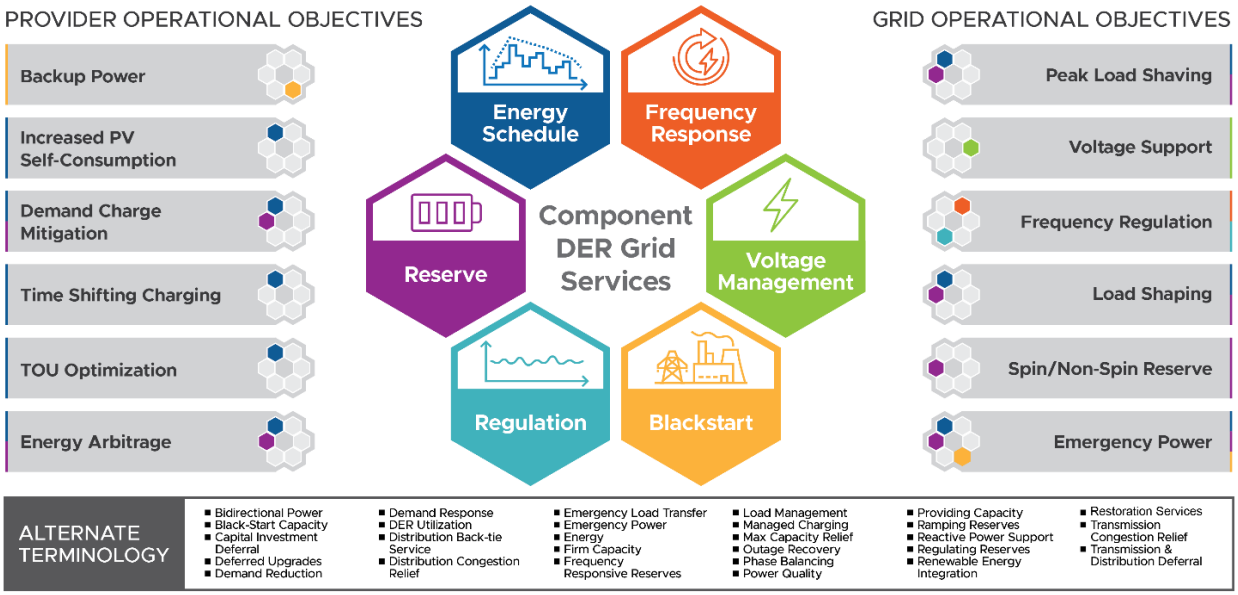

Figure 2: Common Grid Service terms and the associated objectives.

While the terms and concepts for each grid service should be consistent, the attributes or parameters used in the definitions must accommodate the need to specialize the performance expectations and characteristics to meet operational requirements. That is, aspects related to qualification, performance expectations, monitoring, reconciliation, and settlement will need to vary based on the operational policy of the region.

2.2 Performance Attributes

Each grid service has performance expectations for the resources needed to fulfill the service. The performance expectation of each service can be described by a unique combination of several service attributes that dictate the behavior needed from the resource for the provided service to be meaningful. Performance metrics can then be created for each defined grid service based on the most appropriate service attribute(s) for that service. The metrics can be linked to performance-based reconciliation calculations, resource qualification, or both.

Examples of grid service attributes are energy produced or consumed over a specified interval, real versus reactive power capacity, response time, service duration, and related measurement requirements. Note that to qualify for participating in a service agreement, resource owners may need to provide additional information or certification about things like real and reactive power capacity or speed of response.

The following material describes the types of attributes needed for defining grid services. Section 2.3 describes the grid service definitions with the appropriate attributes for each service. Table 1 provides a summary of the performance attributes of grid services discussed in the material that follows.

2.2.1 Electrical Attributes

The electrical attributes are the electrical aspects of the service expectations.

Energy, real and reactive power, and electrical location: Many grid services involve resources producing or consuming power from the grid. From the grid service requester's perspective, reducing load may be equivalent to increasing generation or discharging energy storage. Some grid services require resources to provide reactive power instead of or in addition to real power.

The electrical location is a physical property of where the service is delivered in the electric system. The impact of location in the system depends on the definition and performance expectations of each energy service type.

2.2.2 Timing Attributes

The timing attributes of the service describe the parameters associated with when the service is delivered and the speed of delivery.

Delivery schedule: A service delivery schedule is the period over which the grid service is expected to take place. Its specification includes when the service starts and ends. This can also be calculated based on a start time and a duration of commitment that determine the end time. In the case of on-call services, such as reserves, the delivery schedule covers the time the resource is available to provide the service.

Delivery schedule notification: The timing associated with notification that the delivery schedule for a service is established. For example, the results of a market process are published at specified times and notify the participants of their scheduled delivery of the service.

Response time: Response time is the time allowed to elapse between the moment when the grid service is to start and the moment when the desired behavior meets the defined threshold for a given grid service. Response time requirements can be used to determine the qualifications of resources for providing each service. Expected response times range from milliseconds to hours, depending on the grid service agreement. Some grid services require such rapid response (nearly instantaneous) that autonomous behavior is required, such as those defined through volt/watt and frequency/watt curves.

2.2.3 Additional Information

The following topics provide additional context for understanding the nature of the service and how it is used in practice.

Performance determination: To verify that a grid service provider meets the performance expectations for the service, an agreement describes how it will be quantified. The measurement requirements vary depending on the grid service agreement as specialized by each authority. For example, energy metering requirements need to specify attributes like interval granularity for buffering data that matches the performance period.

Example service requestor operational objectives: This section provides typical applications for using the grid service to achieve an operational objective. For example, scheduling energy is used to balance supply and demand. Such an objective includes addressing forecasted energy peaks by scheduling more supply and/or less demand during the peak period. It can also address line loading issues by scheduling energy in different parts of the system.

Origin of service definition: Describes any operational history for creating the service. For example, spinning reserve was created to address loss of generation or line outages that require quick response from generation to address the imbalance of energy in the system.

2.3 Grid Service Definitions

The following are proposed common definitions for the types of grid services. The attributes (electrical and timing) identify the main areas of specialization by operating authorities for the services desired in their jurisdictions. Table 1 provides a summary of the performance attributes of grid services discussed in the material that follows. Figure 3 shows the relative ranges for typical attribute values for various grid services' response times and duration of delivery schedules.

Table 1: Common grid services with electrical and timing and performance attributes.

Grid Service	Electrical Attributes			Timing Attributes				Performance Determinations
ENERGY	energy (quantity)	power (level)	electrical location	delivery schedule	delivery schedule notice			agreements specify: a) measurement equipment and location, b) measurement units and frequency, and c) calculations of estimating methods. Examples: revenue grade energy interval meters or periodic power measurements to estimate energy.
RESERVE	energy (quantity)	power (level)	electrical location	delivery schedule	delivery schedule notice	speed of response		agreements specify how performances is quantified such as energy interval meters and time-stamped power measurements.
REGULATION	power (level)	power regulation range	power mileage	electrical location	delivery schedule	delivery schedule notice	speed of response	signal periodicity	agreements specify how real power increase or decrease is measured. A performance score or index mechanism may be applied.
FREQ RESPONSE	percent droop	deadband	electrical location	delivery schedule	delivery schedule notice			agreements specify how performance is quantified with frequency response measurements.
VOLTAGE MGMT	target voltage/range	electrical location		delivery schedule	delivery schedule notice	signal periodicity		agreements specify how performance is quantified.
BLACKSTART	power (level)	power regulation range	electrical location	delivery schedule	delivery schedule notice	speed of response		agreements specify how performance is quantified.

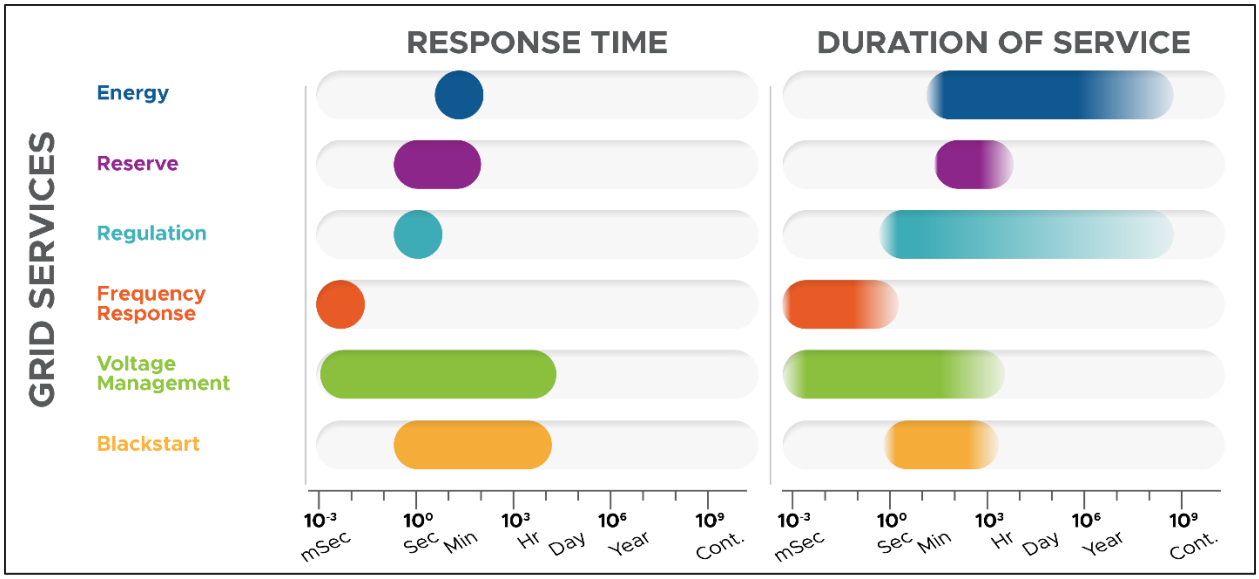

Figure 3: Common grid service types typical timing attributes variation.

2.3.1 Energy Service

Description: A scheduled production or consumption of energy at an electrical location over a committed period.

Performance expectation

- **Electrical attributes:**
  - **Power:** The power level of the resource for production or consumption over the performance period.
  - **Energy:** The quantity of electric energy for production or consumption over the performance period. The agreement can specify the price for a quantity of energy at different power levels (a curve).
  - **Electrical location:** The physical location where the service is delivered in the electric system.
- **Timing attributes:**
  - **Delivery schedule:** The start time and end time of the scheduled energy production or consumption. This can also be specified with a start time and duration.
  - **Delivery schedule notification:** The timing associated with notification that the delivery schedule for the energy service is established. For example, the results of a market process are published at specified times and notify the participants of their scheduled delivery of the service.

Performance measurement: The energy service agreement specifies how performance is quantified, including measurement equipment and location, measurement units and frequency, and calculations or estimating methods. This is usually done with revenue-grade meters that measure energy at intervals synchronized to the delivery schedule for the service. In addition, periodic power measurements can be used to estimate energy over the performance period.

For measurement, the electrical location may be different from the measurement location. Correction factors may be applied to address discrepancies between the delivery point and the measurement point. Also, the electrical location may be related to a pricing node or zone for settlement computations.

Example service requestor operational objectives: System peak load management, balance energy use with production, and manage delivery limitations caused by power flow constraints.

Origin of service definition: The energy service is the basic mechanism for balancing the planned production and consumption of energy in the system to set up a reliable flow of power in the electric system. Scheduling the production and consumption of energy over time allows the system operator to balance energy use with generation to manage delivery limitations caused by power flow constraints as well as stressed periods of operation, such as system peak load management.

Wholesale markets arrange for scheduled blocks of energy to match anticipated loads. These blocks of energy are scheduled in many forms, including bilateral agreements between energy suppliers and energy users. They are also done in centrally managed markets, such as those run by independent market operators. In the wholesale situation, the price and quantity of energy delivery over the performance period is negotiated ahead of time with information provided to an independent system operator to ensure reliable system operation. The agreements also stipulate the penalties or fees for non-performance (over or under production and consumption).

Most independent system operators have real-time (5-minute to one hour) and day-ahead (next operating day) energy markets at the wholesale level. They also have real-time and day-ahead demand response energy scheduling programs for retail customers to be able to respond to wholesale electricity prices. Participants are compensated based on the amount of reduction made during the delivery schedule interval.

2.3.2 Reserve Service

Description: Reserves a specified capacity to produce or consume energy at an electrical location when called upon over a committed period.

Performance expectation

- **Electrical attributes:**
  - **Power:** The power level of the resource for production or consumption over the performance period.
  - **Energy:** The quantity of available electric energy held in reserve that could be called upon for production or consumption. The agreement can specify the price for a quantity of energy at different power levels (a curve) that will be available to be called upon.
  - **Electrical location:** The physical location or region where the service is delivered in the electric system. Zones (an area of the system) are often used in specifying the location.

- **Timing attributes:**
  - **Delivery schedule:** The start time and end time to be available for reserve production or consumption. This can also be specified with a start time and a duration. The service agreement specifies the periodicity of the scheduling agreement (e.g., daily, hourly, or 30-minute periods).
  - **Delivery schedule notification:** The timing associated with notification that the delivery schedule for the reserve service is established. For example, the results of a market process are published at specified times and notify the participants of their scheduled delivery of the service.
  - **Speed of response:** The quality of the resource to change its operating position over a time interval. This can be measured in the amount of time to have the resource available (e.g., 30 minutes), the power level, a percent of the reserved power level per unit time, and/or agreed quantity over an interval.

Performance measurement: The reserve service agreement specifies how performance is measured. Energy interval metering may be combined with time-stamped power measurements.

Example service requestor operational objectives: System operations use the concept of reserves to address unplanned situations that regularly occur. These include contingency responses from line or generation equipment outages or derations that cause deviations from planned operations. Environmental events may also deviate from planned production from solar or wind-generator resources. These deviations may require fast-acting reserves (such as from synchronized generators) or slow response reserves (such as from non-synchronized generators that need several minutes to become available).

Depending on the operational situation, reserves may need to be available at different rates. For example, a weather forecast event may have one or more hours for reserves to respond, while a line or generator outage may require a more rapid response time.

Origin of service definition: System operators use spinning (fast responding) and non-spinning (slower responding) reserves to maintain a reliable balance of production and consumption of energy in the system. Bulk energy systems schedule blocks of energy reserves to support this need. Independent System Operators (ISOs) and Regional Transmission Operators operate wholesale markets to establish reserve resources. In the wholesale market situation, the price and quantity of power and energy available over the commitment period will be negotiated ahead of time with information provided to an independent system operator to ensure reliable system operation. Besides establishing a fee for being available (on reserve), the governing documents also stipulate penalties or fees for non-performance. They also establish the way a service provider will be compensated if the reserve is called upon. Reserve markets typically settle the amount of energy produced or consumed from a reserve service at the real-time market price.

While wholesale markets set prices for operating the resources, the owners agree to follow control instructions for their resources from the system operator during the operating period. In vertically integrated utility situations, generation reserve requirements are established, and generators are scheduled to be on-call to provide the service.

Demand-side resources also participate in many wholesale markets and are used like contingency reserves. That is, aggregated demand response providers may be called upon for

various operating situations. They usually have longer contract intervals and notification periods. They may have stipulations on the maximum number of times they are called in a year or season. Their process for determining performance and settlement can be different than that of traditional generation reserve resources. The objective of defining a reserve service is to be agnostic to whether the service is provided by producers or consumers, as long as they meet the performance expectation.

2.3.3 Regulation Service

Description: Continuously provides an increase or decrease in real power from an electrical location over a specified scheduled period against a predefined real-power basepoint following a service requestor's signal. The signal interval is typically one to several seconds, and the associated performance period is significantly shorter duration than the typical energy service performance period.

Performance expectation:

- **Electrical attributes:**
  - **Power:** The amount of real power change from the resource for increase or decrease over the signal performance period.
  - **Power regulation range:** An upper and/or lower bound for the change in power level (e.g., in MW or kW) expected over the service period.
  - **Power mileage:** The amount of power level up and down movement over the service period. It is the sum of the ups and downs of real power level changes.
  - **Electrical location:** The physical location or region where the service is delivered in the electric system. Zones (an area of the system) are often used in specifying the location.
- **Timing attributes:**
  - **Delivery schedule:** The start time and end time of the service period. This can also be specified with a start time and a duration (e.g., 1 hour or 4-hour periods).
  - **Delivery schedule notification:** The timing associated with notification that the delivery schedule for the regulation service is established. For example, the results of a market process are published at specified times and notify the participants of their scheduled delivery of the service.
  - **Signal periodicity:** The periodicity of the regulation signal (e.g., 2 or 4 seconds).
  - **Speed of response:** The quality of the resource to change its operating position over the signal period.

Performance measurement: The regulation service agreement specifies how real power increases or decreases will be measured to determine performance. Where practical, the real power adjustments are measured at a time interval that aligns with the regulation signal or multiples of the regulation signal intervals. The real power measurement determines the service provider's performance. For most wholesale electricity markets, compensation is based on the market clearing price for regulation services provided during a given settlement period. Compensation for power mileage may also be based on these measurements.

The regulation service is metered, reporting real power change in each time step to closely follow the power up/down movement of the regulation signal and be bound by the power

regulation range committed by the service provider. The ability to closely follow the accuracy of the response can be measured using a metric called “performance score” or “performance index,” which is a unit-less quantity between “0” and “1” (or an accuracy percentage between 0 and 100 [FERC 2012]).

The calculation method for the performance score metric varies by the independent system operator; however, it is typically calculated for each real-time market interval (e.g., 5-minutes or 15-minutes), and the average performance score over a certain period is often used to determine the service provider’s qualification for service and performance payment. Some independent system operators (e.g., California Independent System Operator [CAISO] and Midcontinent Independent System Operator [MISO]) calculate performance scores based on the total deviations from the regulation set point for each four or six second regulation interval (Zhou et al. 2016; Nguyen et al. 2017) or a variation of this concept (NYISO 2020). PJM uses a more sophisticated method, which calculates the performance score in each interval as the average of three components scoring the correlation, delay, and precision between the resource’s response and the request signal (Pratt et al. 2021).

Example service requestor operational objectives: The regulation service is used to balance small fluctuations in supply and demand in real time (Zhou et al. 2016). In the frequency control continuum (NERC 2011), regulation service falls under the secondary control category; for example, once frequency drop has been arrested by primary control (in seconds), regulation service corrects the deviation (1–10 minutes) to the target value.

Origin of service definition: Historically, regulation service has been provided by large generator units. Generators often provide regulation services in conjunction with energy scheduling services. However, single, large-load, storage, and aggregated demand-side resources were also allowed to participate in the regulation service in some markets (e.g., at PJM and CAISO) in the recent decade or so (Pratt et al. 2021).

The resources providing regulation service must be able to respond to regulation signals sent by the system operator periodically, typically within one to several seconds (Zhou et al. 2016). Generators adjust their output up or down following the regulation signal; demand resources increase or decrease consumption based on a predetermined basepoint (Pratt et al. 2021). In some electricity markets in the U.S., separate products are offered for upward versus downward regulation services, for example at CAISO.

In PJM’s market, the Regulation D signal is a fast, dynamic signal for quick responding resources, whereas Regulation A is a slower signal intended to help recover large, long fluctuations.

The term power mileage is used to describe the summation of power level movements up and down that a regulation service provider takes over the course of the delivery schedule. Mileage is a multiplier in the compensation calculation in some electricity markets. In addition, the mileage contained in service request signals can affect a resource’s performance score in these markets.

2.3.4 Frequency Response Service

Description: Responds to a change in system frequency nearly instantaneously by consuming or producing power over a committed period.

Performance expectation

- **Electrical attributes:**
  - **Percent droop:** The amount of real power change for an increase or decrease in frequency over the performance period as expressed in units such as percent of megawatts per one tenth of a Hertz.
  - **Deadband:** The upper and/or lower frequency deviation threshold, expressed in units such as Hertz, is around a nominal system frequency within which the resource will not perform frequency response and beyond which the resource will operate to correct a deviation.
  - **Electrical location:** The location or region where the service is delivered in the electric system. Balancing areas are typically the control area for this service.
- **Timing attributes:**
  - **Delivery schedule:** The start and end times of the on-call schedule for the frequency response. This can also be specified with a start time and a duration (e.g., 1- or 4-hour periods).
  - **Delivery schedule notification:** The timing associated with notification of the on-call schedule for the frequency response.

Performance measurement: Frequency response measurement uses a fixed time interval to determine the initial response to a frequency deviation event. Sustained frequency response establishes an additional fixed interval that can be used to determine if frequency response is being sustained as desired. Together, these metrics are scored to indicate appropriate frequency response.

Tools such as North American Electric Reliability Corporation's (NERC's) Generator Resource Survey are often used to calculate governor frequency response by using historical data or manually calculated values. These tools evaluate an individual resource's ability to provide frequency response during both the initial and sustained periods and are intended to be used as a benchmarking tool for an individual resource as well as for the balancing area. A lack of data availability means that a resource's frequency response is often modeled rather than measured based on survey and benchmark data.

If measured data is available, a graphical approach can be applied to determining if the frequency response is being sustained. Two plots of resource output and frequency are reviewed in the evaluation of resource frequency response, along with supplemental data. The analysis performed is typically a three-step process: sample validation, response type classification, and droop verification.

Example service requestor operational objectives: Stabilize system frequency from large energy impulse events (e.g., loss of a major generating unit or highly loaded line in the transmission system). In an islanded microgrid situation, relatively smaller events can cause frequency fluctuations, requiring a similarly stable response.

Origin of service definition: Frequency response service is used to stabilize frequency immediately following the sudden change in generation or load. It is a critical component to the reliable operation of an electric power system, particularly during disturbances and restoration.

Frequency response service is referred to by NERC as primary control or primary frequency response, which includes inertial response. This is a reliability service for the bulk electric system and has operational guidelines for the balancing authorities, generator operators and owners, and transmission operators and owners. Since frequency response is a bulk electric service traditionally provided by spinning generators with governors, it includes attributes such as deadband and percent droop settings that are measured at the resource level. Balancing authorities are responsible for dispatch and management of their area control error (ACE) and are expected to have available a reserve capacity that exceeds the largest expected loss with margin.

The reliable provision of the frequency response service must be so quick as to require the active response of resources based on locally measured or sensed changes in frequency, i.e., autonomous response. Traditionally, spinning generator governors are applied proportionally to alter operation immediately, based on droop curves for frequency excursions outside of deadband limits. More recently, inverter-based resources have demonstrated their ability to provide frequency response in accordance with the common droop rule.

2.3.5 Voltage Management Service

Description: Provides voltage support (raise or lower) within a specified upper and lower voltage range at an electrical location over a committed period.

Performance expectation

1. **Electrical attributes:**
    a. **Target voltage/range:** The voltage level expressed as electrical voltage units such as kilovolts at the electrical location over a performance period. The agreement can specify a single target, an upper and lower range of voltage magnitude, or an RMS value at the electrical location.
    b. **Electrical location:** The location or region where the service is delivered in the electric system.
2. **Timing attributes:**
    a. **Delivery schedule:** The start and end time to perform the service. This can also be specified with a start time and a duration (e.g., 1 hour or 4-hour periods).
    b. **Delivery schedule notification:** The timing associated with notification that the delivery schedule for the voltage management service is established. For example, the results of a market process are published by specified times and notify the participants of their scheduled delivery of the service.
    c. **Signal periodicity:** The periodicity of the voltage management signal (e.g., daily, hourly, or 15-minute periods).

Performance measurement: The voltage management service agreement specifies how performance is measured. The service may require the demonstration of a lagging and/or leading reactive power (VAR) capability, and performance is verified by metering data (ISO 2022).

Example service requestor operational objectives: Maintain voltage within a reliable operating range for running equipment and maintaining system stability. In the transmission system, equipment is rated to operate efficiently and effectively within a voltage range.

In the distribution system, voltage management maintains a voltage profile along a distribution circuit to manage voltage sags and swells. These issues may come from high-voltage situations caused by neighborhood roof-top solar, low-voltage situations caused by excessive electric vehicle charging, or high or low voltage profiles from circuit sectionalizing. In addition, the voltage is sometimes managed to the lower part of the operating range as an energy efficiency measure, especially for resistive loads.

Origin of service definition: In the bulk power system, due to the highly inductive nature of transmission lines, the frequency and voltage control can be roughly decoupled such that the voltage is associated with the reactive power and the frequency can be controlled by the real power. Voltage management is typically provided by adjusting exciters on rotating generators, changing inverter settings on power electronic controlled devices, and changing transformer tap settings or manipulating capacitor banks in substations.

Due to the dynamic nature of maintaining proper operating voltage, voltage management is traditionally provided through system operation studies, resource assignments, and voltage level settings provided by these engineering studies and based on codes for reliable system operations set forth in governing documents.

In the distribution system, voltage management is done by changing transformer tap settings or manipulating capacitor banks. Inverter equipment power factors can be managed with fixed settings or dynamically configurable settings that can be updated through secure communications.

2.3.6 Blackstart Service

Description: Energize or remain available without grid electrical supply to energize part of the electric system over a committed period.

Performance expectation

- **Electrical attributes:**
  - **Power:** The amount of real power change from the resource expressed as electrical power units such as megawatts or kilowatts for increase or decrease over the signal performance period.
  - **Power regulation range:** An upper and/or lower bound for the change in power level in electrical power units such as megawatts or kilowatts expected over the service period.
  - **Electrical location:** The location or region where the service is delivered in the electric system. Zones (an area of the system) are often used in specifying the location.
- **Timing attributes:**
  - **Delivery schedule:** The start and end times to perform the service. This can also be specified with a start time and a duration (e.g., 1 hour or 4-hour periods).

- **Delivery schedule notification:** The timing associated with notification that the delivery schedule for the emergency service is established. For example, the results of a market process are published by specified times and notify the participants of their scheduled delivery of the service.
- **Speed of response:** The quality of the resource to change its operating position over the signal period.

Performance measurement: A coordinated control scheme might depend on all committed resources' participation. The service agreement specifies how performance is measured. For example, resources may be required to demonstrate that they can operate without access to grid power. Also, the response of the resource could be compared to requests to verify the performance of the service. This could be done with interval meters capable of recording energy flow at intervals that match the timing attributes of the service agreement.

Example service requestor operational objectives: Examples of blackstart service include re-energization after a blackout or balancing supply and demand in an islanding emergency.

Origin of service definition: This service category covers the coordination of resources in dire operating scenarios. Blackstart service is the capability of a generation resource to start and provide power before being connected to the electric grid or to remain available even if the electric grid goes down. More generally, the blackstart service includes procedures that are used as part of a restoration plan following a blackout (NERC 2023).

Planned demand curtailment services, such as New York Independent System Operator's (NYISO's) emergency demand response program, are used to put the system in a more reliable operating posture; however, the service follows the reserve service paradigm. In islanded operating scenarios that may occur after system collapse or as part of system restoration, generation and load balance is achieved with blackstart facilities and managed load pickup by switching in combinations of distribution circuits and controlled loads as generation allows.

System operating organizations recognize that emergency situations require extraordinary actions to preserve and restore the health and integrity of the electric system. Emergency operating procedures are spelled out by each operating organization and comprise emergency alerts or notifications as well as emergency operating procedures. The responsibilities of system operators and other participants are identified in these procedures.

The categorization of common grid services recognizes that the coordination of resources under emergency conditions requires agreements on operating policy. However, from a grid service perspective, the coordination falls into one or more of the common grid service definitions already described. The fact that the service is called upon in an emergency situation explains the operational objective of the service but does not change its basic definition or format of electrical and timing attributes.

3.0 Distribution Level Grid Services

Distribution-level grid service programs encompass a variety of operational objectives, commonly falling under the umbrella description of demand response. The use of such an umbrella term makes it challenging to understand the nature of the service or the performance requirements of a program that could be provided by DER, including those resources that are potentially supplying energy back to the grid, like renewables (photovoltaic and wind) or energy storage systems. Using the service terms and definitions above would clarify expectations and the performance requirements necessary to provide these services, reducing confusion between a potentially wide variety of actors and across jurisdictions. The following material discusses aspects of the grid service types relevant to their use at the distribution level of system operations.

3.1 Energy Service

The energy service plans energy production or consumption over a performance period. Today's distribution-level energy service programs tend to be price-reactive mechanisms like time-of-use rates, or critical-peak pricing rates, or various forms of dynamic pricing programs. These schemes are designed to influence customers to modify their energy use based on a scheduled change in the price of energy. In these schemes, the price is posted for the performance period, but the amount of energy used or consumed is not specified. Instead, the system operator estimates the amount of demand-side reaction that will be delivered from the specified prices.

Some wholesale energy service market programs already engage distribution-level resources. For example, NYISO and PJM have day-ahead demand response programs that allow qualifying customer facilities or aggregators of distribution-level resources with sufficient capacity to make offers to reduce load during scheduled periods. These customers receive performance payments based on the amount of reduction made for that period, usually as measured against a baseline load profile.

Retail price-responsive markets can operate as energy service market programs to their customers; however, some wholesale demand response programs act like reserve service markets. For example, MISO has an option under their demand response energy market that reserves energy from demand response resources to reduce load when called upon. This ability to call upon energy reduction with a signal falls under the reserve service category.

In a NYISO DER-flexibility program, participants have mandatory curtailment notices sent a day or two hours ahead of time. The ICAP-SCR program (ISO 2020) is defined in such a way that it operates as an energy service. The NYISO sends notifications a day before the event and on the day of the event. An ICAP-SCR participant is obligated to reduce load for a minimum of four hours during the event.

In transactive energy systems, DER facilities develop energy schedules to establish their consumption or production as part of their interaction with a local energy market. The distribution-level grid service is similar to the wholesale energy service except that distribution constraints are handled differently than the use of locational marginal prices in transmission-level markets.

Electrical attributes: Programs may leave the amount of energy open while specifying the price of energy over the performance period. Baseline load curves may be established, or load forecasts may be used to determine scheduled energy commitments and performance. Otherwise, the grid service attributes involve energy over a period and rarely include the power level at the electrical location.

Performance measurement: Distribution customers typically require revenue-grade interval meters capable of recording energy usage at intervals that match the timing attributes of the service agreement. For DER facilities such as buildings that may aggregate energy production and usage, this can be a customer site meter. For specific equipment agreements, submetering may be specified to isolate measuring performance, as proposed in some electric vehicle charging scenarios. Distribution-level programs usually involve monitoring changes against an agreed-upon baseline energy schedule (such as calculated from recent energy use averages).

3.2 Reserve Service

As mentioned above for the energy service, some markets allow large loads and aggregators of demand-side resources to participate in programs that are often referred to as demand response. These are typically used as contingency or emergency reserves at the wholesale level. For example, MISO's Demand Response Energy Market option, which dispatches demand-side resources as needed, would fall under the reserve service category. A distribution-level program that arranges a reserve of energy from DERs and engages them based on a call or signal would also fall into the category of a reserve service. In this case, an aggregator could meet a wholesale reserve service obligation by calling on prearranged reserves of retail customer resources under a retail reserve service agreement. Note that today, aggregators typically control customer equipment directly; however, future arrangements could be with a reserve service agreement that delegates the customer site to manage its own equipment to maintain reserves and respond to a reserve signal when called upon.

Electrical attributes: The attributes for reserve service at the distribution level are those in the common reserve service definition above, with some programs offering lump sum compensation to call on a resource a certain number of times either annually or per billing cycle.

Performance measurement: For distribution customers, evaluation of the service response can be done with interval meters capable of recording energy usage at intervals that match the timing attributes of the service agreement. For DER facilities such as buildings that may aggregate energy production and usage, this may be a customer site meter. For specific equipment agreements, submetering may be specified to isolate measuring performance. Performance measurements for aggregators compile measurement data from the aggregated resources.

3.3 Regulation Service

Wholesale markets, such as PJM, ISO New England Inc. (ISO-NE), and Electric Reliability Council of Texas (ERCOT), offer programs for demand-side resources to participate in regulation; however, they require the qualified entities to offer minimums, such as 100 kW, and the appropriate communication and automation to accept their regulation signals. The qualified entities are tested to see that they adequately follow the regulation signal. Large industrial or commercial customers may qualify, but distribution-level resources have not been used for regulation except in microgrid situations and pilot programs (Green Mountain Power 2021). With

improved levels of automation and communication, the future may hold opportunities for participation by these resources.

Pilot programs using demand-side resources, such as batteries, are being investigated. Participation of qualified resources is contingent on being able to receive and respond to the regulation signal as well as 6-second or real-time telemetry. Green Mountain Power's residential energy storage pilot uses Tesla and community energy storage battery systems to participate in the ISO-NE regulation program. Green Mountain Power follows the requirements of ISO-NE, but in aggregate, i.e., automatic response rate of 80 to 95 percent and, again, in aggregate, 1 MW/minute. Additionally, they must demonstrate their ability to follow regulation set points, which requires frequent communication. Green Mountain Power handles this as an aggregator rather than each device having a specific capability.

Some resources, such as inverter-interfaced DERs, can better follow fast, high-mileage signals than many traditional load resources. To differentiate such capabilities, some markets, such as PJM's, offers separate regulation service products distinguishing high versus low mileage (Pratt et al. 2021).

Performance measurement: For distribution retail customers, aggregation is needed in order to qualify for providing the regulation service at the transmission level. This will require investment in communications, automation, and appropriate measuring equipment.

3.4 Frequency Response Service

Frequency response has been a bulk electric system service; however, microgrid controllers and inverter-based frequency stabilization schemes are redefining frequency response in smaller systems. National laboratories, including National Renewable Energy Laboratory (Hoke, et al. 2021) and Pacific Northwest National Laboratory (Tbaileh et al. 2022) have both studied the capability of distribution-level resources to provide frequency response services. ERCOT recently approved a pilot project (Flexon 2022) to study the ability of aggregate DER to provide essential reliability services, including frequency response.

Performance measurement: The type and quality of data required at the distribution level are being investigated in pilot projects, but many are using meter or submeter data to verify performance.

3.5 Voltage Management Service

Voltage management by coordinating the operation of DER resources has been done with inverter systems in photovoltaic, wind, and battery systems using codes of operation that specify the inverters' real and reactive power lead/lag settings. As such, these are operating rules rather than services; however, coordination signals have been proposed and piloted.

The operational objectives for this service in the distribution system include maintaining a voltage profile along a distribution circuit, mitigating voltage spikes, and managing voltage sags and swells. These issues may come from high-voltage situations caused by neighborhood roof-top solar, low-voltage situations caused by excessive electric vehicle charging, or high or low voltage profiles from circuit sectionalizing.

Electric attributes: The electric attributes may include the power factor of the DER facility at the electrical location and/or the injected or absorbed reactive power quantity from the DER.

Performance measurement: The voltage management service agreement needs to specify how performance is measured. For distribution customers, this may be done with grid voltage magnitude or RMS measuring devices capable of recording voltage or power factor (real and reactive power) quantities at intervals that match the timing attributes of the service agreement. For DER facilities such as buildings that may aggregate energy production and usage, this can be a customer site voltage or real/reactive power meter. For specific equipment agreements, submetering may be specified to isolate measuring performance.

3.6 Blackstart Service

Some DER (e.g., photovoltaics, batteries, and backup generators) are able to remain operational during a loss of system electric service. These resources may be able to maintain a facility to operate in islanded mode. They may also be able to support the energization of the distribution system should there be a coordination program in place to do so.

Customer resources at the distribution level are also subjected to emergency response schemes, such as load shedding and rotating circuit disruptions, as managed by system operators. With greater automation and communications, coordination of customer resources could allow for more graceful degradation and prioritization of loads (such as hospitals, emergency response centers, and critical infrastructure) so that societal impact is lessened. This remains an area of research and investigation that may be fulfilled as DER coordination frameworks mature.

Performance measurement: For distribution customers, performance verification could be done with interval meters capable of recording energy usage at intervals that match the timing attributes of the service agreement. For DER facilities such as buildings that may aggregate energy production and usage, this can be a customer site meter. For specific equipment agreements, submetering may be specified to isolate measuring performance.

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Appendix A

Existing Grid Services Mapping

This appendix reviews common grid services from several system operators for energy scheduling and reserve services. The material is provided in the format of the definitions of common grid services. The exercise shows how the electrical and timing parameters change between system operators while the basic definitions remain substantially consistent.

A.1 Energy Service Mapping

A.1.1 California Independent System Operator Energy Services

In addition to energy schedules established in bilateral agreements that are communicated for planning operations, the California Independent System Operator (CAISO) manages two wholesale energy market processes for energy scheduling: day-ahead and real-time.

A.1.1.1 Day-ahead Scheduled Energy Service

“The day-ahead market is made up of three market processes that run sequentially. First, the ISO runs a market power mitigation test. Bids that fail the test are revised to predetermined limits. Then the integrated forward market establishes the generation needed to meet forecast demand. And last, the residual unit commitment process designates additional power plants that will be needed for the next day and must be ready to generate electricity. Market prices set are based on bids.”

The objective of the market is “…to find the least cost energy to serve demand.” (California ISO n.d.)

Description: The day-ahead scheduled energy market receives bids for energy at an electrical location for each of the 24 hours in the trading day (the next operating day). The market operator resolves these bids with out-of-market energy schedules while ensuring that reliability constraints are honored. The results are binding agreements between the market participants.

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy produced or consumed in each of the hourly schedule intervals in MWh.
- **Electrical location:** The electrical locations involved are defined for each scheduled agreement as the “producing node” and “delivering nodes.” These nodes are related to PNodes (pricing nodes) in the CAISO market model. (California ISO 2023)

Timing attributes:

- **Delivery schedule:** The energy schedule covers each 24-hour period of the upcoming trading (i.e., operating) day.
- **Delivery schedule notification:** The day-ahead energy market results are published at 1 p.m. prior to the start of the trading day.

Performance measurement: A metered entity enters into a Meter Service Agreement with CAISO. The meters are to be revenue-quality (certified by CAISO) with readings at the point of system interconnection. The data collected is in kWh or MWh values. Meter data can be elected to be polled and validated from resources not providing ancillary services at 5- or 15-minute intervals to meet the hourly delivery schedule intervals. When there is a failure to get actual data, an estimation procedure is used for financial settlement. (California ISO 2021)

Comments: For the electrical attributes, the power level of the participant is assumed to be flat during the scheduled operating hour.

A.1.1.2 Hourly Real-time Scheduled Energy Service

“The real-time market is a spot market in which utilities can buy power to meet the last few increments of demand not covered in their day ahead schedules.” (California ISO n.d.)

Description: The real-time scheduled energy market receives bids for energy at an electrical location using an hour-ahead scheduling process for delivery in the next trading (i.e., operating) hour. The market operator resolves these bids while ensuring that reliability constraints are honored. The results are binding agreements between the market participants. (California ISO 2022b)

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy produced or consumed in each of the hourly schedule intervals in MWh.
- **Electrical location:** The electrical locations involved are defined for each scheduled agreement as the “producing node” and “delivering nodes.” These nodes are related to PNodes (pricing nodes) in the CAISO market model.

Timing attributes:

- **Delivery schedule:** The energy schedule is for the upcoming trading (i.e., operating) hour.
- **Delivery schedule notification:** The real-time energy market results are published approximately 45 minutes prior to the start of the trading hour.

Performance measurement: The metering requirements (Meter Service Agreement) are the same as the day-ahead scheduled energy service (kWh or MWh), except that the hourly settlement process is based on 15-minute market schedule intervals so that CAISO can integrate the settlement of the real-time ancillary service markets. 60-minute metering is only allowed for scheduling coordinators.

Comments: The CAISO description of the real-time energy market is complicated by other real-time market products. Reference is made to market system dispatches to participants at 15, 5, and 1-minute intervals, but these appear to be for other energy balancing operations involving operator dispatch and not real-time scheduled energy.

A.1.2 Southwest Power Pool – Energy Markets

In addition to energy schedules established in bilateral agreements that are communicated for planning operations, Southwest Power Pool (SPP) manages two wholesale energy market processes for energy scheduling: day-ahead (DA Market) and real-time balancing (RTBM). (SPP Documents & Filings 2011)

A.1.2.1 Day-ahead Market for Energy Service

"The DA Market provides Market Participants with the ability to submit offers to sell Energy…" This information goes into an integrated process involving an analysis of unit commitment and security constraints to minimize total projected production costs.

Description: The day-ahead market for energy receives bids for energy at an electrical location for each of the 24 hours of the next operating day. The market operator resolves these bids with out-of-market energy schedules while ensuring that reliability constraints are honored. The results are binding agreements between the market participants.

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy produced or consumed in each of the hourly schedule intervals in MWh. Used in settlement.
- **Electrical location:** The electrical locations involved are defined for each scheduled agreement. "Electrical nodes (ENodes) represent the physical connection points in the transmission system model." PNodes (pricing nodes) in the SPP commercial model link to ENodes and define the places where market prices are established.

Timing attributes:

- **Delivery schedule:** The energy schedule covers each 24-hour period of the upcoming operating day.
- **Delivery schedule notification:** The day-ahead energy market cleared results are published at 1 pm prior to the start of the operating day.

Performance measurement: Revenue-quality metering equipment and meter data are supplied by a meter agent at the PNodes (meter settlement location—the nearest transmission system bus associated with an asset) for each participant. Meter data of energy (kWh) are supplied at least hourly, or every 5 minutes, and synchronized with the delivery intervals. Real-time metering of power (kW or MW) can be used as a backup for interval energy meter failure to produce estimated energy (MWh). SPP receives meter data converted to MWh. (See Appendix D of the above reference.)

Comments: For the electrical attributes, the power level of the participant is assumed to be flat during the scheduled operating hour.

A.1.2.2 Real-time Balancing Market for Energy Service

"The RTBM provides Market Participants with the ability to submit offers to sell Energy…" This information goes into an integrated process involving the results of the day-ahead market "by determining the security-constrained dispatch that is the least costly means of balancing generation and load (supply/demand) while meeting operating reserve requirements."

Description: The real-time balancing market for energy operates on a 5-minute basis and calculates dispatch instructions for energy. It receives bids for 5-minute intervals of energy in the next operating hour from participants at an electrical location for delivery. The market operator resolves these bids while ensuring that reliability constraints are honored. The results are binding agreements between the market participants.

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy produced or consumed in each of the real-time dispatch (i.e., schedule) intervals in MWh. Used in settlement.
- **Electrical location:** The electrical locations involved are defined for each scheduled agreement. "Electrical nodes (ENodes) represent the physical connection points in the transmission system model." PNodes (pricing nodes) in the SPP commercial model link to ENodes and define the places where market prices are established.

Timing attributes:

- **Delivery schedule:** Offers may be submitted up to 30 minutes prior to each operating hour. The market operator determines the energy dispatch schedule for every 5-minute operating interval in the operating hour.
- **Delivery schedule notification:** The real-time energy market results are not published prior to the start of the operating hour. The settlement is done based on the 5-minute dispatch decisions.

Performance measurement: Revenue-quality metering equipment and meter data are supplied by a meter agent at the PNodes (meter settlement location—the nearest transmission system bus associated with an asset) for each participant. Meter data of energy (kWh) are supplied on a 5-minute basis and synchronized with the delivery intervals. These are combined for an hourly settlement. Where 5-minute energy data is not measured, SPP uses state estimator real-time data profiles for the corresponding PNode. Power (in MW, not MWh) is sampled every 5 minutes, and the profile is used to calculate the hourly energy settlement.

Comments: The real-time balancing of the energy market is linked to other real-time market services. The asset owners bid their resources for dispatch in the upcoming operating hour. If their bids are the most economical (determined by the market operator), then the system operator controls (dispatches) their unit in 5-minute intervals over the operating hour. The result was direct control, though the resource was selected for control by a service-oriented market.

A.1.3 PJM Energy Service

PJM has markets to address their operational objectives of balancing supply and demand. They manage wholesale market processes for energy scheduling: day-ahead and real-time, and additionally have integrated “Demand Response” programs, which provide an opportunity for aggregators of end-use resources to participate in energy markets and “…receive payments for demand reductions they make.” (PJM Learning Center n.d.)

A.1.3.1 PJM Day-ahead Energy Market

“The Day-ahead Energy Market enables participants to purchase and sell energy at binding Day-ahead LMPs”. “...The Day-ahead scheduling process incorporates PJM reliability requirements and reserve obligations into the analysis. The resulting Day-ahead hourly schedules, generated by the dispatch run, and Day-ahead LMPs, generated by the pricing run, represent binding financial commitments to the market participants.” (Day-Ahead and Real-Time Market Operations 2023, pg. 23)

Description: Day-ahead bids for energy are submitted for each of the 24 hours of the upcoming operating day. The bids are processed at 11 a.m., and results are posted by 1:30 p.m. the day prior to the operating day of the resource. There is a re-bid period between the posted results and 2:15 p.m. The market’s operational day begins at midnight.

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy produced or consumed in each of the hourly schedule intervals in MWh. Used in settlement.
- **Electrical location:** The electrical location is defined as a PNode and is “a single pricing node or subset of pricing nodes where a physical injection or withdrawal is modeled and for which a locational marginal price is calculated and used for financial settlements.”

Timing attributes:

- **Delivery schedule:** The energy schedule covers each hour of the 24-hour period of the upcoming (i.e., operating) day.
- **Delivery schedule notification:** The day-ahead energy market results are published at 1:30 p.m. A rebidding period takes place, and results are posted at 2:15 p.m. prior to the start of the operating day.

Performance determination: “For each hour of the Operating Day, PJM calculates an hourly integrated telemetry MWh value using the time-weighted telemetry MW values for each of the five-minute intervals in the hour.” (Market Settlements Development Department 2023)

Comments: Non-binding energy offers can be submitted for days beyond the next operating day. Subsequent offers supersede these non-binding offers.

A.1.3.2 PJM Real-time Energy Market

The PJM intraday balancing market clearing prices are calculated every 5 minutes and are based on deviations between day-ahead market positions and real-time operations.

Description: PJM operates “a spot market–meaning that the product is procured for immediate delivery–in which current prices (called locational marginal prices) are calculated at five-minute intervals based on actual grid operating conditions. Real-time energy prices are posted on the PJM operational data webpage.” (PJM Learning Center n.d.)

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy produced or consumed in each of the real-time dispatch (i.e., schedule) intervals in MWh. Used in settlement.
- **Electrical location:** The electrical location is defined as a PNode and is “a single pricing node or subset of pricing nodes where a physical injection or withdrawal is modeled and for which a Locational Marginal Price is calculated and used for financial settlements.”

Timing attributes:

- **Delivery schedule:** Offers for every 5 minutes of an operating hour may be submitted up to 65 minutes prior to each operating hour. The market operator determines the energy dispatch schedule for every 5-minute operating interval in the operating hour.
- **Delivery schedule notification:** The real-time energy market results are not published prior to the start of the operating hour. The settlement is done based on the 5-minute dispatch decisions.

Performance determination: Generator data is reported as 5-minute revenue meter data and is expected to be flat and bid in MW, thus compensated in MWh. “The balancing settlement is calculated for each Real-time Settlement Interval (five (5) minute interval) based on actual five (5) minute Revenue Data for Settlement MW quantity deviations from Day-ahead scheduled quantities resulting from the dispatch run and on the applicable Real-time prices resulting from the pricing run.” (Day-Ahead and Real-Time Market Operations 2023)

Comments: The calculations for real-time market compensation account for commitments agreed upon in the day-ahead market.

A.1.3.3 PJM Day-ahead Demand Response Market

Through a curtailment service provider (CSP), this program allows a retail customer to respond to wholesale day-ahead market prices, participating with either generation or demand resources. In the Demand Response Market program, the CSP will bid aggregated energy (MWh) according to the service requirements in a similar manner to the regular day-ahead markets; bids of energy are submitted for each of the 24 hours that are expected to be flat and bid in MW, thus compensated in MWh.

Description: “In the day-ahead option, a CSP’s customers can offer–in advance of real-time operations–to reduce the amount of electricity they will draw from the PJM system. If the offers are accepted, they will receive payments based on the day-ahead prices for the reductions.” (PJM 2022)

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.

- **Energy:** The amount of energy reduction in each of the real-time dispatch (i.e., schedule) intervals in MWh. This is used in settlements.
- **Electrical location:** The electrical location is defined as a PNode and is "a single pricing node or subset of pricing nodes where a physical injection or withdrawal is modeled and for which a Locational Marginal Price is calculated and used for financial settlements."

Timing attributes:

- **Delivery schedule:** The energy schedule covers each hour of the 24-hour period of the upcoming (i.e., operating) day.
- **Delivery schedule notification:** The day-ahead energy market results are published at 1:30 p.m. A rebidding period takes place, and final results are posted at 2:15 p.m. prior to the start of the operating day.

Performance determination: "Demand Resources must be equipped with interval meters recording electrical usage at the EDC (electric distribution company) account level. The interval of data collection must be sufficient to provide PJM with hourly, one minute or real time load data as applicable for the wholesale market." The meters capture energy usage for each interval. (PJM Manuals n.d.a)

Comments: CSPs aggregate the participating customers demand responses and submit the verification to PJM. This needs to be resolved on a PNode basis for compensation. The distribution of payments to the demand reduction participants is between the CSP and their customers. Customers' responses are based on the change in energy consumption from a baseline load shape.

A.1.3.4 PJM Real-Time Demand Response Market

Through a CSP, this program allows retail customers to respond to wholesale real-time market prices, participating with either generation or demand resources. In the demand response market program, the CSP will bid aggregated energy in a similar manner to the other energy schedule real-time market. Intraday offers may make changes beginning at 4:30 p.m. the previous day up to 65 minutes before the operating hour according to a 5-minute increment schedule that is expected to be flat and bid in MW, thus compensated in MWh. Bids are made in terms of $/MWh.

Description: "The Real-time Option provides a mechanism by which any qualified Market Participant may offer Demand Resources the opportunity to commit to a reduction and receive payments based on Real-time LMP for the reductions." (PJM Manuals n.d.b)

Electrical attributes:

- **Power:** The MW level of the service. Bid curves consist of MW, $/MWhr quantities.
- **Energy:** The amount of energy reduction in each of the real-time dispatch (i.e., schedule) intervals in MWh. This is used in settlements.
- **Electrical location:** The electrical location is defined as a PNode and is "a single pricing node or subset of pricing nodes where a physical injection or withdrawal is modeled and for which a Locational Marginal Price is calculated and used for financial settlements."

Timing attributes:

- **Delivery schedule:** Offers for every 5 minutes of an operating hour may be submitted up to 65 minutes prior to each operating hour. The market operator determines the demand response dispatch schedule for every 5-minute operating interval in the operating hour.
- **Delivery schedule notification:** The real-time energy market results are not published prior to the start of the operating hour. The settlement is done based on the 5-minute dispatch decisions.

Performance determination: “Demand Resources must be equipped with interval meters recording electrical usage at the EDC account level. The interval of data collection must be sufficient to provide PJM with hourly, one minute or real time load data as applicable for the wholesale market.” The meters capture energy usage for each 5-minute interval. (PJM Manuals n.d.b)

Comments: Like the other real-time energy schedule markets, the service providers do not know how to correct the operation of the demand response resources until they are given the 5-minute signal from the system operator. However, they understand their planned operation for the hour based on the results of the day-ahead market. Customers’ responses are based on the change in energy consumption from a baseline load shape. The compensation incorporates their day-ahead commitment and deviation based on the real-time market price.

A.2 Reserve Service Mapping

A.2.1 CAISO – Reserve Markets

“Spinning reserve is standby capacity from generation units already connected or synchronized to the grid and that can deliver their energy in 10 minutes when dispatched. Non-spinning reserve is capacity that can be synchronized to the grid and ramped to a specified load within 10 minutes.” (California ISO n.d.)

Certified loads are also able to supply spinning and non-spinning reserves based on their qualifying characteristics.

CAISO runs day-ahead and real-time markets for arranging these reserves. The business practices for interacting with the market for these services in terms of timing attributes are the same as for the energy service.

A.2.1.1 Day-ahead Spinning and Non-Spinning Reserves

Spinning Reserve (must be synchronized, be available in 10 minutes, and be maintainable for 30 minutes). Non-Spinning Reserve (must be able to deliver the AS (ancillary service) Award within 10 minutes and be maintainable for 30 minutes). (California ISO n.d.)

Description: The day-ahead markets for spinning and non-spinning reserves receive bids for a power capacity at an electrical location for each of the 24 hours in the next operating day. The market operator resolves these bids, ensuring that reliability constraints are honored. The results are binding agreements between the market participants.

Electrical attributes:

- **Power:** The MW level of the service (called spinning or non-spinning reserve capacity). Bid curves consist of MW, $/MW quantities.
- **Electrical location:** “The CAISO will procure Ancillary Services using Ancillary Service Regions and Ancillary Service Sub-Regions. There are two Ancillary Service Regions and eight Ancillary Service Sub-Regions.” (California Independent System Operator Corporation 2022a)

Timing attributes:

- **Delivery schedule:** The reserve schedule covers each 24-hour period of the upcoming trading (i.e., operating) day.
- **Delivery schedule notification:** The day-ahead spinning and non-spinning reserve market results are published at 1 p.m. prior to the start of the trading day.
- **Speed of response:** “Each provider of Spinning Reserve or Non-Spinning Reserve must be capable of receiving a Dispatch Instruction within one (1) minute from the time the CAISO Control Center elects to Dispatch the Spinning Reserve resource or Non-Spinning Reserve resource and must ensure that its resource can be at the Dispatched operating level within ten (10) minutes after issuance of the Dispatch Instruction.” (California Independent System Operator Corporation 2022b) and be maintainable for a continuous duration of 30 minutes.

Performance measurement: Scheduling Coordinators must ensure that Settlement Quality Meter Data submitted to the CAISO is in intervals of 5 minutes for Loads and Generators providing ancillary services (includes reserves). (California ISO 2021).

Comments: Spinning reserves are allocated based on reliability criteria that include the capability of frequency response that non-spinning reserves may not have.

A.2.1.2 Hourly Real-time Spinning and Non-Spinning Reserves

The CAISO operates an hour-ahead scheduling process (HASP) for operating reserves (spinning and non-spinning). The process framework is the same as the energy service hour-ahead scheduling process. The HASP produces advisory schedules in the upcoming hour, providing guidance as to the expected resource output.

Description: The hour-ahead markets for spinning and non-spinning reserves receives bids for power capacity at an electrical location for the next operating hour. The results of these markets are used to create binding commitments of resources for use by the system operator to operate the least cost resources to meet reliability criteria in real-time.

Electrical attributes:

- **Power:** The MW level of the service (called spinning or non-spinning reserve capacity). Bid curves consist of MW, $/MW quantities.
- **Electrical location:** “The CAISO will procure Ancillary Services using Ancillary Service Regions and Ancillary Service Sub-Regions. There are two Ancillary Service Regions and eight Ancillary Service Sub-Regions.” (California Independent System Operator Corporation. 2022a)

Timing attributes:

- **Delivery schedule:** The reserve schedule covers the next trading (i.e., operating) hour.
- **Delivery schedule notification:** The real-time energy market results are published approximately 45 minutes prior to the start of the operating hour.
- **Speed of response:** “Each provider of Spinning Reserve or Non-Spinning Reserve must be capable of receiving a Dispatch Instruction within one (1) minute from the time the CAISO Control Center elects to Dispatch the Spinning Reserve resource or Non-Spinning Reserve resource and must ensure that its resource can be at the Dispatched operating level within ten (10) minutes after issuance of the Dispatch Instruction.” (California Independent System Operator Corporation 2022b) and be maintainable for a continuous duration of 30 minutes.

Performance measurement: Scheduling Coordinators must ensure that Settlement Quality Meter Data submitted to the CAISO is in intervals of 5 minutes for Loads and Generators providing ancillary services (includes reserves). (California Independent System Operator Corporation 2021)

Comments: The hour-ahead attributes are the same as the day-ahead attributes for spinning and non-spinning reserves.

A.2.2 SPP – Reserve Markets

SPP procures spinning and supplemental reserves in day-ahead and real-time “operating reserve” markets. SPP operating reserves also include ramp capability up/down and regulation up/down services; however, these are classified and discussed in the regulation service category. A contingency reserve requirement also needs to be met for reliable SPP operations; however, this is a required reserve operating level to which other procured services contribute. It is not procured separately. (SPP Document & Filings 2011)

A.2.2.1 Day-ahead Spinning Reserve

Spinning reserve is the unloaded generation that is synchronized to the system and ready to serve additional demand. (SPP Glossary)

Description: The day-ahead market for spinning reserves receives bids from generating resources as allocated to SPP-defined reserve zones for each of the 24 hours in the next operating day. The market operator resolves these bids, ensuring that reliability constraints are honored. The results imply that the selected generating resources will be scheduled to be online on the operating day and are binding agreements. A resource offer for spinning reserve means that a supplemental reserve offer cannot be made. Only spin-qualified resources can make offers.

Electrical attributes:

- **Power:** The power capacity reserved and available in the resource in MW for dispatch. Bid curves consist of MW, $/MWh quantities.
- **Energy:** The amount of energy produced or consumed (MWh). Used in settlement.

- **Electrical location:** Operating reserves (including spinning reserves) are procured on a reserve zone basis. A reserve zone is, “A zone containing a specific group of Price Nodes for which a minimum and maximum Operating Reserve requirement is established.”

Timing attributes:

- **Delivery schedule:** The reserve schedule covers each 24-hour period of the upcoming operating day.
- **Delivery schedule notification:** The results for spinning reserve generators are posted at 6 a.m. prior to the operating day.
- **Speed of response:** The resource is to be capable of deploying 100 percent of the cleared spinning reserve quantity within a continuous duration of 60 minutes from when a contingency reserve deployment period is called. That is, “The time period following the issuance of a Contingency Reserve Deployment Instruction within which a Resource has to deploy Contingency Reserve which is set at ten (10) minutes.”

Performance measurement: Revenue quality metering equipment and meter data are supplied by a meter agent at the PNodes (meter settlement location—the nearest transmission system bus associated with an asset) for each participant. Meter data of energy (kWh) are supplied on a 5-minute basis and synchronized with the delivery intervals. These are combined for an hourly settlement. Where 5-minute energy data is not measured, SPP uses state estimator real-time data profiles for the corresponding PNode. Power (in MW, not MWh) is sampled every 5 minutes, and the profile is used to calculate the hourly energy settlement. Spin-qualified resources must provide telemetered output data that can be scanned every 10 seconds.

Comments: The day-ahead spinning reserve market is linked to the other real-time market services. The asset owners bid their resources for dispatch in the upcoming day. If their resource is chosen, the system operator can issue a contingency reserve deployment instruction and directly dispatch the resource.

A.2.2.2 Real-time Spinning Reserve

The real-time spinning reserve market applies only to those resources available from the day-ahead spinning reserve market results.

Description: The real-time market for spinning reserves receives bids from generating resources that have already been cleared in the day-ahead spinning reserve market. They may update their offers up to 30 minutes before the operating hour, and they are binding agreements.

Electrical attributes:

- **Power:** The power capacity reserved and available in the resource is in MW for dispatch.
- **Energy:** The amount of energy produced or consumed (MWh). Used in settlement.
- **Electrical location:** Operating reserves (including spinning reserves) are procured on a reserve zone basis. A reserve zone is, “A zone containing a specific group of Price Nodes for which a minimum and maximum Operating Reserve requirement is established.”

Timing attributes:

- **Delivery schedule:** Offers may be submitted up to 30 minutes prior to each operating hour. The market operator determines the energy dispatch schedule for every 5-minute operating interval in the operating hour.
- **Delivery schedule notification:** The real-time energy market results are not published prior to the start of the operating hour. The settlement is done based on the 5-minute dispatch decisions.
- **Speed of response:** The resource is to be capable of deploying 100 percent of the cleared spinning reserve quantity within a continuous duration of 60 minutes from when a contingency reserve deployment period is called. That is, “The time period following the issuance of a Contingency Reserve Deployment Instruction within which a Resource has to deploy Contingency Reserve which is set at ten (10) minutes.”

Performance measurement: The same performance measurement requirements for the day-ahead spinning reserve market apply to the real-time balancing market.

Comments: The real-time spinning reserve market is linked to the other real-time market services. The system operator can issue a contingency reserve deployment instruction based on the updated real-time bid and directly dispatch the resource.

A.2.2.3 Day-ahead Supplemental Reserve

Supplemental reserve is generation not connected to the system but capable of serving demand within a specified time or interruptible load that can be removed from the system in a specified time. (SPP Glossary)

Description: The day-ahead market for supplemental reserves receives bids from generating resources as allocated to SPP-defined reserve zones for each of the 24 hours of the next operating day. The market operator resolves these bids, ensuring that reliability constraints are honored. The results imply that the selected generating resources will be scheduled to be available during the operating day but not necessarily online (spinning) and are binding agreements.

Electrical attributes:

- **Power:** The power capacity reserved and available in the resource is in MW for dispatch. Bid curves consist of MW, $/MWh quantities.
- **Energy:** The amount of energy produced or consumed (MWh). Used in settlement.
- **Electrical location:** Operating reserves (including supplemental reserves) are procured on a reserve zone basis. A reserve zone is, “A zone containing a specific group of Price Nodes for which a minimum and maximum Operating Reserve requirement is established.”

Timing attributes:

- **Delivery schedule:** The reserve schedule covers each 24-hour period of the upcoming operating day.
- **Delivery schedule notification:** The day-ahead supplemental reserve market cleared results are published at 1 p.m. prior to the start of the operating day.

- **Speed of response:** The supplemental qualified resource is to be capable of deploying 100 percent of the cleared spinning reserve quantity from an offline state within a continuous duration of 60 minutes from when a contingency reserve deployment period is called. That is, “The time period following the issuance of a Contingency Reserve Deployment Instruction within which a Resource has to deploy Contingency Reserve which is set at ten (10) minutes.”

Performance measurement: Revenue quality metering equipment and meter data are supplied by a meter agent at the PNodes (meter settlement location–the nearest transmission system bus associated with an asset) for each participant. Meter data of energy (kWh) is supplied on a 5-minute basis and synchronized with the delivery intervals. These are combined for an hourly settlement. Where 5-minute energy data is not measured, SPP uses state estimator real-time data profiles for the corresponding PNode. Power (in MW, not MWh) is sampled every 5 minutes, and the profile is used to calculate the hourly energy settlement. Spin-qualified resources must provide telemetered output data that can be scanned every 10 seconds.

Comments: The day-ahead supplemental reserve market is linked to the other real-time market services. The asset owners bid their resources for dispatch in the upcoming day. If their resource is chosen, the system operator can issue a contingency reserve deployment instruction and directly dispatch the resource.

A.2.2.4 Real-time Supplemental Reserve

The real-time supplemental reserve market applies only to those resources available from the day-ahead supplemental reserve market results.

Description: The real-time market for supplemental reserves receives bids from generating resources that have already been cleared in the day-ahead supplemental reserve market. They may update their offers up to 30 minutes before the operating hour, and they are binding agreements.

Electrical attributes:

- **Power:** The power capacity reserved and available in the resource is in MW for dispatch.
- **Energy:** The amount of energy produced or consumed (MWh). Used in settlement.
- **Electrical location:** Operating reserves (including supplemental reserves) are procured on a reserve zone basis. A reserve zone is, “A zone containing a specific group of Price Nodes for which a minimum and maximum Operating Reserve requirement is established.”

Timing attributes:

- **Delivery schedule:** Offers may be submitted up to 30 minutes prior to each operating hour. The market operator determines the energy dispatch schedule for every 5-minute operating interval in the operating hour.
- **Delivery schedule notification:** The real-time energy market results are not published prior to the start of the operating hour. The settlement is done based on the 5-minute dispatch decisions.
- **Speed of response:** The supplemental qualified resource is to be capable of deploying 100 percent of the cleared spinning reserve quantity from an offline state within a continuous

duration of 60 minutes from when a contingency reserve deployment period is called. That is, “The time period following the issuance of a Contingency Reserve Deployment Instruction within which a Resource has to deploy Contingency Reserve which is set at ten (10) minutes.”

Performance measurement: The same performance measurement requirements for the day-ahead spinning reserve market apply to the real-time balancing market.

Comments: The real-time supplemental reserve market is linked to the other real-time market services. The system operator can issue a contingency reserve deployment instruction based on the updated real-time bid and directly dispatch the resource.

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