Common Grid Services

Terms and Definitions Workpaper

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# Categorization of Grid Services

An operational objective (Pratt 2020) 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 up or down to follow load changes and manage area control error, and calling on extra generation capacity during an unplanned equipment outage.

A grid service, on the other hand, describes a service provider’s expected performance in response to a service request. The performance expectation should describe what needs to be done at the connection point to the electric system 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 is cleanly separated from the performance expectation of the service provider’s resources.

Existing grid service terms used by system operators can derive from a limited operational objective instead of the more general service to be performed. While an operational objective descriptor might be something like “peak load management,” performance expectations are related to the physical and temporal characteristics of the service. Examples of performance characteristics include providing energy within a given response time for a specified duration. Performance characteristics can be used to quantify the capability of a service provider 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 types of grid service terms and definitions. To clarify these definitions, performance expectations are described, along with potential ways to measure adequate performance to expectation. 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.

## 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 performance expectations 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 specified period.
	+ Reserve Service: A service where the provider agrees to produce or consume energy at an electrical location when called upon over a specified period.
	+ Regulation Service: A service which where the provider increases or decreases real power production or consumption at an electrical location over a specified scheduled period against a predefined real-power base point following a system requestor’s signal. The signal interval is one to several seconds and the associated performance period is of a significantly shorter duration than the typical energy scheduling service performance period.
	+ Frequency Response Service: A service that provides “the response of resources and load to arrest local changes in frequency” (NERC 2021)
	+ Voltage Management Service: A service where the service provider provides voltage support (raise or lower) within a specified upper and lower voltage range at an electrical location over a specified scheduled period.
	+ Emergency Service: A service where the service provider exercises capability to energize without an outside electrical supply or quickly change energization levels during an electric grid emergency.

While the terms and concepts for each grid service should be consistent, the attributes or parameters used in the definitions must accommodate the need for specializing 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.

## Performance Expectations

Each grid service has performance expectations for the resources to fulfill the service. The performance expectation of each service can be described by a unique combination of several service attributes which 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 calculation and/or resource qualification. For any given power market or electrical system, the market operator will maintain Governing Documents that specify how the grid service is implemented in that market.

Examples of grid service attributes are energy produced or consumed over a specified interval, real vs reactive power, response time, service duration, and related measurement requirements. Note, to qualify for participating in a service agreement, service providers 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. Table 1 provides a summary of the performance attributes of grid services discussed in the material that follows.

### Electrical Attributes

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

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

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

### Timing Attributes

The timing of the service attribute describes those 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 when it ends. This can also be calculated by a start time and a duration of operation that determines the end time. In the case of on-call services, such as reserves, the timing attributes start from when the service is called.

**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 by specified times and notify the participants of their scheduled delivery of the service.

**Response time**: Response time is the allowed elapsed time 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 determine the qualification 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.

### 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, sometimes referred to as measurement and verification (M&V), vary depending on the grid service agreement as specialized by each market operator. For example, energy metering requirements need to specify attributes like interval granularity for buffering data that matches the performance period.

## Grid Service Definitions

The following are the common definitions for the types of grid services. The attributes (electrical and timing) are identified as the main places where operating authorities specialize the attributes for each service desired in their jurisdictions.

### Energy Service

**Description**: A service where a resource adjusts supply or demand to make energy available at an electrical Service Location over a specified period. (from 8/4 meeting)

Widergren proposal: A scheduled production or consumption of energy at an electrical Service Location over a specified period.

**Background**

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 manage stressed periods of operation, such as system peak load management.

Wholesale markets arrange for scheduled blocks of energy to match anticipated load. 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 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 for ensuring reliable system operation. The agreements also stipulate the penalties or fees for non-performance (over or under production and consumption).

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

**Performance Expectation**

* **Electrical Attributes**: (from 9/7 meeting)
	+ **Energy**: the quantity of electric energy, expressed as electrical energy units such as megawatt hours or kilowatt hours, over the performance period. The agreement can specify the price for a quantity of energy at different power levels (a curve).
	+ **Power**: the power level of the resource expressed as electrical power units such as megawatts or kilowatts over the performance period.
	+ **Electrical location**: the location where the service is provided to the electric system.
* **Timing Attributes**:
	+ **Delivery schedule:** the start time and end time to perform the service. This can also be specified with a start time and a 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 by specified times and notify the participants of their scheduled delivery of the service.

**Performance Determination**: The Governing Documents specify 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 in 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 measurement point. Also, electrical location may be related to a pricing node or zone for settlement computations.

### Reserve Service

**Description**: A service where a resource commits to make energy available at an electrical Service Location when called upon over a specified period. (from 8/4 meeting)

* Widergren proposal: A service where the provider agrees to produce or consume energy at an electrical location when called upon over a specified period.

**Background**

System operations uses the concept of reserves to address unplanned situations that regularly occur. These include contingency response 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 generating 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 upon 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.

System operators use spinning (fast responding) and non-spinning (slower responding) reserves to maintain reliable balance of production and consumption of energy in the system. Wholesale market participants negotiate scheduled blocks of energy reserves to support this need. These are done in ISO/RTO markets, such as those run by independent market operators. In the wholesale 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 for ensuring reliable system operation. Besides establishing a fee for being available (on reserve), the governing documents also stipulate the 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 of their resources from the system operator during the operating period.

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 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.

**Performance Expectation**

* **Electrical Attributes**:
	+ **Energy**: the quantity of electric energy, expressed as electrical energy units such as megawatt hours or kilowatt hours, held in reserve which could be called upon over the performance period. The agreement may specify the price for a quantity of energy at different power levels (a curve) that will be available when called upon.
	+ **Power**: the power level of the resource expressed as electrical power units such as megawatts or kilowatts over the performance period.
	+ **Electrical location**: the location or region where the service is provided to 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 perform the service. This maay also be specified with a start time and a duration. The Governing Documents specify the periodicity of the scheduling agreement (e.g., daily, hourly, 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 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 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 reserved power level quantity per unit time, and/or an agreed quantity over an interval.

**Performance Determination**: The reserve service Governing Documents specify how performance is measured. Energy interval metering may be combined with time stamped power measurements.

### Regulation Service

**Description**: The regulation service 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 one to several seconds and the associated performance period is of a significantly shorter duration than the typical energy schedule service performance period.

**Background**

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, i.e., once frequency drop has been arrested by primary control (in seconds), regulation service corrects the deviation (1-10 minutes) to the target value.

Historically, regulation service has been provided by generating units. Generators often provide regulation service in conjunction with energy scheduling service. However, single, large-load, storage, and aggregated demand-side resources have been 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. 2020).

The resources providing regulation service must be able to respond to regulation signals sent by the system operator periodically - typically 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. In some RTO/ISO markets in the U.S., separate products are offered for upward vs. 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.

Mileage is a multiplier in the compensation calculation in some markets. In addition, the mileage contained in service request signals can affect a resource’s performance score.

**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.
	+ **Power mileage**: the amount of power level up and down movement over the service period. It is the sum of the up and down real power level changes.
	+ **Service 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 time and end time to perform the service. This may 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 by 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 Determination**: The regulation service Governing Documents specify how real power increase or decrease 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, for the regulation service 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 the regulation signal and bounded 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 RTO/ISO; however, it is typically calculated for each real-time market interval (e.g., 5-minute or 15-minute) 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 RTO/ISOs (e.g., CAISO and 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, T. 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. 2020).

### Frequency Response Service

**Description**: The frequency response service is “the response of resources and load to arrest local changes in frequency” (NERC 2021).

**Performance Expectation**: TBD

**Performance Measurement**: TBD

**Example Service Requestor Operational Objectives**: TBD

**Origin of Service Definition**: TBD

### Voltage Management Service

**Description**: The voltage management service provides voltage support (raise or lower) within a specified upper and lower voltage range at an electrical location over a specified scheduled period.

**Performance Expectation**: TBD

**Performance Measurement**: TBD

**Example Service Requestor Operational Objectives**: TBD.

**Origin of Service Definition**: TBD

### Emergency Service

**Description**: The emergency service uses the capability of provider resources to energize without an outside electrical supply or quickly change energization levels during an electric grid emergency.

**Performance Expectation**: TBD

**Performance Measurement**: TBD

**Example Service Requestor Operational Objectives**: TBD

**Origin of Service Definition**: TBD

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# Appendix A: Existing Grid Services Mapping

This appendix reviews common grid services from several system operators. 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.

## Energy Schedule Service Mapping

### CAISO Energy Services

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

#### CAISO 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.”

(<http://www.caiso.com/market/Pages/MarketProcesses.aspx>)

**Description**: The day-ahead scheduled energy market receives bids for energy at an electric service 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. (Section 11 of <http://www.caiso.com/Pages/documentsbygroup.aspx?GroupID=E4ACC97A-173F-44CE-94CD-E33FA7EC5DF1>)

**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 1pm prior to the start of the trading day.

**Performance determination**: 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 with 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. (Section 10 – Metering <http://www.caiso.com/Documents/Section10-Metering-asof-Jan1-2021.pdf>)

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

#### CAISO 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.” (<http://www.caiso.com/market/Pages/MarketProcesses.aspx>)

**Description**: The real-time scheduled energy market receives bids for energy at an electric service 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. (<http://www.caiso.com/Documents/Section34-Real-TimeMarket-asof-Jun1-2022.pdf>)

**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 ~45 minutes prior to the start of the trading hour.

**Performance determination**: 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 not real-time scheduled energy.

### SPP – Energy Markets

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

Reference: “Market Protocols SPP Integrated Marketplace,” Revision 89.1 (<https://www.spp.org/spp-documents-filings/?id=18162>)

#### SPP 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 electric service location for each of the 24 hours in 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 1pm prior to the start of the operating day.

**Performance determination**: 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.

#### SPP 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 electric service 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 determination**: 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 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 direct control result though the resource was selected for control by a service-oriented market.

### 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 representing end-use resources to participate in energy markets and “…receive payments for demand reductions they make”.

#### 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.”

<https://www.pjm.com/~/media/documents/manuals/m11.ashx>

**Description**: Day-ahead bids of energy are submitted for each of the 24 hours in the upcoming operating day. The bids are processed at 11am and results are posted by 1:30pm the day prior to the operating day of the resource. There is a re-bid period between the posted results and 2:15pm. The market 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 1:30pm. A rebidding period takes place and results are posted at 2:15pm 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”. (<https://pjm.com/-/media/documents/manuals/m28.ashx>)

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

#### PJM Real-Time Energy Market

The PJM intraday balancing market clearing prices are calculated every 5 minutes and 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.” (<https://learn.pjm.com/three-priorities/buying-and-selling-energy/energy-markets>)

**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 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.” (<https://pjm.com/-/media/documents/manuals/m11.ashx>, pg. 23)

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

#### PJM Day-Ahead Demand Response Market

Through a curtailment service provider (CSP), this program allows 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 is 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.” (<https://learn.pjm.com/-/media/about-pjm/newsroom/fact-sheets/demand-response-fact-sheet.ashx>)

**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. 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 1:30pm. A rebidding period takes place and final results are posted at 2:15pm prior to the start of the operating day.

**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 interval. (<https://www.pjm.com/directory/manuals/m11/index.html#Sections/10.4%20Demand%20Resource%20Metering%20and%20Settlement%20Data%20Requirements.html>)

**Comments**: CSP’s aggregate the participating customers demand response 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 upon the change of energy consumption from a baseline load shape.

#### PJM Real-Time Demand Response Market

Through a CSP, this program allows retail customer 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 4:30PM the previous day up to 65 minutes before the operating hour according to 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.” (<https://www.pjm.com/directory/manuals/m11/index.html#Sections/101%20Overview%20of%20Demand%20Resource%20Participation.html>)

**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. 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 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. (<https://www.pjm.com/directory/manuals/m11/index.html#Sections/10.4%20Demand%20Resource%20Metering%20and%20Settlement%20Data%20Requirements.html>)

**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 upon the change of energy consumption from a baseline load shape. The compensation incorporates their day-ahead commitment and deviation based on the real-time market price.

## Reserve Service Mapping

### 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.” <http://www.caiso.com/market/Pages/MarketProcesses.aspx>

Certified loads are also able to supply spinning and non-spinning reserve 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 the energy schedule service.

#### CAISO 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). (“Business Practice Manual for Market Instruments, v71,” 29 June 2022, <https://bpmcm.caiso.com/Pages/BPMDetails.aspx?BPM=Market%20Instruments>)

**Description**: The day-ahead markets for spinning and non-spinning reserves receives bids for a power capacity at an electric service 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.” (Section 8.3.3, California Independent System Operator Corporation, Fifth Replacement FERC Electric Tariff, Effective as of June 17, 2022, <http://www.caiso.com/Documents/Conformed-Tariff-as-of-Jun17-2022.pdf> )

**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 1pm 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.” (Section 8.4.2, California Independent System Operator Corporation, Fifth Replacement FERC Electric Tariff, Effective as of June 17, 2022, <http://www.caiso.com/Documents/Conformed-Tariff-as-of-Jun17-2022.pdf>) and be maintainable for a continuous duration of 30 minutes.

**Performance determination**: Scheduling Coordinators must ensure that Settlement Quality Meter Data submitted to the CAISO is in intervals of five (5) minutes for Loads and Generators providing Ancillary Services (includes reserves). (Source: California Independent System Operator Corporation Fifth Replacement FERC Electric Tariff January 1, 2021, Section 10 Services, <http://www.caiso.com/Documents/Section10-Metering-asof-Jan1-2021.pdf> .

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

#### CAISO 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 schedule 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 a power capacity at an electric service 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.” (Section 8.3.3, California Independent System Operator Corporation, Fifth Replacement FERC Electric Tariff, Effective as of June 17, 2022, <http://www.caiso.com/Documents/Conformed-Tariff-as-of-Jun17-2022.pdf> )

**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 ~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.” (Section 8.4.2, California Independent System Operator Corporation, Fifth Replacement FERC Electric Tariff, Effective as of June 17, 2022, <http://www.caiso.com/Documents/Conformed-Tariff-as-of-Jun17-2022.pdf>) and be maintainable for a continuous duration of 30 minutes.

**Performance determination**: Scheduling Coordinators must ensure that Settlement Quality Meter Data submitted to the CAISO is in intervals of five (5) minutes for Loads and Generators providing Ancillary Services (includes reserves). (Source: California Independent System Operator Corporation Fifth Replacement FERC Electric Tariff January 1, 2021, Section 10 Services, <http://www.caiso.com/Documents/Section10-Metering-asof-Jan1-2021.pdf> .

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

### 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 SPP reliable operations; however, this is a required reserve operating level to which other procured services contribute. It is not procured separately.

Reference: “Market Protocols SPP Integrated Marketplace,” Revision 89.1 (<https://www.spp.org/spp-documents-filings/?id=18162>)

#### SPP 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 on-line 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 (includes 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 6am prior to the operating day.
* **Speed of response**: the resource is to be capable of deploying 100% 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 determination**: 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.

#### SPP 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 who 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 are binding agreements.

**Electrical attributes**:

* **Power**: The power capacity reserved and available in the resource in MW for dispatch.
* **Energy**: The amount of energy produced or consumed (MWh). Used in settlement.
* **Electrical location**: Operating reserves (includes 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% 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 determination**: The same performance determination 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 upon the updated real-time bid and directly dispatch the resource.

#### SPP 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 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 available the operating day but not necessarily online (spinning) and are binding agreements.

**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 (includes 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 1pm prior to the start of the operating day.
* **Speed of response**: The supplemental qualified resource is to be capable of deploying 100% of the cleared spinning reserve quantity from an off-line 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 determination**: 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 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.

#### SPP 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 who 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 are binding agreements.

**Electrical attributes**:

* **Power**: The power capacity reserved and available in the resource in MW for dispatch.
* **Energy**: The amount of energy produced or consumed (MWh). Used in settlement.
* **Electrical location**: Operating reserves (includes 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% of the cleared spinning reserve quantity from an off-line 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 determination**: The same performance determination 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 upon the updated real-time bid and directly dispatch the resource.

######

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