The Role of Electricity Markets and Market Design in Integrating Solar Generation

Solar Integration Series. 2 of 3

Renewables & Grid Variability

Variable generation (VG) technologies such as solar, wind, and hydro increase the level of variability and uncertainty in power grid operations; characteristics that are inherent of electric power systems. In addition to the unpredictable nature of demand, power plants and transmission lines can unexpectedly drop out of service. Although adding VG may increase variability and uncertainty, it is necessary only to balance demand and supply in the aggregate. Individual changes in VG do not need to be matched one-for-one by changes in conventional generation.

To manage these issues and maintain reliability, grid operators and planners use multiple techniques, such as **load forecasting, scheduling** and **dispatching** generating power plans, and employing different types of generation and demand-based **operating reserves**. Grid operators rely on **ancillary services** and **reserves** to maintain electric reliability and to follow variations in generation and demand that happen faster than energy markets can follow. Ancillary services and reserves may be provided by both generation and **demand response** (i.e., customers reducing or increasing demand in response to instructions from grid operators). This fact sheet will review some of the market design options that aid in integrating VG such as solar.

Domestic Electricity Operations

There are over 130 **balancing authorities**, or control areas, in the United States. Each is responsible for integrating resource plans, maintaining **load-interchange-generation** balance within a **Balancing Authority Area** (sometimes referred to as a balancing area, BA), and ensuring consistent frequency. To maintain electric reliability, the Federal Energy Regulatory Commission (FERC) requires that grid operators incorporate certain ancillary services in their tariffs, including:

- *Scheduling*, ***system control***, *and dispatch*, whereby the system operator controls the generation, transmission, and demand response to assure that generation and load are continuously and instantaneously in balance and the transmission system is secure and reliable.

- ***Reactive supply*** *and* ***voltage control*** *from generation sources* to help maintain voltages throughout the transmission system.

- *Regulation and* ***frequency response*** to follow moment-to-moment variations in electricity demand or scheduled generation delivery to maintain frequency at 60 cycles per second (60 Hz) and to control flows on the transmission system. [1]

- ***Energy imbalance service*** for correcting any hourly deviations between advance generation schedules and actual delivery.

- ***Spinning reserve, non-spinning reserve***, *and* ***supplemental reserve*** to maintain reliability in case of an unplanned event such as a generation or transmission outage. Spinning reserve is generation and demand response that is on-line, begins to respond immediately, and can fully respond within 10 minutes. Non-spinning and supplemental reserve is generation and demand response that can be off-line, but can respond within 30 or 10 minutes respectively.

Regional Transmission Organizations and Independent System Operators

There are seven **regional transmission organizations** (RTOs) and **independent system operators** (ISOs) that manage parts of the electric grid in the United States. They operate in the Northeast and Mid-Atlantic, Midwest, South-central regions, most of California (the only one in the West: California Independent System Operator, or CAISO), New York, and Texas. Most RTOs/ISOs administer wholesale energy markets with sub-hourly (5 minute) scheduling and dispatch and location-specific market prices for each marginal unit of electricity that is demanded or generated, also known as **locational marginal pricing** (LMP). For the Southeast and the non-CAISO portions of the Western Interconnection, the electric grid is managed by transmission owners with hourly schedules and dispatch. These entities rely mostly, if not entirely, on bilateral transactions between market participants. Table 1 provides more detail.

Grid Operating Timeframes

Grid operations can be divided into three timeframes: regulation, load following, and unit commitment, as described below and illustrated in Figure 1.

- *Regulation* provides the system operator with balancing resources that operate faster than the sub-hourly energy market or the economic dispatch cycle and typically ranges from several seconds to 5 minutes. [2] Generation (and now demand response in some regions) automatically responds to minute-by-minute deviations in load and generation in response to signals from grid operators. Changes in load and generation during this timeframe must be met

[1] Electricity in the United States is delivered to customers using alternating current that alternates direction, as opposed to direct current where the flow of electricity is only in one direction. Frequency represents the number of cycles per second; one complete cycle is defined as one Hertz (Hz). Electricity is delivered at 60 Hertz (Hz) in the United States, or equivalently 60 cycles per second.
[2] There are some differences in the precise time-frame boundaries and ancillary service names in different balancing and market areas.

Table 1. Basic Features of Markets and Dispatch in RTO's and non-RTO's

Grid Operator	Energy Market Structure	Dispatch Frequency	Ancillary Services Market
California ISO (CAISO)	RT and DA LMP-based energy markets	5 minutes	RT, DA
Electric Reliability Council of Texas (ERCOT)	Zonal market; RT and DA LMP-based energy market in 2010/11	5 minutes (planned in Dec 2010)	RT, DA
ISO New England (ISO-NE)	RT and DA LMP-based energy markets	5 minutes	RT, DA
Midwest ISO (MISO)	RT and DA LMP-based energy markets	5 minutes	RT, DA
New York ISO (NYISO)	RT and DA LMP-based energy markets	5 minutes	RT, DA
PJM Interconnection	RT and DA LMP-based energy markets	5 minutes	RT, DA
Southwest Power Pool (SPP)	DA bilateral energy market and RT LMP-based energy imbalance market. RT and DA LMP-based energy market in 2013/14	DA bilateral market; imbalance market dispatched every 5 minutes	
West (outside CA); the Southeast	Bilateral transactions between market participants	Hourly	

RT = Real-Time, DA = Day-Ahead, LMP = locational marginal price of electricity. Source: Based on UWIG (2009) and Milligan and Kirby (2010).

through generation and demand response that is on-line, grid-synchronized, and under automated control by the grid operator. This includes governor response and load frequency control components. Non-market areas of the Western Interconnection have hourly block schedules; therefore all within-hour variability must be met by regulating units. Schedule changes at the top of the hour require a significant regulation to counter the abrupt changes.

- *Load following* generally ranges from 5–15 minutes to a few hours. Demand response and generating units that have been previously committed, or can start generating power quickly, can provide this service subject to operating constraints on the generator. Load following typically occurs when generators respond to energy market price signals while regulation occurs using dedicated generating capacity.
- *Unit commitment* usually encompasses a period of several hours to several days, and involves the scheduling and committing of generating plants to meet expected electric demand. Large thermal generators (i.e. coal plants) can require a day or more to be brought on-line. Gas-fired generation typically requires less notification time to be ready to operate.

Market Design

There are two key market design characteristics that can help ease the integration of variable generation onto the grid: large balancing areas and sub-hourly markets.

Large Balancing Areas

In general, larger BAs will have an increased ability to integrate more solar power. This occurs for two primary reasons. Large BAs can take advantage of the principles of non-coincidence: the variability of loads and solar generation increases with size, but at a decreasing rate. Secondly, larger BAs have a larger suite of generation that can help manage variability. Large BAs are described in fact sheet #3 of the Solar Integration Series.

Sub-Hourly Markets

In aggregate, the mix of conventional resources provides sufficient flexibility to respond to the daily electric demands of consumers. **Baseload generating plants** are designed to run continuously and at relatively constant output. **Intermediate** (power plants that serve both high- and mid-demand periods) and **peaking plants** (power plants that almost entirely serve periods of high demand) are designed to run at different generating points and to cycle on and off. Because these plants have relatively higher operating costs than baseload generating plants, the market price for electricity varies throughout the day as different plants are **on the margin**. Conventional generating units have significant maneuvering capability to serve the varying load; however, increasing penetrations of solar and wind will increase the need for this capability.

Sub-hourly energy markets (and sub-hourly economic dispatch of generation in regions without markets) allow access to the maneuvering capability of conventional generators. Regions where generators can only change schedules hourly do not have full access to the physical capability of conventional generators, but this is a consequence of regional market rules, not generator capabilities. The RTOs/ISOs all operate relatively fast sub-hourly markets, where generating units hold their output at a specific level for each 5-minute dispatch period. To contrast, some areas without RTOs/ISOs use hourly dispatch, with generators required to follow flat hourly schedules set one hour or more in advance. This constrains the ability of the system operator to manage variability.

Sub-hourly markets provide economic signals to generators and demand response, making it profitable for conventional generators and responsive loads to respond to fluctuations in load and variable generation, thereby utilizing the flexibility of the entire conventional generation fleet.[3] Load following is a by-product of sub-hourly markets, as generators respond to the price signals and adjust their output accordingly. With high penetrations of solar and wind, there may be a need for an additional ancillary service for supplemental ramping or load following when the generation fleet providing energy can't respond fast enough.

Within each market/dispatch interval, changes in load or generation are met with generating units on regulation service. In sub-hourly markets, regulation units are required to meet the generally small changes in load only over the sub-hourly 5-minute dispatch interval. In areas that use hourly dispatch, system operators must rely on the relatively more expensive regulation service for an hour at a time or longer. Within-hour changes in load and generation can be significant, especially with higher penetrations of variable solar and wind generation. The timing of solar and wind variability occurs more in the sub-hourly to multiple-hour timeframe, not in the minute-to-minute timeframe for which regulation service is intended. Sub-hourly dispatch leads to lower overall system operating costs even without solar and wind generation.

Shorter market periods or schedules provide better access to generator flexibility than longer market periods; more grid operators are transitioning to sub-hourly markets. After SPP implements 5-minute markets in 2013-2014, nearly two-thirds of U.S. electricity demand will be found in regions with 5-minute markets. That said, the California ISO is the only area in the West with sub-hourly markets, yet the West is the region with the largest solar resource potential. Greater cooperation among balancing areas, such as sharing of North American Electric Reliability Corporation (NERC) reliability and FERC ancillary service requirements and moving from hourly scheduling of generation resources to sub-hourly scheduling, will help efficiently integrate solar resources.

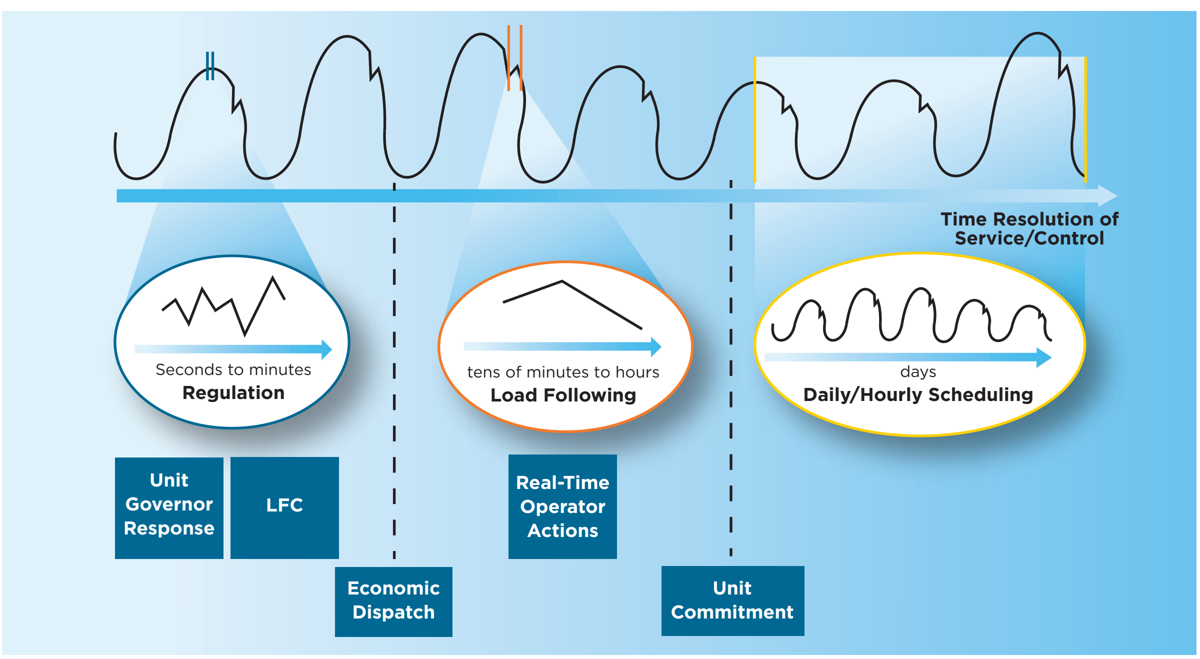

Figure 1. System operating timeframes and control mechanisms

[3] Some responsive loads increasingly provide flexibility in the 5 minute time frame as well as providing ancillary services.

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