**Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation (**[**link**](https://www.nrel.gov/docs/fy14osti/61765.pdf)**)**

**Executive Summary**

Variable generation (VG) such as wind and solar PV power have a few unique characteristics that differentiate these sources from other types of energy which have supplied the majority of electricity in the past:

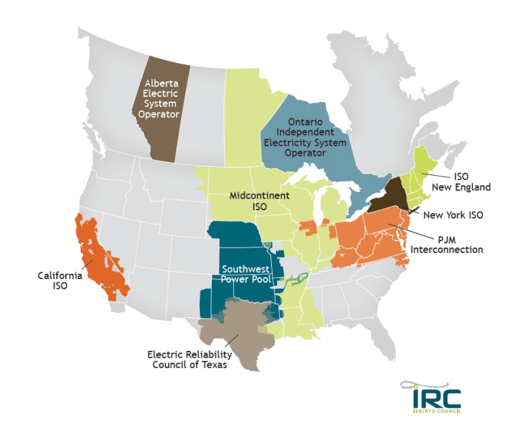
* VG increases the net load (load minus VG) because the available power at any given time changes with the source (wind speed or solar irradiance).
* VG increases the uncertainty of the net load because available power is imperfectly predicted at all future time horizons
* Despite its significant fixed capital costs, VG has near-zero or zero variable production codes because of the free source of fuel; when subsidies exist, the variable cost can actually be negative
* VG has unique daily and seasonal patterns which may not correspond to times of high electricity demand, thus creating a risk of insufficient generation

These characteristics present challenges in planning and operating the power system, and can influence the performance and outcomes from electricity markets. This paper provides a review of wholesale electricity markets and how the introduction of VT has impacted them. Specifically, there are two issues related to how these markets are designed: *revenue sufficiency* *for long-term reliability* and *incentivizing flexibility in the short-term*. Meaning – is there a sufficient amount of revenue to be gained in the long-term by building the infrastructure needed for VG energy sources, and how can those markets encourage VG adoption by rewarding the most efficient use of VG sources.

Nine wholesale electricity operators – referred to as *independent system operator* (ISO) or *regional transmission organization* (RTO) – account for two-thirds of US electricity consumption.

Although there are variations in the rules for each ISO, the common market design framework is there are two places to buy energy – one in the day-ahead market (DAM) and the other in the real-time markets (RTM). These markets include *location marginal pricing* (LMP), *financial transmission rights* (FTR), as well as ancillary services which have *spinning* and *non-spinning contingency reserve*, as well as *regulating reserve*.

Additionally, so-called market mitigation procedures exist to protect against certain player(s) distorting the market to cause bids to not reflect the true variable costs, thus having a significant impact on market outcomes and competition.

Finally, *forward capacity markets* ensure long-term reliability of electricity generation so there is enough capacity to meet future demand

That’s a lot of vocab, so here are the definitions of each one of those terms:

**Location marginal pricing (LMP):** LMP allows prices to reflect the differences in locations and the associated variation in patterns of load, generation and the physical limits of the transmission system

**Financial transmission rights (FTR):** Contracts that lock in the price of energy to be bought/sold before the actual time of transmission/consumption. These financial instruments hedge against locational differences in energy prices.

**Spinning contingency reserve:** Idle capacity connected to the energy system to ensure reliable operations in the case of outages.

**Non-spinning contingency reserve:** Additional capacity that is not currently connected to the nergy system but can be brought online after a short delay (~10 minutes)

**Regulating reserve:** Provides an automatic response from the electricity generators immediately after a loss of supply. The generators automatically slow down through a governor because of the drop in supply, and the regulating reserve speeds up the generator to continue electricity output at a normal rate

**Forward capacity markets:** These capacity markets ensure that there is enough revenue available for electricity generators so they can recover the total costs of building and operating large facilities

Each one of these market products involve auctions by the market operator so that market participants can buy or sell energy at various prices to be delivered/sent at different times. Each element revolves around the reliability of the system as a whole along with the principles of economics regarding operation and competition. Additionally, these are always changing as new technologies are brought to the market; VG is no different in that regard. This report deals with how the existing market mechanisms can allow for the integration of VG in an efficient and reliable manner.

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Variability and uncertainty have been a problem that electricity generators have dealt with for quite some time. Some of the tools to reliably and efficiently manage these historical challenges include *operating reserve requirements*, *network transmission service*, and *frequent system redispatch*. However, these solutions were developed for problems like forced outages which are somewhat different from the issues posed from VG.

Newer tools to mitigate variability and uncertainty challenges have also been proposed, including *advanced scheduling models*, *operational VG forecasting*, *balancing authority area cooperation*, *intelligent operating reserve requirements*, along with new of changing ancillary service markets.

**Operating reserve requirements:** Minimum amount of energy available to be used in emergencies; usually is a certain percentage of peak load and can be spun up nearly instantaneously (< 10 minutes)

**Network transmission service:** Customers can receive energy from multiple sources, NTS allows customers to pay for that energy from different sources under one transmission contract. The customer pays for use of the transmission system as opposed to paying multiple sources depending on how much energy they use from each source.

**Frequent system redispatch:** Although the market dynamics described above exist to meet the planned load on the energy system, these plans can change depending on a variety of factors. Frequent system redispatch allows transmission system operators to request that power plants adjust their output in order to avoid or eliminate congestion. By lowering the output of one or more power plans while increasing the output of one or more others, it is possible to relieve congesting while keeping the total power on the grid close to constant.

**Advanced scheduling models:** Smart homes can adjust their energy usage depending on the price of energy now and in the near-term. This reduces overall peak power usage on the grid since such models use more energy at off-peak periods

**Operational VG forecasting:** Accurately predict the available wind and solar energy that will be able to be generated at various timescales.

**Balancing authority area cooperation:** Various regions experience different levels of available solar/wind power at different points in time. Increased coordination between the power system operators that manage energy within geographic boundaries would allow energy to flow from one area to another more efficiently.

**Intelligent operation reserve requirements:** Instead of a static operation reserve requirement, this can be adjusted depending on load and forecast

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Initial evidence suggests that high penetrations of VG will require increased levels of flexibility in order to manage increased net load variability and uncertainty. If firms are expected to be willing to provide services based on VG, the market needs to incentivize them to take that risk. It is unclear whether or not the current market designs have the right incentives to encourage market players to adopt solutions built around VG.

Metrics around *resource adequacy* (electricity providers have more than enough capacity to fulfill peak loads) and *revenue sufficiency* (the expected revenue from selling energy justifies the cost for electricity providers to build the infrastructure around providing energy) have been developed long before increasing penetration of VG were feasible. Thus, these three factors – flexibility, resource adequacy and revenue sufficiency – need to be monitored to determine if the original market designs produce inefficiencies, reduced competition and/or reliability degradation.

*Impacts on the Energy Market*

There are certain market dynamics that have been observed with increasing levels of VG:

* VG can reduce average locational marginal pricing because of its low, zero, or negative operating cost. This affects the revenue stream of other sources of enegery because VG almost always is at the bottom of the [bid stack](https://energynews.us/2013/06/17/midwest/explainer-how-capacity-markets-work/), meaning it is offered at the lowest price and therefore is bought first relative to other sources
* VG can also cause LMP to be more volatile from one time period to another because of its increased variability. Also, VG tends to cause a larger disparity between the day-ahead market prices and real-time market prices because of the increased uncertainty
* In conjunction with increased variability and uncertainty, VG can also increase the need for flexibility in the system. When there isn’t a way to incentivize for this flexibility, reliability or distortion of the market can occur

*Impacts on the Ancillary Service Market*

Increasing VG penetration also impact ancillary service markets:

* Operating reserved typically better manages variability and uncertainty; with increasing levels of VG (and therefore increasing system variability and uncertainty), more operating reserves may be needed.
* Again due to increased variability and uncertainty, reserve needs may differ through time and could change between DAM and RTM
* VG can displace traditional power plants that were designed to optimize on *frequency response* so that the demand and supply of energy is (more or less) in constant equilibrium ([around 50Hz in the UK](https://www.kiwipowered.com/solutions/demand-response/frequency-response/)). Without the technology to provide sufficient frequency response, additional actions in the market are needed to meet the required frequency response thresholds
* Again due to variability and uncertainty, VG can lead to ancillary service requirements being unmet, which can cause more price spikes and higher cost to consumers and revenue for generators
* It is important that flexibility is incentivized in the ancillary service markets

*Impacts on the Forward Capacity Market*

Additionally, increasing penetration of VG can impact the forward capacity market in a few ways:

* The reduction in LMP from conventional resources will result in reduced revenues in the energy market, which may lead energy generators to become a [capacity-based resources as opposed to energy-based resources](https://resource-solutions.org/wp-content/uploads/2015/08/IntPolicy-CapacityvsEnergyBased.pdf). In order for these conventional resources to remain in the market, they may have to rely on forward capacity markets (or revenues from other markets besides the main energy market). This is the revenue-sufficiency question, and
* To maintain resource adequacy, VG may require more flexible forms of generating electricity
* “Must-offer” prices – price floors that are designed to limit market power, may increase the risk that a generator that builds renewable capacity to satisfy a state-mandated renewable energy standard may not be able to sell energy at that minimum price

*Impacts on Financial Transmission Rights markets*

There are also some impacts on the financial transmission rights (FTR) part of the market, although this is not a focus of this report

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The above summary lead to two questions which will be the focus of the report:

*Do the energy plus ancillary service markets provide the revenue to cover all costs?*

*Does the current market structure ensure that there are resources available which balance variability and uncertainty inherent in VG?*

**Revenue Sufficient and Long-Term Reliability**

To meet long-term resource adequacy needs, planners use a variety of metrics to understand how much capacity is required and how each source of energy in the system can contribute to meeting that requirement.

One such metric is the *planning reserve margin*, which is a metric that determines the generation capacity that needs to be installed in order to meet future demand; generally speaking it is 12-15% above peak demand. However, when planning reserve margin is used in isolation from other metrics regarding reliability, a lot of information can be lost when making decisions about efficient resource adequacy. Additionally, the metric weighs forced outage probabilities more heavily than availability based on weather, which diminishes the metric’s usefulness in regards to VG sources.

When VG is a large part of the resource mix, *loss of load expectation* and *effective load-carrying capability (ELCC)* are two metrics that are more appropriate, especially when they’re calculated on an hourly instead of daily basis.

**Loss of load expectation:** The number of hours per year in which it is statistically expected that supply will not meet demand

**Effective load-carrying capability /capacity (ELCC):** The amount of additional load a system can be increased while maintaining reliability

ELCC is useful in contexts with greater VG since it can show how each resource contributes to long-term resource adequacy and therefore provides information about how many of each resource the market should allow for recovery of capital costs. The seasonal/daily patterns of wind and solar energy generation dictate their ELCC as opposed to forced outage rates associated with these VG sources.

Different areas have adopted various methods taken from differing time periods to calculate ELCC for wind and solar. A few examples are listed in the table below. *Average capacity factor* – The average power generated divided by peak load – is another metric that other ISO’s use to determine the ELCC of VG.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Regional Transmission Organization** | **Season** | **Months** | **Time** | **Term** | **Method** |
| ISO-NE | Summer | June-Sept | 1-6pm | 5 year rolling | Median net generation |
| ISO-NE | Winter | Oct-May | 5-7pm | 5 year rolling | Median net generation |
| NYISO-Existing | Summer | June-August | 2-6pm | Previous year | Average capacity factor |
| NYISO-Existing | Winter | Dec-Feb | 4-8pm | Previous year | Average capacity factor |

There is the concept of the *missing money issue* in power systems, which reflects the idea that prices for energy may not fully reflect the value of investment in the resources needed to meet customers’ expectations for reliable electric service. The missing money issue is widely-debated in the industry, and results from the existence of price caps to consumers, inadequate scarcity pricing, and inability for consumers to purchase different levels of reliability due to the interconnected nature of the power system. With increased penetrations of VG, energy prices are likely to be reduced, which can exacerbate the missing-money issue and make it more difficult for generators to achieve revenue sufficiency.

VG increases the need for new attributes of the power system, namely that sources that provide energy need to have increased flexibility to successfully integrate VG into the bulk power system. This question pertains to long-term reliability – how much and what type of generation or in which to invest. This is related, but different, from the question posed above about *incentivizing* flexibility in operations which is focused on providing flexibility in the short-term. Both of these questions are related to flexibility, however, and incentivizing the development of sufficient flexible resources in order to utilize that flexible asset in market operations.

Flexibility, similar to the provision of energy itself, can have both fixed and variable operating costs. Careful evaluation of both short- and long-term markets should take place to determine whether incentives are in place for flexibility to be a part of new installed capacity, existing resources through modifications, and in system operations when needed.

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It should be emphasized that one of the reasons why all of these markets exist is because the revenue generated from the main energy market (i.e., the *marginal cost* of energy that consumers pay) does not necessarily recover costs incurred (both fixed to create the infrastructure and variable to extract energy on an ongoing basis); in other words, there isn’t sufficient revenue for market participants to make money. Often times, VG sources can recover the marginal cost since variable costs are so low; other sources need to have revenue from marginal costs augmented in order for it to make sense The two main existing mechanisms for providing revenue sufficiency are *scarcity pricing* and forward capacity markets.

**Scarcity pricing:** Economic term referring the increase in prices as demand edges close to supply limits

Forward capacity markets have been established in a few, but not all, of the ISOs – specifically the BYISO, ISO-NE, and PJM. These markets are in place to ensure a steadier revenue supply for investors in new capacity which will be needed and implemented in the future, and prices are set depending on the ISO’s current capacity and its predicted capacity at a future date (prices vary depending on the time horizon). Price caps and floors can be enforced to make sure the prices guaranteed in such markets are within a particular range.

In other ISOs, there are changes (or proposed changes) to design of the market to address some of the issues with resource adequacy and revenue sufficiency. In ERCOT – which has an energy-only market – changes have been made to the way the price of energy is calculated. First, the price cap is gradually being increased to $9,000/MWh. Also, an operating reserve demand curve is implemented in the real-time market so the price of operating reserve is dependent on the hourly probability that supply will not meet demand (aka probability of lost load). Both have the effect of increased energy prices, which will allow for additional revenue to help recover fixed costs.

In CAISO, a proposal will require that generators have sufficient flexible capacity to meet forecasted load, in addition to the existing requirements around resource capacity. This would be the first US market to include flexibility requirements to resource adequacy planning.

**Incentivizing Flexibility in System Operations**

There are alternate definitions of “flexibility in the power system”, but one of the more common ones in the literature is found below:

*The ability of a resource, whether any component or collection of components of the power system, to respond to the known and unknown changes of power system conditions at various operational timescales*

Different types of resource excel at different forms of flexibility, and have different impacts on the cost when providing that flexibility. If providing flexibility increases the cost of fuel, wear-and-tear, or any other component of the price, then it is important that the market incentivizes investing in this additional cost.

There are a few reasons why increased flexibility is paramount with VG:

* VG output varies at different timescales,
* VG output cannot be predicted perfect in advance, and so any generation based off VG must be able to quickly respond to the actual output of VG being different than what was predicted
* VG is constrained by location, and peak VG output does not correspond with peak load

When VG is integrated into the power system, there is a greater demand for flexibility from non-VG resources as well, therefore requiring flexibility from non-VG sources. There are existing market dynamics which meet these needs, such as 5-minute scheduling and ancillary service markets, but there might be new markets or augmentations to existing markets which more efficiently meet the burgeoning need for flexibility of energy sources. Some of the existing mechanisms in the market include *5-minute scheduling, 5-minute settlements, centralized scheduling and pricing, ancillary-service markets, make-whole payments,* and *day-ahead profit guarantees.*

**Five-minute scheduling / settlements:** Generators had been scheduled on a 5-minute basis, but the settlement process determining the price paid for energy was operated on a longer timescale, usually 30 or 60-minutes; this was a product of the technology available at the time this system was implemented in the late 90s. This lead to inefficiency because scheduling occurred on one timescale, while pricing was determined on another. The pricing anomaly could lead to inappropriate investments whereby generators aren’t incentivized to increase flexibility. Improvements in technology eliminated these original limitations, and ISOs can now implement scheduling and settlement on the same, five-minute timescale.

**Centralized scheduling:** ISOs determine which resources are dispatched, as opposed to *self-scheduling* where the market participant commits to the amount of energy it will provide.

**Make-whole payments:** Provides additional revenue to generators when costs are higher than revenues at a certain timescale.

**Day-ahead profit guarantee:** When profits earned in the day-ahead market are larger than the profits to be gained by participating in the real-time market, day-ahead profit guarantees ensure that generators maintain the level of profit from DAM so they participate in actions that benefit the system in real-time.

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New market mechanisms have also been proposed to incentivize flexibility in system operations. Some of these include generation from non-traditional sources like demand response, energy storage and VG to provide flexibility.

Other ancillary service designs include *pay-for-performance* and *frequency response markets*.

**Pay-for-performance:** Programs that track and reward energy savings as they occur. A more common approach is to estimate savings in advance of installation of energy efficient products, and providing a lump-sum payment ahead of time

**Frequency response markets:** Electricity needs to be generated at a constant rate – plus/minus 10% of 50 Hertz is a common threshold. When demand increases, it requires more generation from providers to generate 50 Hertz. When demand decreases, it requires less generation to meet the 50Hz threshold. A few ISOs in the USA are beginning to implement this market which incentivizes the necessary flexibility to remain the required frequency limits.

**Flexible Ramping Products:** Less mature than pay-for-performance and frequency response markets, flexible ramping products involve a generation resource’s ability to rapidly change its output (upward or downward) to respond to a change in forecasted net load.