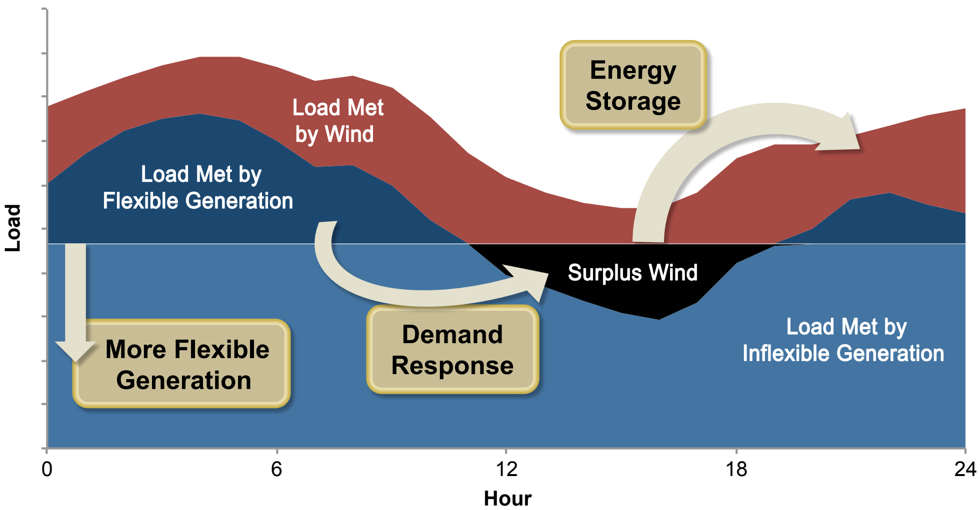
THE ROLE OF STORAGE AND DEMAND RESPONSE



Demand response and energy storage are sources of power system flexibility that increase the alignment between renewable energy generation and demand. For example, demand response provides a means to shift demand to times of relatively high wind generation and low load, while storage technologies can store excess wind generation for use in times of relatively low wind generation and high load. This figure also shows how more flexible generation could accommodate increased RE penetration and can provide an alternative or supplement to DR and storage.

THE NEED FOR FLEXIBILITY

Affordably integrating high levels of variable renewable energy (VRE) sources such as wind and solar requires a flexible grid. Numerous grid integration studies have identified two major categories of tools for increasing grid flexibility:

1) Resources that allow VRE to be used directly to offset demand and increase instantaneous VRE penetration;[1] and

2) Resources that improve the alignment of VRE supply and demand.

Demand response and storage are among a limited set of options in the latter category of tools. Storage and demand response provide means to better align wind and solar power supply with electricity demand patterns: storage shifts the timing of supply, and demand response shifts the timing of demand.

REDUCING CURTAILMENT AT HIGHER PENETRATIONS OF VRE

The role of demand response and storage becomes increasingly important at very high penetrations of wind and solar. To date, integration studies have found that the grid can accommodate about 30% of annual electricity demand from variable generation largely with flexibility options that increase the instantaneous penetration of VRE [1]. As a result, energy storage and demand response are not needed; instead, integration of VRE requires changes in operational practices, which are expected to be lower in cost than additional storage deployment.

At penetrations beyond 30%, integrating VRE to the grid becomes more challenging due to the limited alignment between wind and solar generation and electricity demand, as well as the inflexibility of conventional generators to ramp up and down to balance the system. Without a sufficiently flexible grid, thermal plants cannot reduce output and wind and solar will need to be curtailed, which can add to system costs.[2] However, even with a completely flexible grid in which thermal generation can be turned off during periods of high VRE output, curtailment can occur when very high penetrations of VRE lead to an excess of wind and solar generation relative to demand. As curtailment increases, VRE offsets less fossil generation, decreasing its value. Demand response and storage are enabling technologies that can reduce curtailment and facilitate higher penetrations of VRE on the grid.

ENERGY STORAGE TECHNOLOGIES AND APPLICATIONS

Electric energy storage is the set of technologies capable of storing electricity generated at one time and for use at a later time. Energy storage technologies can be divided into two general categories based on the amount of energy stored [2]:

- Technologies providing *operating reserves* respond rapidly and discharge within seconds to minutes, making them well suited to provide regulating and contingency reserves. They typically can provide energy for 15 minutes to about 1 hour depending on the specific application. Common storage technologies for provision of operating reserves include flywheels (which store energy in a rotating mass), and certain battery technologies.
- Technologies for *energy management* provide flexibility over longer timescales and require continuous discharge over several hours. These technologies also often provide operating reserves as well as firm system capacity. Storage technologies associated with energy management include high-energy (long-duration) batteries, pumped hydro storage, compressed air energy storage, and thermal energy storage.

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[1]For more information on this category, see a related fact sheet, "Sources of Operational Flexibility."

[2]Curtailment refers to a reduction in the output of a generator from what it could otherwise produce given available resources.

BENEFITS AND TRADEOFFS OF DEMAND RESPONSE AND STORAGE

By shifting supply and demand patterns, storage and demand response can not only significantly increase the penetration of VRE, but also can provide other significant sources of value such as provision of firm capacity, which can eliminate the need for conventional peaking capacity. This is particularly important at high VRE penetrations when the marginal capacity value of solar and wind resources can drop significantly.[3] Furthermore, in addition to providing load shifting, both storage and demand response can also provide operational flexibility.[4] For example, storage and demand response can provide operating reserves to the system, which otherwise may require use of partially loaded thermal generators that limit the instantaneous penetration of VRE.

Power system operators can weigh the benefits of demand response and storage against implementation costs. Many storage technologies are still costly and somewhat inefficient, because only 70–85% of stored energy is recoverable. Demand response programs typically do not incur such an efficiency penalty. However, demand response programs do have significant implementation costs, for example, to attract participants and manage their electricity demand.

ANALYSIS CHALLENGES

The point at which storage or demand response is economically needed (or the least-cost flexibility option) is difficult to quantify, primarily because the availability and cost of grid flexibility options are not well understood and vary by region. High penetrations of variable generation increase the need for all flexibility options and create market opportunities for storage and demand response technologies. Historically, storage has been difficult to justify, not only due to high costs, but also because of the difficulties associated with quantifying the value of the array of services it provides—particularly the operational benefits such as ancillary services. The challenge of simulating energy storage in the grid, estimating its total value, and actually recovering those value streams continues to be a major barrier to implementation. VRE complicates this issue because variability adds additional analysis challenges. The ability to simulate the cost impacts of VRE and benefits of storage is still limited by the methods and datasets available. It is understood that VRE increases the need for flexible generation and operating reserves, which can be met by energy storage. However, the value of energy storage is best captured when selling to the entire grid instead of any single source. Evaluating the role of storage and DR with VRE sources requires continued analysis, improved data, and new techniques to evaluate the operation of a more dynamic and intelligent grid of the future.

[3] For more information on capacity value, see a related fact sheet, "Using Wind and Solar to Reliably Meet Demand."

[4] Load shifting refers to a grid management technique that involves moving sources of electricity supply and demand to different times, e.g., from peak hours to off-peak hours.

DEMAND RESPONSE MECHANISMS

Demand response refers to voluntary (and compensated) load reduction used as a system reliability resource. Two broad categories of demand response mechanisms are available to power systems [3]:

- *Price-based* demand response programs vary the price of electricity over time to encourage consumers to change their electricity usage patterns. Price-based mechanisms include time-of-use pricing (which assigns prices for consumption during different blocks of time), critical peak pricing (which specifies a very high rate for a limited number of hours), and real-time pricing (which varies rates in response to wholesale market prices, often on an hourly basis).
- *Incentive-* or *event-based* demand response programs provide financial compensation to customers who allow the program administrators to directly control certain electricity-consuming equipment and/or reduce their electricity demand upon request. Examples of incentive- and event-based mechanisms include demand bidding or buyback programs, emergency demand response programs, capacity markets, and ancillary services markets.

REFERENCES

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Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy into the grid.

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