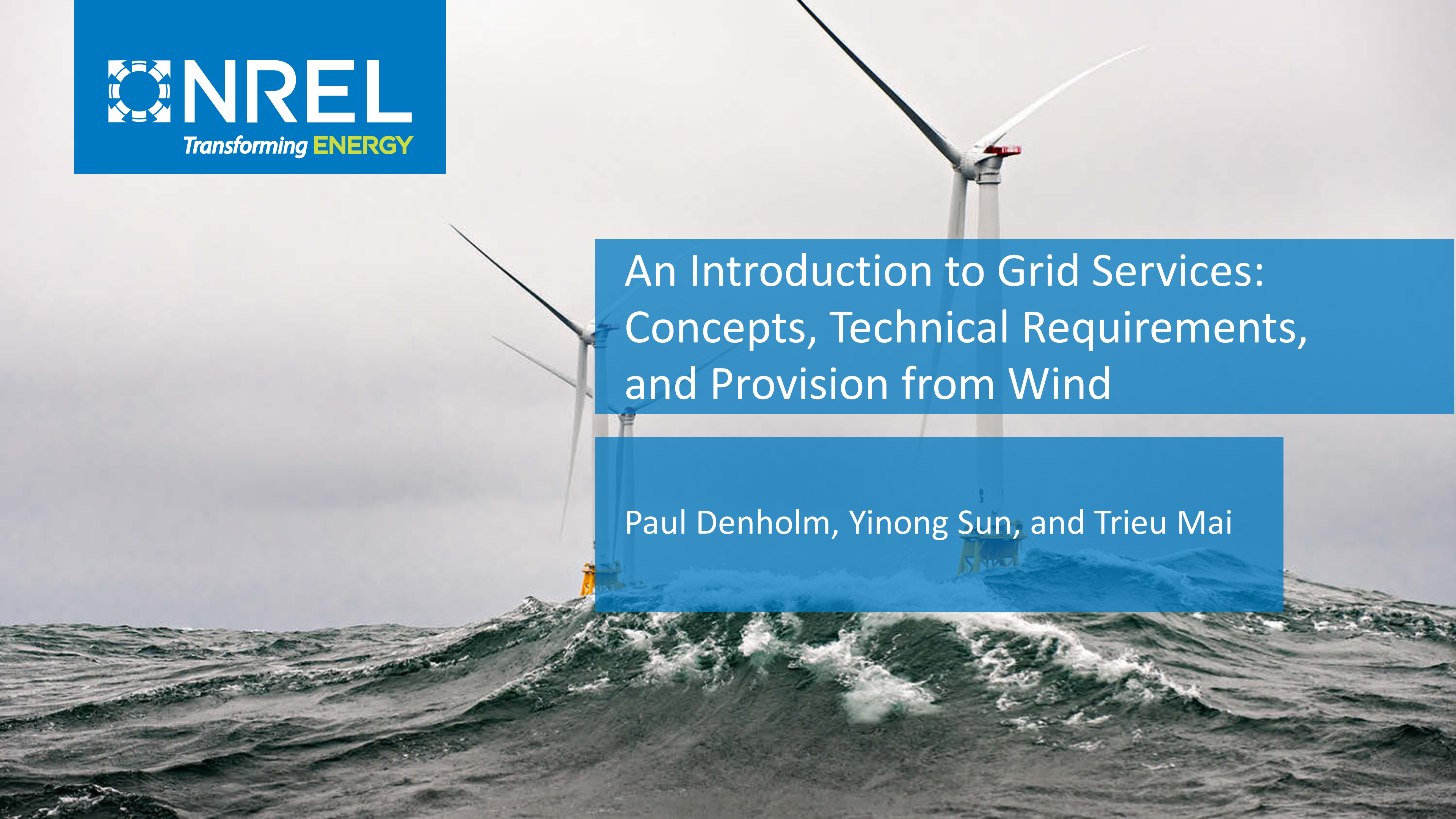


An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind

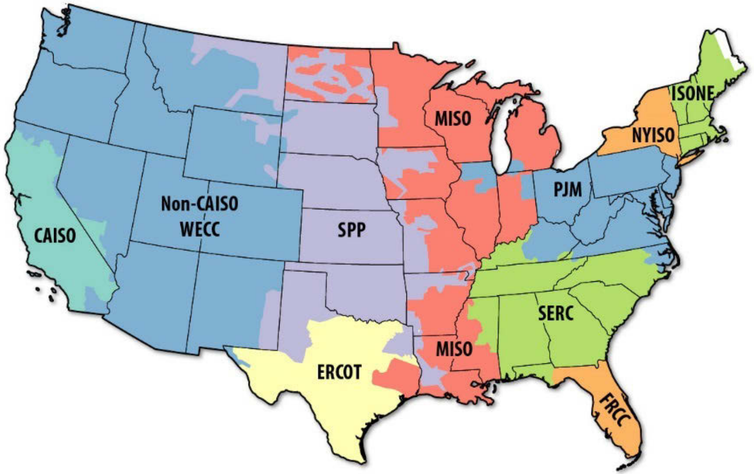
Paul Denholm, Yinong Sun, and Trieu Mai

Introduction

- Geographical Scope
- Regions Analyzed

Geographical Scope and Regions Analyzed

Market Regions	Estimated Electric Demand (TWh / % of U.S.)	Estimated Population (million / % of Total)
CAISO	228 / 6%	30 / 9%
PJM	759 / 19%	65 / 20%
ERCOT	357 / 9%	23 / 7%
ISO-NE	121 / 3%	14.5 / 4%
NYISO	157 / 4%	19.5 / 6%
MISO	656 / 16%	48 / 15%
SPP	246 / 6%	18 / 6%
Regulated Regions		
Non-CAISO WECC	654 / 16%	52 / 16%
FRCC	231 / 6%	16 / 5%
SERC	673 / 16%	39.4 /12%

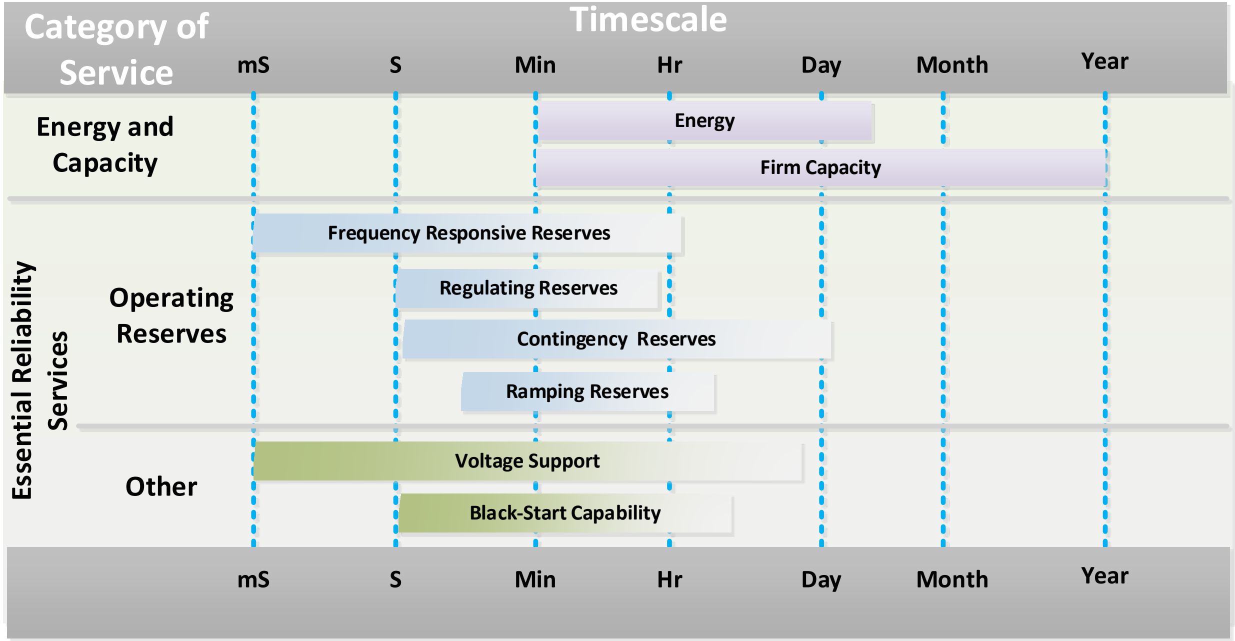


Current Grid Services

- Energy and Capacity
- Operating Reserves
- Other Essential Reliability Services
- Relative Total System Costs

Current Grid Services

- We separate energy and capacity services into one category and group the remaining services into a general essential reliability service (ERS) category.
- ERSs are further subdivided into operating reserves and other ERSs.



Historical Capacity Requirements

U.S. Power System Historical Peak and Annual Energy Demand

Region	Peak Demand (GW)	
	2016	2017
CAISO	46.2[a]	50.1[a]
PJM	152.2[c]	145.6[c]
ERCOT	71.1[e]	69.5[e]
ISO-NE	25.6[g]	24.0[g]
NYISO	32.1[i]	29.7[i]
MISO	121.0[k]	120.6[k]
SPP	50.6[m]	51.2[m]
Non-CAISO WECC	110.8[o]	106.0[o]
FRCC	47.7[q]	46.6[q]
SERC	129.0[s]	132.2[s]
Total[t]	786	775

Each region is required to maintain sufficient capacity to meet the peak demand plus additional capacity to address outages or unanticipated increases in demand.

2020 Estimated Regional Capacity Requirements

U.S. Power System Peak Capacity Requirement Estimates

Region	2020 Estimated Peak Demand (GW)[a]	NERC Estimated Reference Margin Level (%)[b]	2020 Estimated Total Peak Capacity Requirement (GW)	2020 Estimated Reserve Margin (%)
Market Regions				
CAISO	53.6	16.14	62.3	20.6
PJM	147.5	16.60	172.0	28.0
ERCOT	73.7	13.75	83.5	18.0
ISO-NE	26.3	16.90	30.3	23.8
NYISO	32.1	15.00	36.9	25.0
MISO	121.4	15.80	140.6	19.4
SPP	52.5	12.00	58.8	28.9
Regulated Regions				
Non-CAISO WECC	110.0	range of 14.17 to 16.38	136.0	23.7 (range of 22.6 to 27.7)
FRCC	45.8	15.00	52.7	22.5
SERC	131.2	15.00	150.9	23.1

All U.S. regions are expected to have adequate generation capacity to meet peak demand in the near future.

Energy Capacity Costs and Prices

- Most costs associated with power system generation are the fixed and variable costs associated with providing capacity and energy.
- Price caps and other factors typically require additional costs of capacity (i.e., “missing money”) to be captured via other mechanisms, including resource adequacy payments and/or capacity markets.
- Most U.S. regions have more capacity than is needed for resource adequacy/planning reserve targets, which tends to suppress capacity market prices.

Energy Capacity Costs and Prices

U.S. Power System Energy Requirements

Region	Average Energy Price ($/MWh)		Capacity Market Price ($/kW-month)[a]	
	2016	2017	16/17	17/18
Market Regions				
CAISO	$33.1[b]	$33.3[b]	N/A	
PJM	$29.68[c]	$30.85[c]	$1.81[c]	$3.66[c]
ERCOT	$24.62[d]	$28.25[d]	NA	
ISO-NE	$31.74[e]	$35.23[e]	$3.15[e]	$7.03[e]
NYISO	$31.32[f]	$34.62[f]	Summer: $1.73[g] Winter: $5.77[g]	Summer: $1.25[g] Winter: $6.49[g]
MISO	$26.80[h]	$29.46[h]	NA	
SPP	$22.43[i]	$23.43[i]	NA	

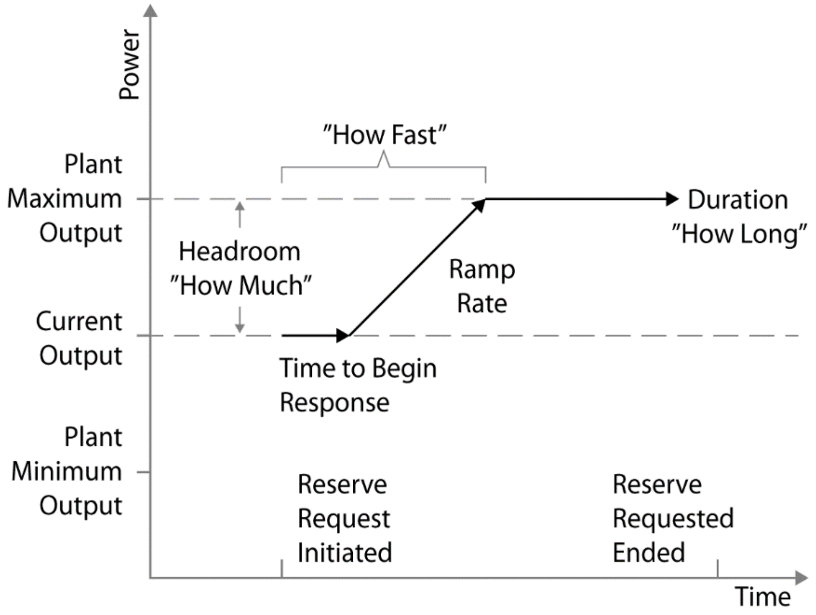
Operating Reserves

Defined as the capability above firm system demand required to provide for regulation, load forecasting error, equipment forced and scheduled outages, and local area protection.

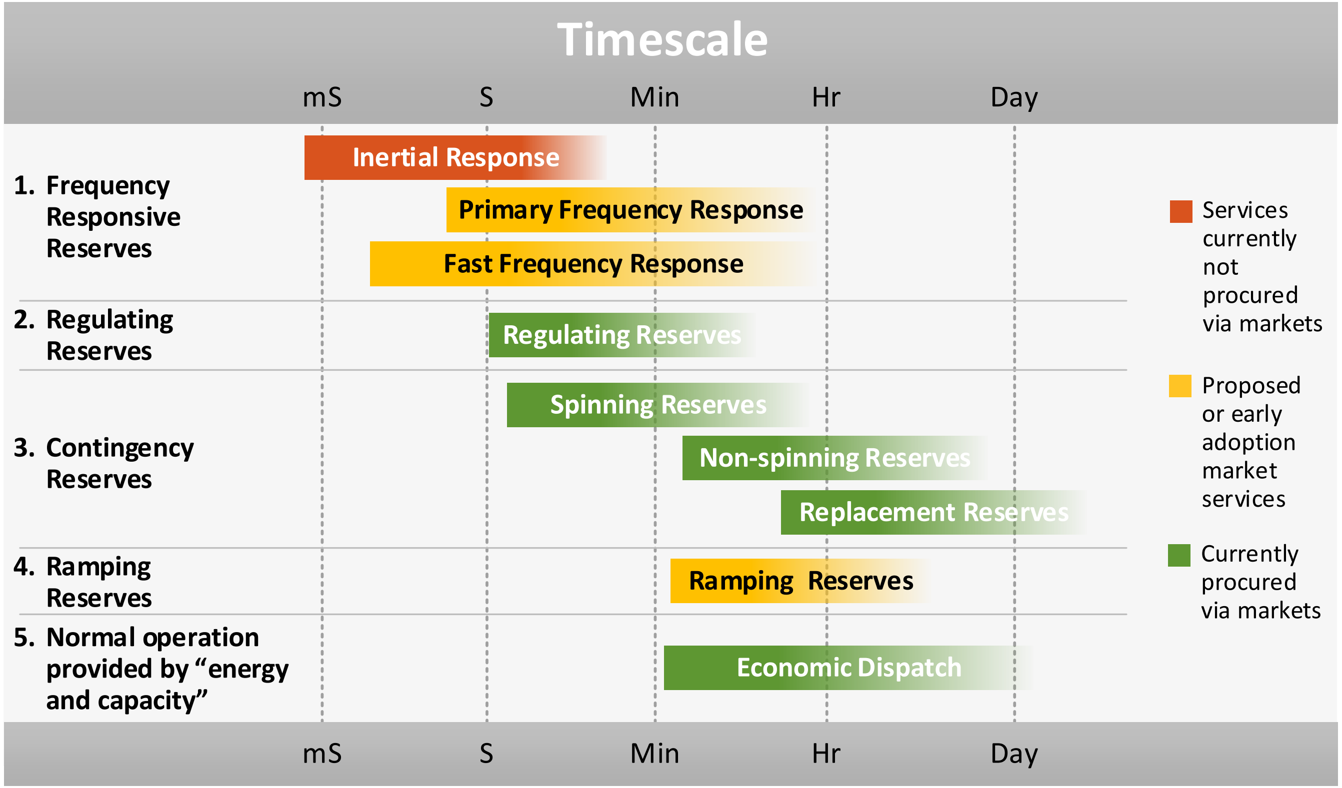
Distinctions can be characterized by three factors:

- **How much**
- **How fast**
- **How long**

There are no uniform definitions for various operating reserve products.



Timescales of Operating Reserve Requirements



Operating Reserves

Resources with different technical characteristics are deployed at different times; typically, they are deployed in order of response speed, from very fast to slow (and with corresponding costs that range from more to less expensive).

Frequency-Responsive Reserves

- Inertial Response
- Primary Frequency Response
- Fast Frequency Response

Regulating Reserves

During normal operation, reserves are still required to meet random variations in net load

Operating Reserves

Contingency Reserves

- Spinning Reserves
- Non-Spinning/Supplemental Reserves

Ramping Reserves

- Least well defined of the reserve products
- Not yet a common market product

Economic Dispatch (Normal System Operation)

All reserves are eventually replaced by the normal economic dispatch of conventional generators as the system is restored to a pre-contingency state. This is not considered an operating reserve or ERS and is provided by generators delivering energy and capacity services.

Frequency-Responsive Reserve Requirements

Frequency-responsive reserves traditionally consist of two services:

- Inertial response
- PFR
- Neither inertial response nor PFR is a market product in any ISO/RTO market

Inertial Response

- Not much detailed estimation of inertial response requirements in U.S.
- Growing analysis of potential need to procure inertial response services
- Only ERCOT has studied the amount of inertia potentially "required"
- Requirement is measured in energy—how much energy can be injected rapidly into the system
  - Often measured in GW-seconds
- No "headroom" component of inertial response
  - The amount of inertia that can be provided by a generator is independent of instantaneous power output

Frequency-Responsive Reserve Requirements

Primary Frequency Response Obligation

Interconnection	Region	IFRO (MW/0.1Hz)[a]	MDF (Hz)[b]	Requirement (MW / % of Peak Demand)
ERCOT	ERCOT	381	0.405	1,543 / 2.2%
Western	Western Total	858	0.28	2,402 / 1.5%
	CAISO	196.5		550 / 1.1%
	Non-CAISO	661.5		1,852 / 1.7%
Eastern	Eastern Total	1015	0.42	4,263 / 0.8%[c]
	FRCC	76.2		320 / 0.7%
	SERC	303.6		1,275 / 1.0%
	NYISO	49.9		210 / 0.7%
	PJM	258.3		1,085 / 0.7%
	ISO-NE	38.3		161 / 0.7%
	MISO	210		882 / 0.7%

PFR

- NERC has established minimum recommended standards for PFR for each of the three U.S. grids

- Each interconnection has a frequency response obligation
    - Further divided by BA in proportion to demand so that each region “shares” its obligation

Regulating Reserve Requirements and Costs

- Regulating reserves are a market product in each ISO/RTO
  - Most technically demanding requirements of the various reserve products in terms of response rate and the need for nearly continual ramping of the plant providing this service
  - Typically the most costly of the reserve services

Regulating Reserve Requirements and Costs

Regulating Reserve Requirements

For the requirement in non-market regions, we multiply the percentage requirement of a large utility in that region by the total peak demand of the larger region in which it is located

Market Regions	Average Regulation Requirement (% of Peak Demand / MW)	2017 Average Price ($/MW-hr)
CAISO	Regulation Up: 0.64% / 320 Regulation Down: 0.72% / 360[a]	Regulation Up: $12.13 Regulation Down: $7.69[b]
PJM	Off-peak: 0.36% / 525 On-peak: 0.55% / 800[c]	$16.78[d]
ERCOT	Regulation Up: 0.48% / 318 Regulation Down: 0.42% / 295[e]	Regulation Up: $8.76 Regulation Down: $7.48[f]
ISO-NE	0.25% / 60[g]	$29.23[h]
NYISO	0.73% / 217[i]	$10.28[j]
MISO	0.35% 425[k]	$9.74[l]
SPP	Regulation Up: 0.92% / 470 Regulation Down: 0.63% / 325[m]	Regulation Up: $8.20 Regulation Down: $6.60[n]
Regulated Regions[o]	(% of Peak Demand / Estimated Region Requirement in MW)	Tariff ($/kW-month / $/MW-hr)
Non-CAISO WECC **(proxy utility: Arizona Public Service)**	1.17% / 1,240[p]	$7.41/$10.29
FRCC **(proxy utility: Florida Power & Light)**	1.35% / 629[q]	$4.8/$6.67
SERC **(proxy utility: Southern Company)**	1.15% / 1,477[r]	$4.2/$5.83
National	(% of Total)[s] / Estimated Total Requirement	Average Price ($/MW-hr)[t]
	0.90% / 6,000 MW	$11.24

Contingency Reserve Requirements and Costs

The actual quantity procured is typically greater than regulation requirements, but the price is typically lower due to the infrequent ramping requirements.

Spinning Contingency Reserve Requirements

Market Regions	Spinning Requirement (% of Peak Demand / MW)	2017 Average Price ($/MW-hr)
CAISO	1.60% / 800 MW[a]	$10.13[b]
PJM	1.03% / 1,504.8 MW[c]	$3.73[d]
ERCOT	3.76% / 2,616.8 MW[e]	$9.77[f]
ISO-NE	3.75% / 900 MW[g]	$2.96[h]
NYISO	2.20% / 655 MW[i]	$5.00[j]
MISO	0.61% / 740 MW[k]	$2.94[l]
SPP	1.14% / 585 MW[m]	$5.25[n]
Regulated Regions	(% of Peak Demand) / Estimated Region Requirement	Tariff ($/kW-month / $/MW-hr)
Non-CAISO WECC (Arizona Public Service)	1.50% / 1590	$6.26 / $8.69
FRCC (Florida Power & Light)	0.43% / 200	$5.16 / $7.17
SERC (Southern Company)	2.00% / 2,568	$4.2 / $5.83
National	(% of Total)[o] / Estimated Total Requirement	Average Price ($/MW-hr)[p]
	1.58% / 12,160	$6.15

Contingency Reserve Requirements and Costs

The procurement requirement (total MW) for non-spinning reserves is typically similar to that of spinning reserves (because non-spinning typically replace spinning). They have the lowest technical requirements in terms of response rate and are therefore typically the least expensive of the market reserve products.

Non-Spinning Contingency Reserve Requirements

Market Regions	Non-Spinning Requirement (% of Peak Demand / MW)	2017 Average Price ($/MW-hr)
CAISO	1.60% / 800 MW[a]	$3.09[b]
PJM	1.03% / 1,053.2 MW[c]	$2.11[d]
ERCOT	2.21% / 1,534.5 MW[e]	$3.18[f]
ISO-NE	10-minute total reserve: 5.98% / 1435 MW 30-minute operating reserve: 3.33% / 800 MW[g]	10-minute non-spinning reserve: $0.89 30-minute operating reserve: $0.82[h]
NYISO	10-minute total reserve: 4.41% / 1310 MW 30-minute reserve: 8.82% / 2620 MW[i]	10-minute non-spinning: $4.18 30-minute component: $4.01[j]
MISO	0.92% / 1,110 MW[k]	$1.14[l]
SPP	1.43% / 730 MW[m]	<$1[n]
Regulated Regions	(% of Peak Demand)/ Estimated Region Requirement	Tariff ($/kW-month / $/MW-hr)
Non-CAISO WECC (Arizona Public Service)	1.50% / 1,590	$0.97 / $1.35
FRCC (Florida Power & Light)	1.31% / 527	$4.83 / $6.71
SERC (Southern Company)	2.00% / 2,568	$4.20 / $5.83
National	(% of Total)[o] / Estimated Total Requirement	Average Price ($/MW-hr)[p]
	1.98% / 14,768	$2.92

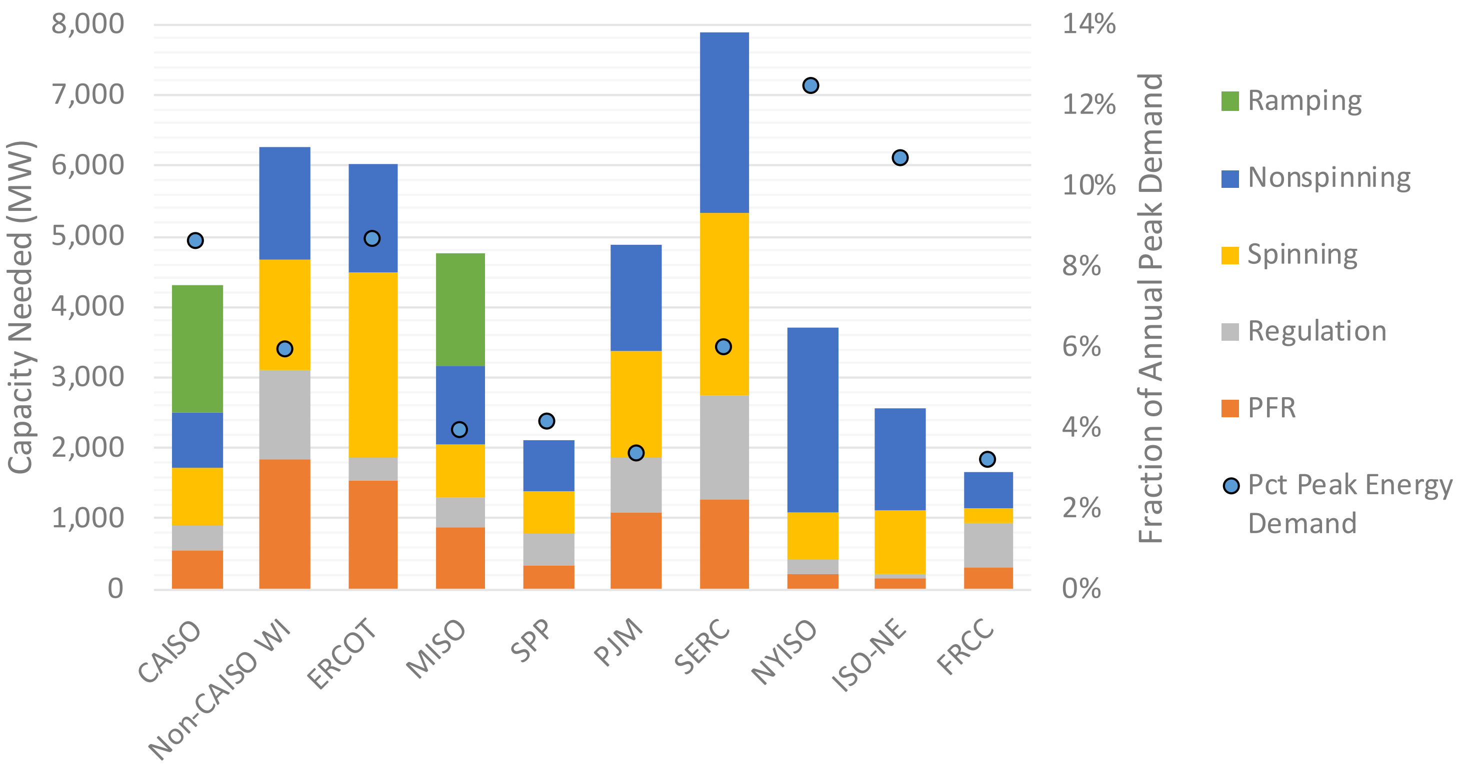
Ramping Reserve Requirements

Ramping (Flexibility) Requirements by Region

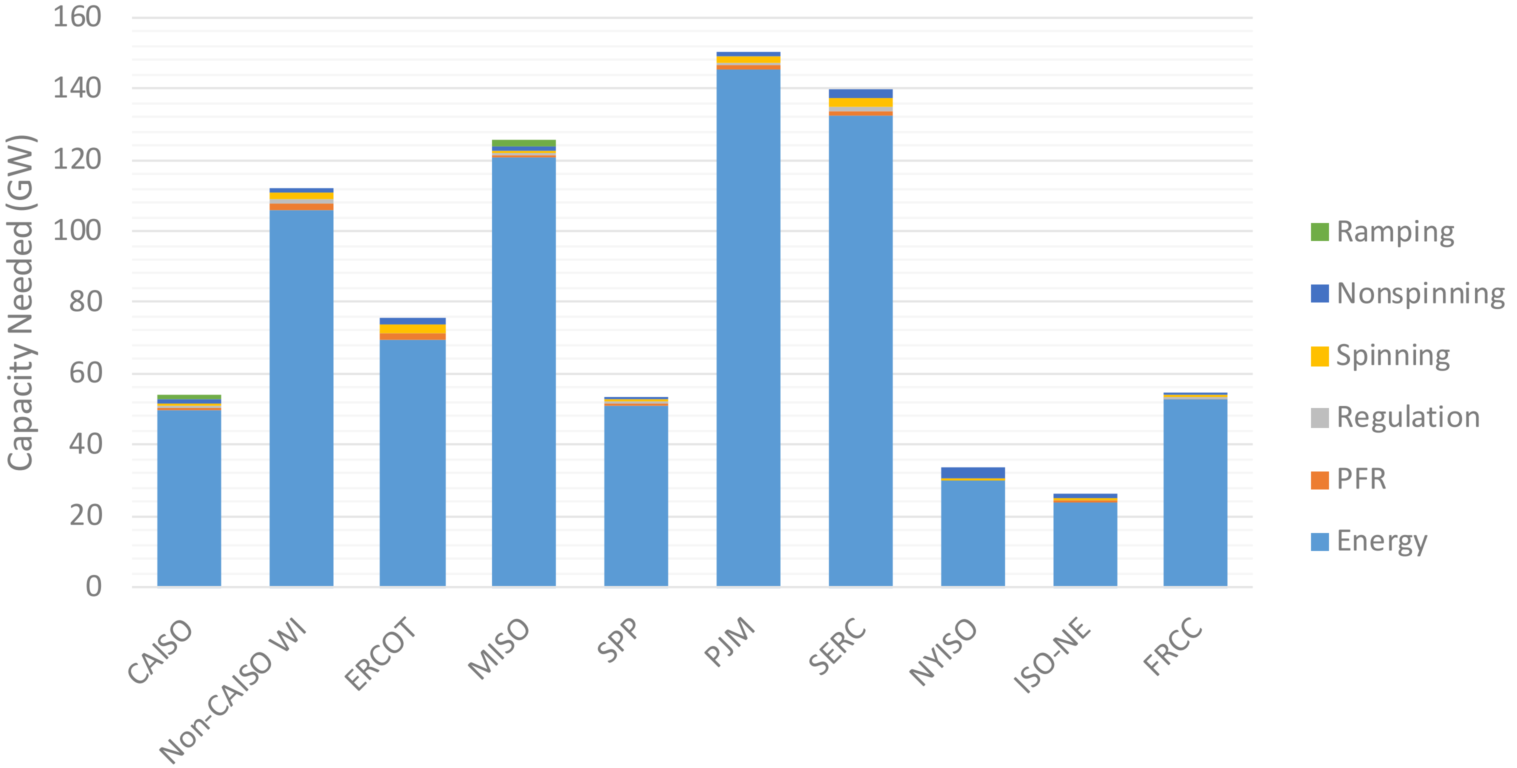
Region	Requirement
CAISO	• Maximum flexible ramp up and down requirements are defined as the 2.5% and the 97.5% percentile of net load change • Uncertainty threshold: ○ For the system in the 15-minute market: -1,200 MW in the downward direction and 1,800 MW in the upward direction; ○ For the system in the 5-minute market: -300 MW and 500 MW in the downward and upward direction[a]
MISO	• Depends on the sum of the forecasted change in net load and an additional amount of ramp up/down (575 MW for now) • Highest hourly average real-time ramp-up requirement: 1,554 MW • Highest hourly average real-time ramp-down requirement: 1,614 MW[b]

These reserves are an emerging product with limited market data for analysis.

Total Reserve Requirements



Total Energy and Reserve Requirements



Other Essential Reliability Services

- There are a number of other ERSs; two of the most important are:
  - **Black-start**
  - **Voltage support**

- A significant difference from other services is that these are typically acquired on a cost-of-service basis

Black-Start

- Represents capacity that can be started without external power and then subsequently provide power and energy to start other power plants

- Typically relatively small power plants including certain hydroelectric facilities, diesel generators, or small gas turbines

- Historically been procured on a cost-of-service basis, even in wholesale market regions
  - Each region has specific technical requirements for the type and quantity procured

Voltage Support

- Ensuring electric system reliability requires maintaining both **frequency** and **voltage**
  - Frequency is constant throughout the grid.
  - Voltage varies depending on location.
- Devices that provide voltage control maintain appropriate voltage on the grid during both normal operating conditions and fault conditions.
- Voltage is controlled by different methods at different points of the grid.
  - Key element of this is the ability to inject or absorb reactive power.
- Reactive power cannot be transmitted over long distances.
  - Voltage control is performed at each of the three major parts of the grid, including at the point of generation, at various points in the transmission system, and in the distribution network. For additional discussion of reactive power.
- Reactive power is provided by “active” devices such as synchronous generators or power electronics devices or by “passive” devices such as capacitor banks.

Relative Total System Costs

- Vast majority of generation-related costs are associated with the provision of energy and capacity

2017 ISO-NE Market Settlements Summary[a]

	Billing ($ Million)	Percentage
Energy markets total	4,522	49.50%
Forward capacity market payments	2,244	24.56%
Regional network service	2,163	23.68%
Reserve markets total	70	0.77%
Net commitment-period compensation	52	0.57%
Regulation market	32	0.35%
Financial transmission rights (FTRs)	20	0.22%
Black-start	12	0.13%
Volt-ampere-reactive capacity cost	20	0.22%
Demand-response payments	1	0.01%
Total	$9,136	100.00%

2017 PJM Market Settlements Summary[b]

	Billing ($ Million)	Percentage
Energy market	21,087	52.49%
Capacity	9,103	22.66%
Transmission[c]	8,739	21.75%
Scheduling	366	0.91%
Reactive services	309	0.77%
Regulation market	104	0.26%
Black-start	72	0.18%
Operating reserves	68	0.17%
Synchronized reserve market	49	0.12%
Day-ahead scheduling reserve market	34	0.08%
Other	241	0.60%
Total	$40,172	100.00%

Provision of Grid Services from Wind

- Energy and Capacity
- Operating Reserves
- Other Essential Reliability Services

Provision of Services from Wind

More than 1,000 MW of wind generation capacity has been deployed in each of the regions analyzed, with the exception of SERC and FRCC.

The value of the energy and capacity provided by wind is impacted by the variable nature of the resource.

Wind tends to be somewhat negatively correlated with demand patterns over the diurnal and seasonal cycle.

2017 Wind Energy Provision

Region	Installed Capacity (MW)	Annual Energy (GWh)	Fraction of Demand (%)
Market Regions			
CAISO	6,296	12,823	6.0
PJM	8,141	20,714	2.7
ERCOT	21,704	62,193	17.4
ISO-NE	1,401	3,444	2.6
NYISO	1,826	4136	2.7
MISO	17,000	50,535	7.7
SPP	17,591	58,874	23.2
Regulated Regions			
Non-CAISO WECC	16,766	43,967	6.7
FRCC	0	0	0
SERC	237	514	0
Total	87,331	225,585	5.5

Energy and Capacity

- Most ISO/RTOs and large utilities with substantial wind deployments have performed capacity credit analysis of wind.

- The following table demonstrates that for nearly all regions of the United States, a capacity credit of significantly less than 50% is applied to wind, with capacity credits well under 20% applied in many cases.

Energy and Capacity

Capacity Credit by Market Region

Region	Capacity Credit
Market Regions	
CAISO[a]	Summer values of about 27%.
PJM[b]	Initially applies 13% of nameplate; after three years of operation, historic performance over seasonal peak periods determine unit's capacity credit.
ERCOT[b]	Based on average historical availability during the highest 20 seasonal peak load hours for each season (2009–2016). Values recalculated after each season with new historical data. Current contribution: 58% coastal and 14% noncoastal (summer); 35% coastal and 20% noncoastal (winter).
ISO-NE[b]	Summer values average to approximately 13.2% of nameplate rating.
NYISO[c]	Onshore: summer 10%; winter 30% Offshore: 38%
MISO[d]	
2016	15.6%
2017	15.6%
2018	15.2%
SPP	5% assumed for first three years if the load-serving entity (LSE) chooses not to perform the net capability calculation during the first 3 years of operation, after which the net capability calculations are applied by selecting the appropriate monthly MW values corresponding to the LSE's peak load month for each season.
Regulated Regions	
Non-CAISO WECC	Varies. For example, Xcel Colorado uses 16%.[e] Portland General Electric uses 5%–15% for wind resources located in the Pacific Northwest.[f]
FRCC	Not applicable.
SERC	Varies.

Operating Reserves

- Wind was once considered a non-dispatchable “must-take” resource without the ability to provide reserves
- Now recognized that the output of a wind turbine can be accurately controlled (up to the amount allowed by instantaneous wind speed)
- Wind has important differences that provide both relative advantages and disadvantages compared to more traditional resources.

Key Parameters for Provision of Operating Reserves for Thermal/Hydro Resources and Wind

Parameter	Thermal/Hydro	Wind
Dispatch Range (“how much”)	Min to max, min is typically 25% to 50% of max[a]	0 to max, where maximum output is variable (limited by current wind speed)
Ramp Rate (“how fast”)	Start time ranges from several minutes to hours. Ramp rate when online ranges from about 1%/min for combined-cycle/coal to 5%/min for combustion turbine	Ramp rate greater than 5%/second[c]
Availability of Output (“how long”)	Typically unconstrained with fuel availability	Contingent on wind resource, which has increased unpredictability with duration

Operating Reserves

- Wind performance is different from that of conventional generators
    - Technical ability of wind to provide reserves varies by service

- Key element of providing reserves from wind is the need for pre-curtailment, which incurs the opportunity cost of reduced energy sales
    - Pre-curtailment requires reducing the output of the wind turbine, performed by changing the blade pitch angle and reducing the amount of energy extracted from the wind
    - Pre-curtailment requirement reduces the revenue from electricity sales for a wind generator providing this service, at least under current market conditions

- Wind generators will always prefer to provide energy instead of reserves as long as the price of energy is greater than the price of reserves.

Operating Reserves

- As variable generation penetration increases, there may be times when the price of energy falls to zero and wind is curtailed.

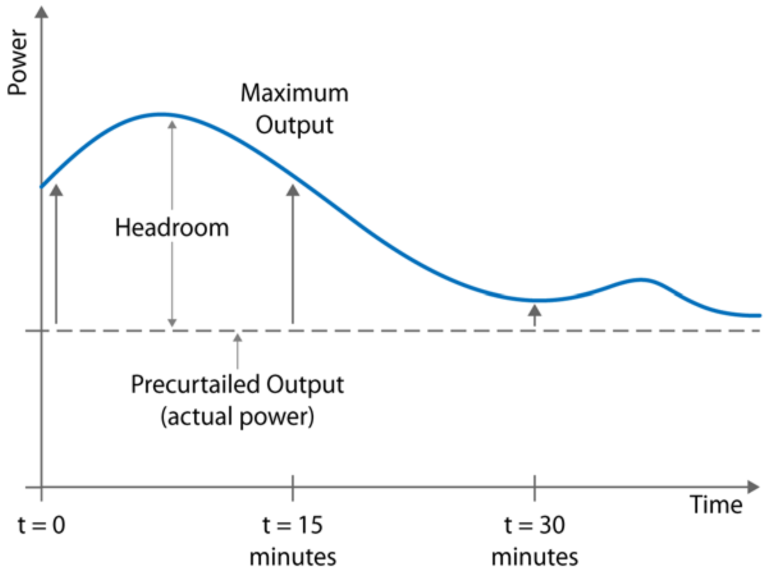
- Under certain conditions, it may be economically advantageous—for the wind plant and the system—for curtailed wind to provide reserves and wind can potentially improve overall system dispatch by allowing decommitment (turning off) of more costly (on an operating basis) generators that are online primarily to provide reserves.

- Most wind curtailment has been due to transmission constraints, where wind would not be able to provide reserves, as the location where reserves are needed does not correspond to the location of the wind.

Operating Reserves

While the need for pre-curtailment is an economic factor, an important technical factor is ensuring that headroom will remain available for the response time needed.

Impact of variable output on the ability of wind to provide upward reserve services



Operating Reserves

- Wind can increase output very rapidly, but the duration of response becomes problematic.
- The "how long" component of reserve service from wind is limited by both the likelihood of wind remaining at or higher than current output *and* the predictability of this output.
- While the forecast accuracy of wind is increasing, the ultimate limit to wind headroom is the relatively low capacity credit.
- A system operator may not be able to plan on the availability of wind to provide upward reserves, and insufficient wind during certain periods may require other sources of capacity to be available to provide reserves.
- Wind will act to reduce the variable costs associated with providing reserves, but have somewhat limited availability to reduce the fixed costs.

Frequency-Responsive Reserves

- Wind generators have demonstrated the ability to provide both an “inertia-like” product and PFR, and FERC requires new wind turbines to provide PFR.

- Modern wind turbines do not use synchronous generators
  - Do not provide inertia in the traditional sense (defined as automatically resisting changes in frequency)
  - Have kinetic energy in the rotating mass of the blades, shaft, and generator that can be extracted to rapidly inject real power into the grid

- Provision of inertial service in this fashion requires active sensing of grid frequency.
  - When a decrease in frequency is sensed, the generator can be programmed to increase output to beyond what can be supported by “steady state” wind speeds.

Frequency-Responsive Reserves

- The provision of inertia from wind turbines in this manner is unique compared to other reserve service provisions in that it does not require pre-curtailment of wind.
- Sometimes been referred to as "synthetic" inertia
- Combination of extracting energy from rotating wind turbines and using pre-curtailed wind energy to provide a rapid increase in output can mimic traditional frequency-responsive reserves
  - These services do not precisely match those from conventional generators.
  - Terminology is still in flux.

Frequency-Responsive Reserves

- “Fast frequency response” (FFR) has emerged as a preferred term that captures the ability of non-synchronous generators to inject real power into a grid upon sensing a change in frequency.
- Difference between FFR and PFR is less clear; generally PFR would reflect a somewhat slower response (but still measured in a few seconds or less)
- Still important to distinguish frequency response that is derived from extraction of turbine kinetic energy as opposed to from pre-curtailment, given the potentially economic implication of these different sources

Terms Applied to Frequency-Responsive Services

Conventional Synchronous Generator	Wind (Previous Terms)	Wind (Current Terms)
Inertia	Synthetic inertia (derived from kinetic energy)	FFR (derived from kinetic energy)
PFR	PFR from pre-curtailment	PFR or FFR (from pre-curtailment)

Frequency-Responsive Reserves

- Ability of wind to provide frequency response from both extraction of kinetic energy and increased output from pre-curtailed wind is well established
  - Major wind turbine manufacturers offer this service.
  - ERCOT requires all new turbines to have FFR capabilities.

- Manner in which wind can provide frequency-responsive services is also evolving
  - Can be “programmed” to provide a response similar to that of legacy synchronous generators
  - It is possible wind response can be optimized to grid requirements and vary based on both the current frequency and the rate of change of frequency (ROCOF).

Regulating Reserves

- Require synchronized generator to have the ability to increase or decrease output in response to a signal from the system operator

- Wind requires pre-curtailment to provide upward reserves
  - There has been limited use of wind to provide regulating reserves, with one example being Xcel Energy in Colorado.

- Regulating reserves are typically the highest-cost reserve product

- Rules for wind providing regulating reserves are unclear, inconsistent, and evolving in U.S. ISO/RTO markets

Ramping Reserves

- Similar to regulating reserves in that they require a generator to have the ability to increase or decrease output in response to a dispatch signal.
  - Primary difference is that flexibility reserves are generally slower (i.e., lower ramp rate) and longer (i.e., requiring the generator to hold output for a longer period)
  - Makes this reserve product easier to meet for a conventional generator, and a lower-cost service from the system perspective

- A flexibility reserve product is likely to have lower costs than regulation.

Contingency Reserves

Spinning Contingency Reserves

- Must have the ability to:
    1. Be synchronized to the grid and begin responding quickly (within a few seconds)
    2. Reach setpoint within about 10 minutes
    3. Hold output for at least 30 minutes (60 in a few locations)

- For pre-curtailed wind, criteria 1 and 2 are well within the technical requirements.
    - Third requirement could be more challenging given the greater variability and lower predictability of wind over longer timescales

- Contingency reserve prices are typically lower than those of regulation.
    - Little incentive for wind to provide this service, and market rules have limited explicit discussion of wind providing it

Contingency Reserves

Non-spinning Contingency Reserves

- Upward-only reserve product that can be provided by online generators, or units that can start quickly

- Non-spinning reserves typically the lowest-cost operating reserve service

- Long-duration requirement (multiple hours) may limit the ability of wind to provide this service given the constraints of predictability and limited capacity credit

Other Essential Reliability Services

Voltage Support

- Power electronics built into wind turbines are well suited to providing voltage control and reactive power.

- Variable generation power plants larger than 20 MW must provide reactive power
  - Aggregated capacity of the plant, which typically consists of multiple turbines or solar arrays

- Modern wind turbines can also provide reactive power even when not generating.

- Voltage support is a localized service, and grids often need it in areas where it is not possible to place wind turbines.

Other Essential Reliability Services

Black-Start Capacity

- Must be able to start on its own without grid power and create a reference grid frequency
  - Provides other generators with sufficient power to energize station power requirements, start, and synchronize
- Wind turbines typically start using external grid power.
- Parasitic/operating loads are relatively small and could be provided using a battery or small auxiliary generator.
- Some have “grid-forming” capacity, or the capability to create an AC reference.
- Primary challenge of black-start capability from wind turbines is their low capacity credit and variability.
- There has been very little analysis of the ability of wind to provide black-start capability in the United States.

Summary – Grid Services from Wind

- Both existing practices and ongoing research indicate that wind can technically provide nearly all services procured and utilized in the grid, but this ability is constrained by the geographical and temporal availability of the wind resource.

- Wind does not provide all services in U.S. regions currently due to market rules, the aforementioned constraints, and economic considerations.

- Until there is significant curtailment of wind energy, wind will likely continue to act primarily as an energy resource.

Summary – Grid Services from Wind

Service	Market Procured and Compensated Service?	Wind Can Technically Provide?[a]	Wind Currently Provides in U.S.?	Requires Pre-Curtailment for Wind to Provide?
Capacity	Y	Y	Y	N
Energy	Y	Y	Y	N
Inertial Response	N	Y	N/A	No[b]
Primary Frequency Response	Required but not compensated – proposals only	Y	Limited	Y
Fast Frequency Response	N – proposals only	Y	Limited	Y
Regulating Reserves	Y	Y	Limited	Y
Contingency – Spinning	Y	Y	Limited	Y
Contingency – Non-spinning	Y	Y	No	Y
Contingency – Replacement	Y	Maybe	No	Y
Ramping Reserves	Y (some locations)	Y	Limited	Y
Voltage Support	Y – cost of Service	Y[c] – location dependent	Limited	N
Black-Start	Y – cost of Service	Unclear, location dependent	No	N

Conclusions and Research Needs

Conclusions

- There is potential for growth in and changes to essential reliability service requirements—and potential for wind energy to provide them.

- Wind has already demonstrated the capability to provide multiple reserve services, with response rates that meet or exceed those from conventional synchronous generators.

- Major limitation in providing operating reserves is the need to pre-curtail and provide upward headroom
  - Reduces the amount of energy that can be sold
  - Little economic incentive to provide these services in today's grid

- As curtailment increases due to greater wind deployment, or as reserve requirements increase, it may become more economic for wind to provide reserves.

- Wind is far more suited for shorter-term (but more valuable) services that can take advantage of wind's rapid response rate, including FFR, PFR, and regulating reserves.

Research Needs

- Further analysis is needed to determine both the types and quantities of reserves needed to address greater variability and uncertainty of net load under future grid conditions.

- Important consideration is the evolution of energy markets under these future conditions.

- A variety of technologies including wind can provide services needed by the grid, but market products may need to be altered to align the technical needs with appropriate economic incentives.

Read the full report:
https://www.nrel.gov/docs/fy19osti/72578.pdf

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