

accenture

# NETWORK OF THE FUTURE: WIND BEYOND 50%

**Integrating high penetrations of  
wind into the transmission network**



**01**

# **INTRODUCTION**

**Electricity grids around the world were originally designed to safely, reliably and efficiently transport and deliver power from synchronously connected generators.**

With increasing amounts of wind and solar generation connected asynchronously to the grid and interfaced with the bulk power system (BPS) through power electronics, the way grids deliver greener electricity safely, reliably and efficiently will also change. At the end of 2018, there were approximately 590 GW<sup>1</sup> of global cumulative wind capacity and this generation is primarily transmission-connected. At the end of 2018, there were also about 500 GW of solar capacity,<sup>2</sup> and 25% to 50% of this capacity is utility-scale or transmission-connected (depending on the market) as a large share of solar is distribution-connected. Much of the published discussion on renewables and the grid has focused on distribution-connected resources, and the integration of energy resources connected to the low-voltage distribution system has significant implications for the transmission and distribution interface.

In this report we focus on wind generation and the transmission system, one of many topics that warrant a deep dive in understanding how the grid needs to transform. In the United States, the integration of utility-scale renewable resources, connected through power electronics, is already changing the system operation guidelines. For example, Federal Energy Regulatory Commission (FERC) Order 842 requires new generation units to have functioning primary frequency-response capability, and FERC Order 827 eliminates exemptions for newly connected wind generators from the requirement to provide reactive power. However, changes to the system operation represent only one of many levers in integrating renewables.

There are now six European countries (Denmark, Ireland, Portugal, Germany, Spain, United Kingdom) with wind penetration higher than 20%, and with plans to increase penetration above 30%. In the United States, three states have wind penetration over 30% (IA, KS, OK), three with wind penetration over 20% (SD, ND, ME) and five states with wind penetration over 15% (MN, CO, VT, TX, NM). All these markets have taken different approaches to integrating a high penetration of wind into the grid.

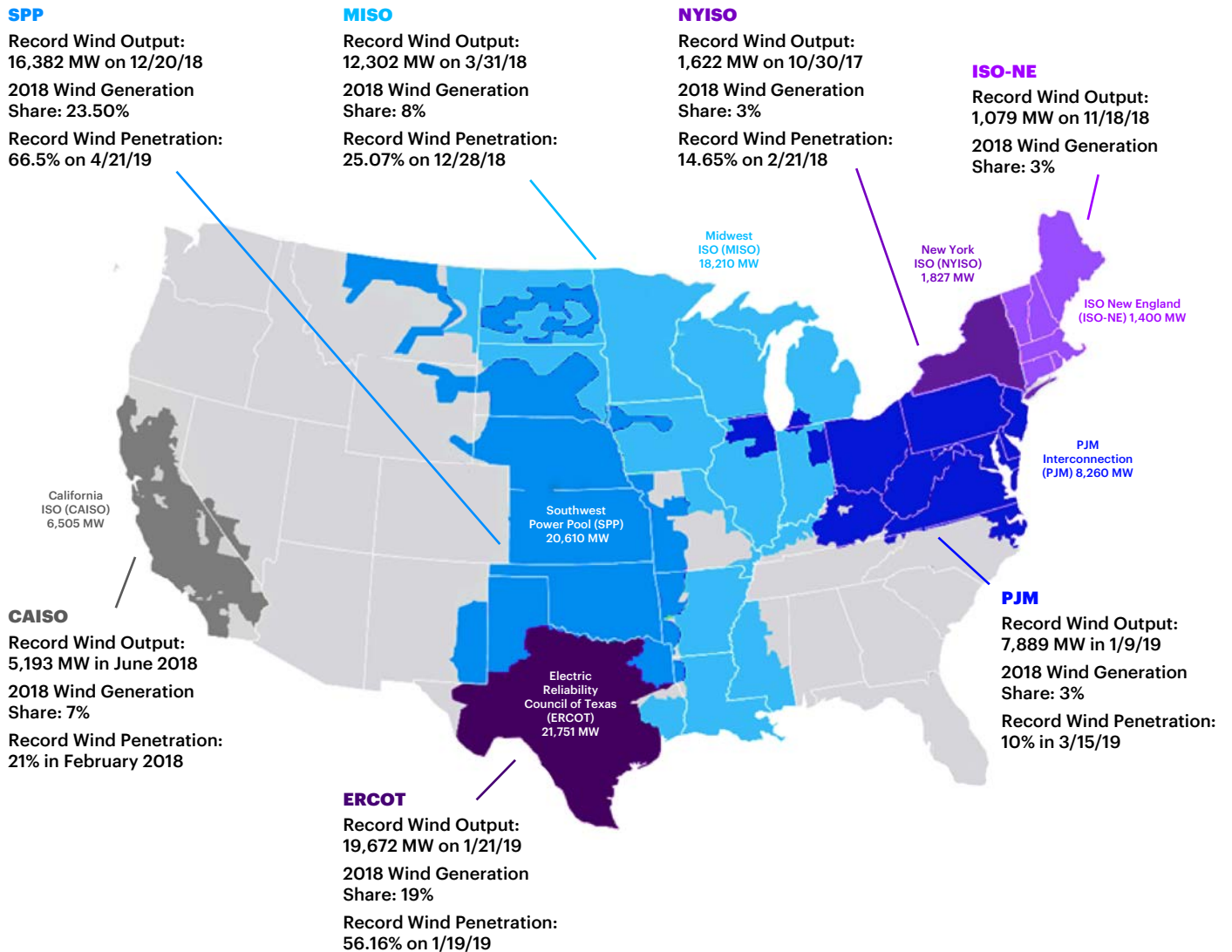
For example, in Europe, Spain benefits from significant hydropower resources it uses to complement the wind, and Germany leverages the interconnection to other European markets. The different markets are also creating new ancillary service products that take advantage of the power electronics capabilities of the new generation resources. In the United Kingdom, National Grid's fastest ancillary service tool had been Firm Frequency Response (FFR), with response times for primary and secondary FFR of 10 seconds and 30 seconds, respectively. The deployment of Enhanced Frequency Response (EFR), with a sub-second response time, will provide National Grid with greater control over frequency deviations.

Diverse approaches also exist in the U.S. Although renewable targets are set at the state level, most states are in operating regions managed by regional transmission organizations (RTO) or independent system operators (ISO) deploying a mix of market mechanisms and approaches across system operation, services from variable renewables, load management, flexible generation, transmission, and storage.



Figure 1 illustrates the diversity of wind penetration and record wind output across the RTOs in the United States. Both Southwest Power Pool (SPP) and the Electric Reliability Council of Texas (ERCOT) have significant wind penetration at 23.5% and 19%, respectively, with max wind penetration over 66% and 56%, respectively.

**Figure 1. Wind penetration across North America.**



Source: AWEA (American Wind Energy Association): <https://www.aweablog.org>.

This report provides an overview of the different options for integrating utility-scale wind and solar assets into the transmission grid (with an emphasis on wind), including case studies comparing different approaches implemented at ERCOT and SPP in the U.S., and in Europe, the U.K, and Ireland (SEM—the integrated market across Ireland and Northern Ireland), the highest wind penetration market outside of the U.S. Table 1 shows the dimensions of the markets.

**Table 1. Comparison of dimensions across SPP, ERCOT, SEM, and the United Kingdom.**

	<b>Total wind installed (GW)</b>	<b>2018/2019 % wind generation share</b>	<b>2018/2019 record wind penetration</b>	<b>2018/2019 curtailment</b>	<b>Electricity price (MWh)</b>
<b>SPP</b>	20.6 GW	23.85% (2018)	66.5% (2018)	1.29% (2018)	\$30.43 (2018 annual avg. spot, lowest in U.S.) <sup>3</sup>
<b>ERCOT</b>	28.9 GW	18.55% (2018)	56.16% (2018)	2.54% (2018)	\$41.51 (2018 annual avg. spot, mid-range U.S.) <sup>4</sup>
<b>SEM (Ireland)</b>	4.92 GW	32.9% (2019)	63% (2019)	6% (2019)	€56.85 (DAM, 10/2018 – 9/2019)
<b>United Kingdom</b>	21.7 GW <sup>5</sup>	22% <sup>6</sup> (2019)	47.9% <sup>7</sup> (2019)	3% <sup>8</sup> (2019)	£57.20 (DAM, 2018 annual average) <sup>9</sup>

Sources: See references.

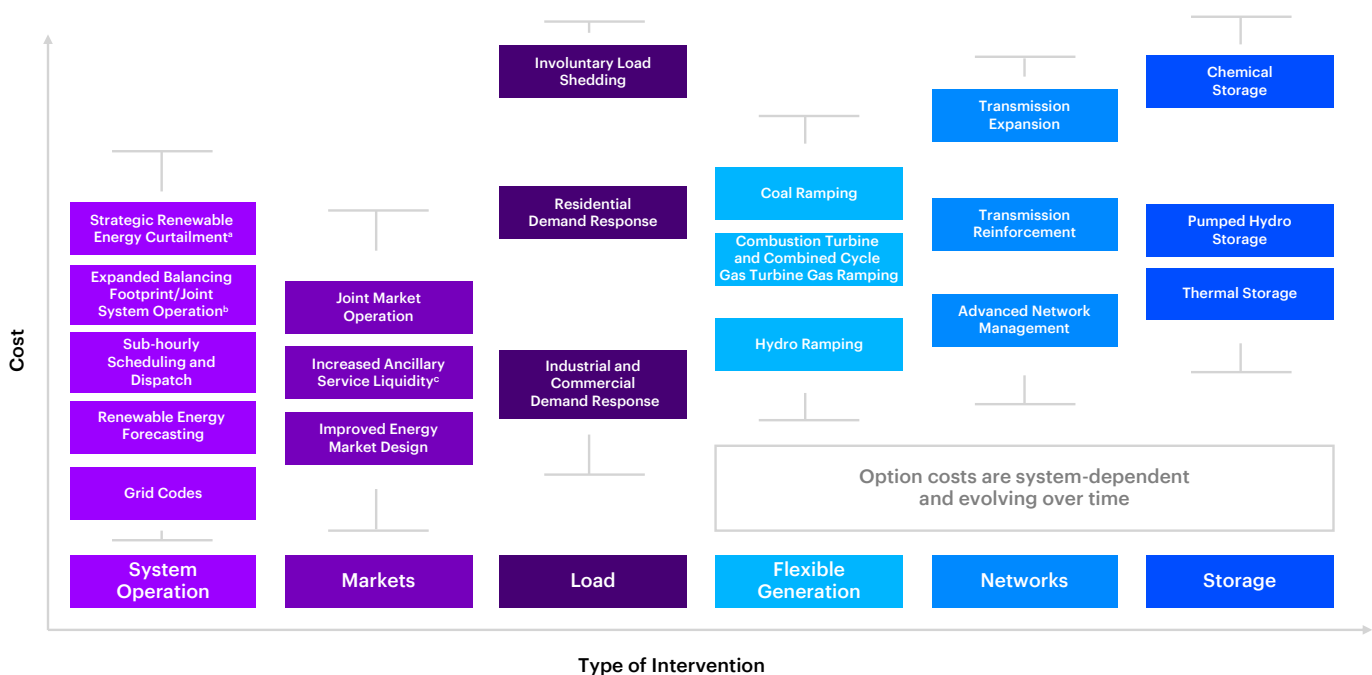
**02**

# **INTEGRATION OPTIONS FOR RENEWABLE GENERATION ASSETS**

With multiple markets achieving more than 20% wind penetration, it is widely accepted that approximately 30% penetration is possible with existing tools and learnings. However, achieving wind penetration beyond 30%, which will be required to achieve the 100% renewable electricity or net zero-emissions targets of many cities and states, will be a challenge to achieve at a reasonable cost.

In Figure 2, National Renewable Energy Laboratory (NREL) has provided an overview of the integration options and their relative costs. The optimal approach to integrating renewable assets will differ by market.

**Figure 2. NREL- relative economics of integration options.**



Source: Grid Integration and the Carrying Capacity of the U.S. Grid to Incorporate Variable Renewable Energy,” National Renewable Energy Laboratory, April 2015, [www.nrel.gov](http://www.nrel.gov).

## Notes

- There is a trade-off between costs of flexibility and benefits of reduced or no curtailment, hence a certain level of curtailment may be a sign that the system has an economically optimal amount of flexibility.
- Joint system operation typically involves a level of reserve sharing and dispatch co-optimization but stops short of joint market operation or a formal system merger.
- Wind power can increase the liquidity of ancillary services and provide generation-side flexibility. The curtailed energy is also used in many systems to provide frequency response, for example Xcel Energy (U.S.), EirGrid Group (Ireland), and Energinet (Denmark).

Table 2 provides additional descriptions of the different integration options.

**Table 2. Description of integration options.**

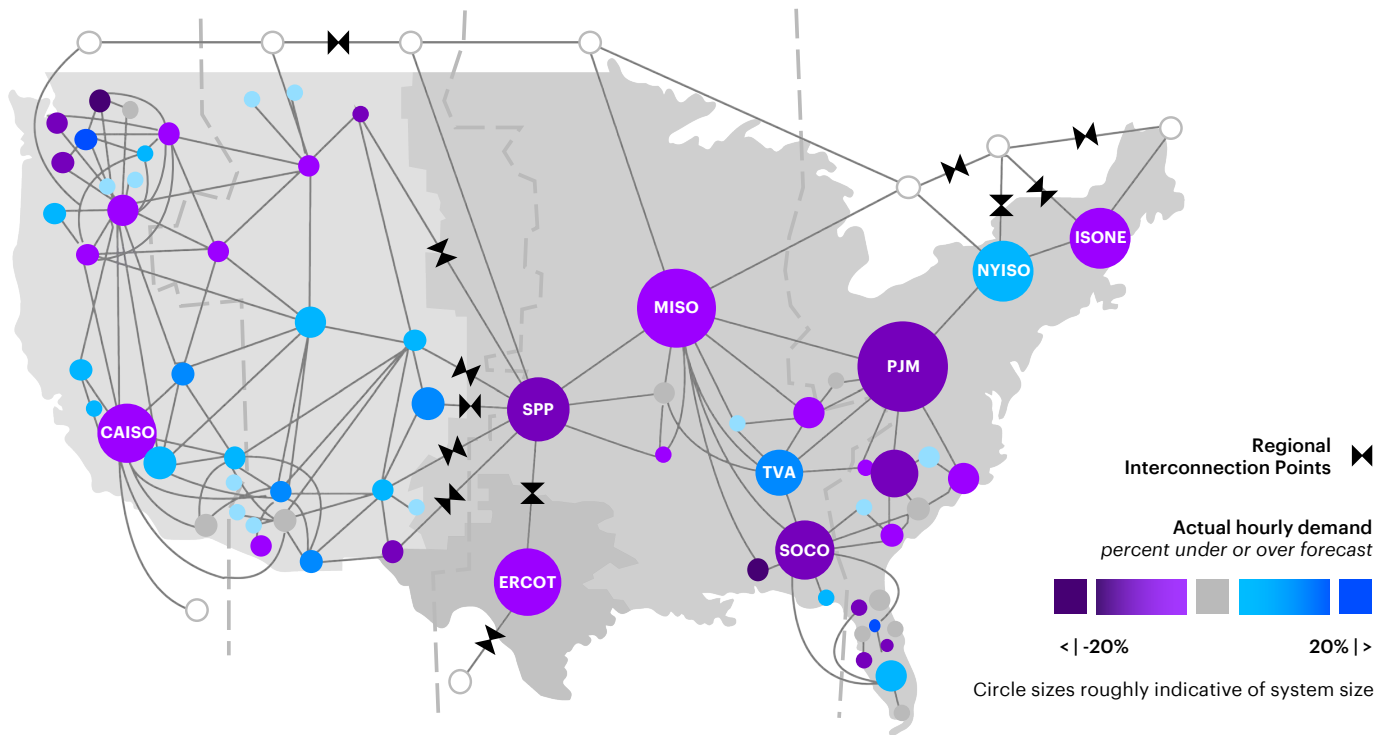
<b>Integration Option</b>	<b>Description</b>	<b>Examples</b>
<b>System Operation</b>	Change the rules for generation scheduling and dispatch; i.e., include wind forecasts, reliability requirements for participants, and interconnections with external areas.	<ul style="list-style-type: none"> <li>• Incorporate renewable generation forecasting into the overall unit commitment and dispatch formulations to improve the scheduling of other generators to reduce reserves, fuel consumption and O&amp;M costs.</li> <li>• Increase the frequency of the dispatch computations.</li> <li>• Use smart network technologies and advanced network management practices to enforce transmission constraints in the scheduling and dispatch tools, to minimize bottlenecks and optimize transmission usage.</li> <li>• Use wind and solar plants to provide voltage support.</li> </ul>
<b>Markets</b>	Change the rules on how the markets operate to better match variable renewable generation and increased connectivity across markets.	<ul style="list-style-type: none"> <li>• Implement short-term market products for flexible generation; (e.g., ramping products) to help ensure existing physical flexibility is available when needed.</li> <li>• Implement technology advancements to enable wind and solar plants to provide the full spectrum of balancing services (synthetic inertial control, primary frequency control, and automatic generation control).</li> <li>• Use wind and solar assets to provide voltage support.</li> <li>• Increase the size or connect balancing areas.</li> </ul>
<b>Load</b>	Demand-side management with automated response times within seconds to minutes.	<p>Enable demand response, particularly with commercial and industrial loads, to include:</p> <ul style="list-style-type: none"> <li>• Automated load control (within agreements set with factories) by the system operator.</li> <li>• Real-time pricing.</li> <li>• Time-of-use tariffs.</li> <li>• Interruptible load resources bidding into the energy and ancillary services markets.</li> </ul>
<b>Flexible Generation</b>	Use flexible renewable assets and conventional generation with flexibility to follow the load.	<ul style="list-style-type: none"> <li>• Use coal and gas (ideally in conjunction with carbon capture and storage [CCS]), hydro, biomass or geothermal plants that can rapidly ramp up and ramp down output to follow the net load, quickly start up and shut down, and operate efficiently at a lower minimum level during periods of high wind and solar output.</li> <li>• Firmed renewables, hybrid plants, with the ability to follow load.</li> </ul>
<b>Networks</b>	Expansion of the transmission network and connectivity across markets.	<ul style="list-style-type: none"> <li>• Provide greater access to a range of balancing resources.</li> <li>• Weather patterns are less correlated over larger areas, smoothing the variability of the wind and solar plants.</li> <li>• Aggregation of all generation assets and enlarging the balancing areas lowers the net variability and uncertainty of load.</li> <li>• Support the development of renewables in lowest LCOE areas to be transported to higher demand areas.</li> <li>• Reduce congestion costs.</li> </ul>
<b>Storage</b>	Technologies to absorb energy when its value is low and release energy when needed.	<ul style="list-style-type: none"> <li>• Storage technologies allow reducing curtailment and provide additional operational flexibility through its fast response times.</li> <li>• Many storage technologies (e.g., batteries, flywheels, supercapacitors) have fast response rates (seconds to sub-second) available over a short timeframe that can provide additional ancillary services revenue stream.</li> <li>• Other energy storage technologies, such as pumped hydro and compressed air, are better suited to offering flexibility in the timeframe of hours to days.</li> </ul>

Source: National Renewable Energy Laboratory (NREL), Accenture analysis.



In the U.S., the “market” for the optimal approach to integrating renewables is a mix of state, RTO and ISO areas with varying levels of connectivity to other markets. As illustrated in Figure 3, there are multiple balancing authorities (that maintain appropriate operating conditions for the electric system by ensuring a sufficient supply of electricity is available to serve the expected demand), and balancing can occur at multiple levels.

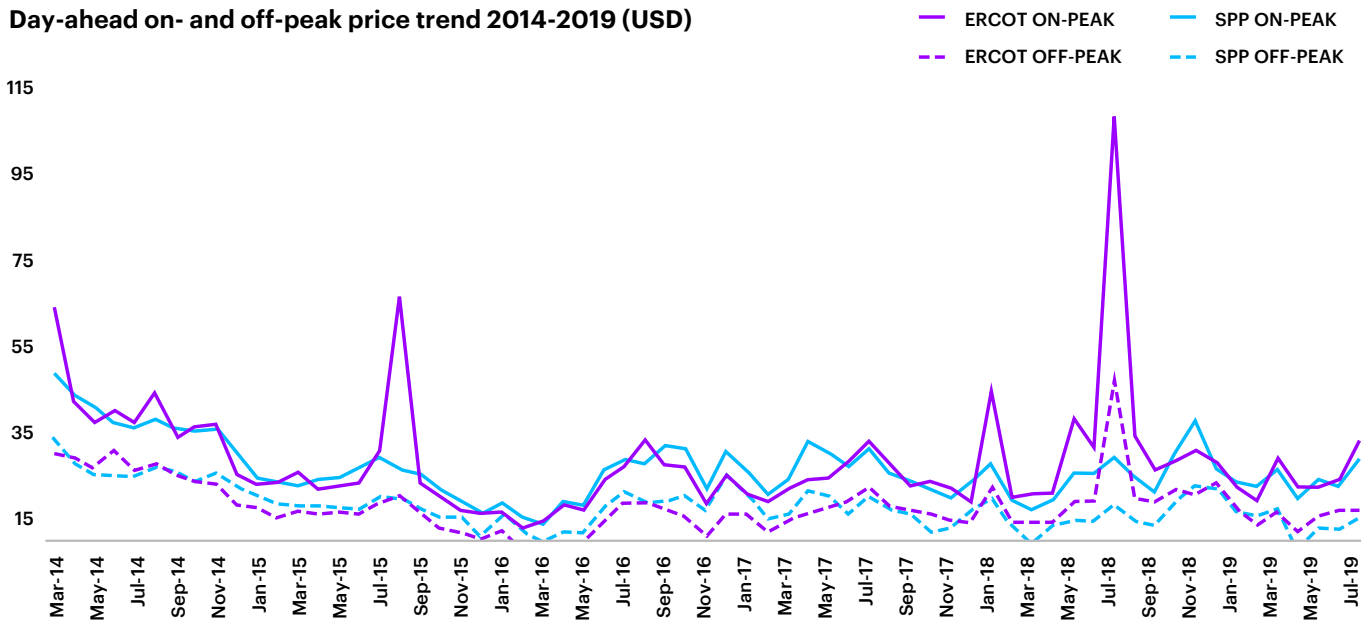
**Figure 3. Snapshot of U.S. balancing authorities.**



Source: “Hourly Electric Grid Monitor,” Energy Information Administration, [www.eia.gov](http://www.eia.gov).

Additionally, depending on the approach taken to integrate renewables, there will be a difference in the cost of electricity and the volatility of the prices. Figure 4 compares the wholesale electricity prices in SPP and ERCOT. Both markets have high penetrations of wind, relatively low curtailment and no forward capacity markets. However, although the off-peak prices are similar, the on-peak prices in ERCOT are much more volatile than SPP.

**Figure 4. Comparison of ERCOT and SPP on-peak and off-peak prices.**



Source: S&P Global Market Intelligence; Accenture analysis.

The following case studies will deep-dive on the approaches to integrating renewables taken by ERCOT and SPP in the United States, by SEM, where EirGrid Group acts as a single balancing authority across Ireland and Northern Ireland, and by the United Kingdom.

# 03

## ERCOT: A RESOURCE-RICH ISLAND WITH CREZ

The ERCOT region has the strongest load growth anywhere in the United States. Driven by oil- and gas-related activity along with general population growth, ERCOT’s weather-adjusted load—which attempts to estimate load under seasonally normal weather conditions—has consistently grown by at least 2% per year, while most other regions are flat or in decline.

Texas continues to rely more heavily on wind generation each passing year. While that means lower emissions and generally lower energy prices, it also means managing increased variability during periods of shortage that could lead to price spikes.

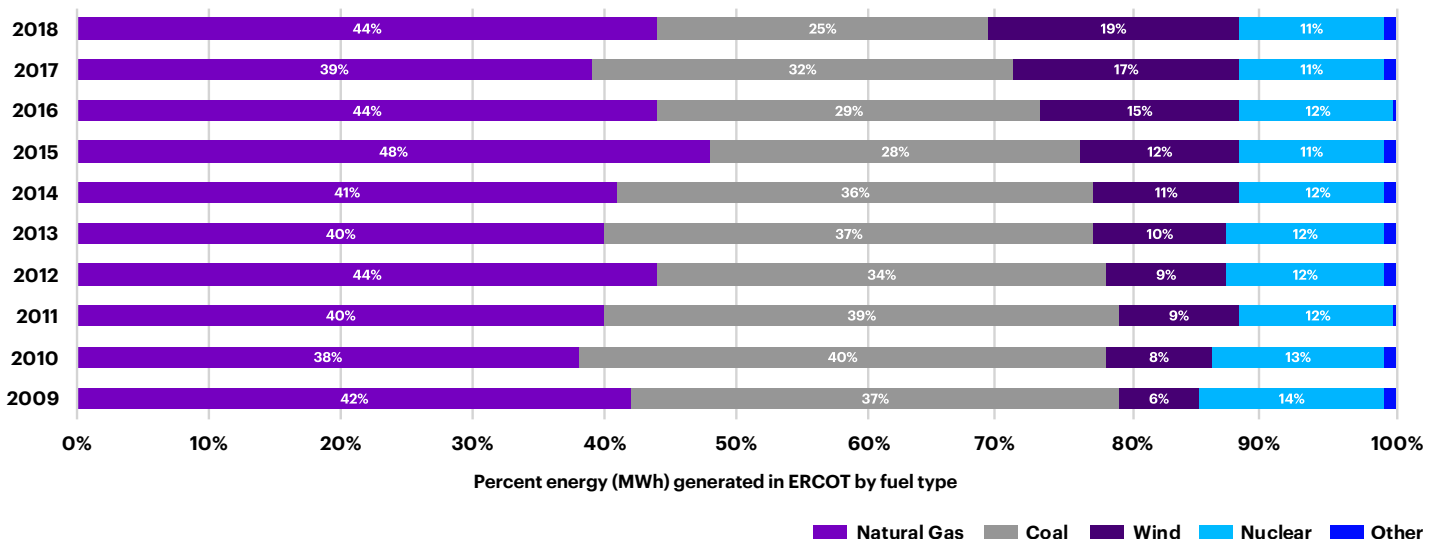
A major reason for the volatility of the ERCOT market is that the ERCOT power system is electrically isolated from the Eastern and Western interconnections. The only connections between the ERCOT grid and its neighboring electrical systems is via direct current (DC) ties. Being an electrical island makes ERCOT particularly vulnerable to the variability of wind and solar generation.

ERCOT’s dramatic increase in renewable energy deployment is the result of the economics of wind and solar power, facilitated by the state energy policy to integrate its significant western wind resources to eastern cities, known as Competitive Renewable Energy Zones (CREZ). Since the CREZ began in 2009, the wind generation capacity has grown from 6% to 19% of ERCOT’s energy mix.

When the wind generation peaks (typically at night), it can supply more than half of the total ERCOT demand. The highest recorded percentage is 56.16% of the grid demand. Additionally, since 2009, the amount of wind generation being curtailed due to lack of transmission and demand has shrunk from about 17% in 2009 to less than 0.5% in 2014 to 2.54% in 2018,<sup>10</sup> a result of \$7 billion in new transmission capacity enabled by CREZ, as well as ERCOT’s work to build weather forecasting and demand management into the grid operations infrastructure.

**Figure 5. ERCOT energy mix.**

**A decade of ERCOT fuel mixes**



Source: Greentech Media/The University of Texas at Austin Energy Institute, <https://greentechmedia.com>.

A key element of CREZ is the premise that the cost of connectivity to the transmission infrastructure is the same for all generators, irrespective of how far away from demand electricity is generated. This policy has supported the development of wind resources (and other renewable and conventional resources) far away from the demand centers. Recently, Calpine and NRG tried to change this policy by proposing that transmission losses be charged based on the distance the electricity traveled. This would have disadvantaged wind generators (and any other generators) that developed plants far away from demand centers. This proposal was rejected by the Public Utility Commission of Texas.

ERCOT's approach to integrating renewables has included changes to the operation of the power system, market structure, management of demand resources and use of flexible baseload generation.

## **System Operation – Power System Changes**

The ERCOT protocols describe the scheduling, operation, planning, reliability and settlement policies, rules, guidelines, procedures, standards and criteria of ERCOT including the performance monitoring requirements. These requirements detail how the performance of ERCOT, the transmission service providers (TSPs) and the qualified scheduling entities (QSEs) are measured against the requirements of these protocols. ERCOT continually assesses its operations performance for the following activities:

- Coordinating the wholesale electricity market transactions
- System-wide transmission planning
- Network reliability

In addition, ERCOT publishes system adequacy reports to assess the adequacy of the resources and transmission facilities to meet the forecasted demand. ERCOT provides reports on a system-wide basis and by forecast zone, where applicable.

Also, since the power system inertia has been declining as a consequence of the increasing penetration of renewables, ERCOT continually monitors the system inertia in real-time to ensure that it stays above the critical level currently set at 100 GWs.

## **Markets – Ancillary Services and Load Management**

ERCOT is responsible for procuring ancillary services as needed to maintain grid security and reliability, consistent with ERCOT and North American Electric Reliability Corporation (NERC) standards. The ERCOT protocols recognize the following ancillary services:

- **Regulation Up Service (Reg-Up):** A service providing capacity that can respond to signals from ERCOT within five seconds to correct deviations from the scheduled system frequency. The amount of Reg-Up capacity is the amount of capacity available from a resource that may be called on to change its output as necessary to maintain a proper system frequency. A generation resource providing Reg-Up must be able to increase energy output when deployed and decrease energy output when recalled. A load resource providing Reg-Up must be able to decrease load when deployed and increase load when recalled. ERCOT dispatches Reg-Up by a load frequency control (LFC) signal.



- **Fast Responding Regulation Up Service (FRRS-Up):** A subset of Reg-Up in which the participating resource provides Reg-Up capacity to ERCOT within 60 cycles of either its receipt of an ERCOT dispatch instruction or its detection of a trigger frequency independent of an ERCOT dispatch instruction. Except where otherwise specified, all requirements that apply to Reg-Up also apply to FRRS-Up. The LFC signal for FRRS-Up is separate from the LFC signal for other Reg-Up.
- **Regulation Down Service (Reg-Down):** A service providing capacity that can respond to signals from ERCOT within five seconds to correct deviations from the scheduled system frequency. The amount of Reg-Down capacity is the amount of capacity available from a resource that may be called on to change its output as necessary to maintain a proper system frequency. A generation resource providing Reg-Down must be able to decrease energy output when deployed and increase energy output when recalled. A load resource providing Reg-Down must be able to increase load when deployed and decrease load when recalled. ERCOT dispatches Reg-Down by an LFC signal.
- **Fast Responding Regulation Down Service (FRRS-Down):** A subset of Reg-Down in which the participating resource provides Reg-Down capacity to ERCOT within 60 cycles of either its receipt of an ERCOT dispatch instruction or its detection of a trigger frequency independent of an ERCOT dispatch instruction. Except where otherwise specified, all requirements that apply to Reg-Down also apply to FRRS-Down. The LFC signal for FRRS-Down is separate from the LFC signal for other Reg-Down.
- **Responsive Reserve Service (RRS):** A service used to restore or maintain the frequency of the ERCOT system in response to—or to prevent—significant frequency deviations, as backup regulation service, or by providing energy during an Energy Emergency Alert (EEA). RRS may be provided by using frequency-dependent response from online resources to help restore the frequency within the first few seconds of an event that causes a significant frequency deviation in the ERCOT system and/or manually or by using a four-second signal to provide energy on deployment by ERCOT. RRS may be used to provide energy during the implementation of an EEA. Under the EEA, RRS provides generation capacity, capacity from controllable load resources or interruptible load available for deployment on 10 minutes' notice. RRS may be provided by:
  - Unloaded, online generation resource capacity.
  - Load resources controlled by high-set, under-frequency relays.
  - Controllable load resources.
  - Hydro RRS as defined in the operating guides.
- **Non-spinning Reserve Service (Non-Spin):** Provided by using generation resources, whether online or offline, capable of being synchronized and ramped to a specified output level within 30 minutes and running at a specified output level for at least one hour, or controllable load resources qualified for dispatch by security-constrained economic dispatch (SCED) and capable of ramping to an ERCOT-instructed consumption level within 30 minutes and consuming at the ERCOT-instructed level for at least one hour. Non-Spin may be deployed by ERCOT to increase available reserves in real-time operations.

- **Voltage Support Service (VSS):** ERCOT, in coordination with the TSPs, establishes and updates, as necessary, the ERCOT System Voltage Profile and posts it on the market information system secure area. ERCOT, the interconnecting TSP or that TSP's agent may modify the voltage setpoint described in the voltage profile based on current system conditions. All generation resources (including self-serve generating units) that have a gross rating greater than 20 MVA or those units connected at the same point of interconnection (POI) that have gross ratings aggregating to greater than 20 MVA, that supply power to the ERCOT transmission grid, must provide VSS. Each generation resource required to provide VSS must comply with the following reactive power requirements:
  - An overexcited (lagging or producing) power factor capability of 0.95 or less, determined at the generating unit's maximum net power to be supplied to the ERCOT transmission grid and the generation resource's setpoint in the voltage profile measured at the POI.
  - An underexcited (leading or absorbing) power factor capability of 0.95 or less, determined at the generating unit's maximum net power to be supplied to the ERCOT transmission grid and the generation resource's setpoint in the voltage profile measured at the POI.
  - The reactive power capability must be available at all MW output levels and may be met through a combination of the generation resource's unit reactive limit (URL), which is the generating unit's dynamic leading and lagging operating capability, and/or dynamic var-capable devices. This reactive power profile is depicted graphically as a rectangle. For variable renewable resources (VRRs), the reactive power requirements must be available at all MW output levels at or above 10% of the VRR's nameplate capacity. When a VRR is operating below 10% of its nameplate capacity and is unable to support voltage at the POI, ERCOT may require a VRR to disconnect from the ERCOT system for purposes of maintaining grid reliability.
- As part of the technical resource testing requirements prior to the commissioning date, all generation resources must conduct an engineering study, or demonstrate through performance testing, compliance with the reactive power capability requirements. Any study or test results must be accepted by ERCOT prior to the resource commissioning date.
- Wind generation resources (WGRs) that commenced operation on or after February 17, 2004, and have a signed Standard Generation Interconnection Agreement (SGIA) on or before December 1, 2009 ("Existing Non-Exempt WGRs"), must be capable of producing a defined amount of reactive power to maintain a setpoint in the voltage profile established by ERCOT in accordance with the reactive power requirements established above.
- **Black Start Service:** An ancillary service provided by a generation resource that can start without support of the ERCOT transmission grid.
- **Reliability Must-Run Service (RMR):** An ancillary service provided from an RMR unit under an agreement with ERCOT. An RMR unit is a generation resource that would not otherwise be operated except that it is necessary to provide voltage support, stability or management of localized transmission constraints under credible single contingency criteria where market solutions do not exist.

After years of declining quantities, the total requirements for ancillary services increased in 2018 to greater than 4,900 MW, an increase from the average total requirement of approximately 4,800 MW in 2017 and roughly equal to the 2016 requirements. The principal cause for the overall increase in ancillary service requirements in 2018 was larger responsive reserve requirements due to an emphasis on ensuring adequate online system inertia. Figure 6 compares the average annual price for each ancillary service in 2018 with respect to 2017. The higher prices for the Responsive, Non-Spin and Reg-Up services in 2018 are explained by the combination of larger requirements, and expectations for high energy prices as evidenced by higher day-ahead energy prices. The decrease in the average price for the Reg-Down service is explained by lower opportunity costs of providing that service due to more on-line capacity to meet the higher load requirements in 2018.

## Load – Demand Response

Demand resources participate in the ancillary services markets and are critical to the balancing of supply and demand given ERCOT’s low reserve margin (difference between total generation and forecasted peak demand). The reserve margin was 8.6% entering the 2019 peak summer demand.<sup>11</sup> As a result, ERCOT is proactive in publishing information to allow demand to adjust based on price signals. For example, ERCOT launched an app in 2012 to help consumers conserve electricity. This app now includes current electric demand and operating reserves, important real-time notifications, and real-time wholesale prices.<sup>12</sup> When tight conditions were expected in September 2019, ERCOT requested conservation on specific days and times: “Consumers and businesses are urged to reduce their electricity use on Thursday, September 5 and Friday, September 6, especially during the hours of 2 p.m. to 7 p.m.” and explained how to do this in steps to reduce electricity use.<sup>13</sup> ERCOT also publishes its peak-load forecasts in seasonal assessments.

**Figure 6. ERCOT ancillary service prices.**

	2017 (\$/MWh)	(+/-)	2018 (\$/MWh)
<b>Responsive Reserve</b>	<b>\$9.77</b>	<b>+7.87</b>	<b>\$17.64</b>
<b>Non-spin Reserve</b>	<b>\$3.18</b>	<b>+6.02</b>	<b>\$9.20</b>
<b>Regulation Up</b>	<b>\$8.76</b>	<b>+5.27</b>	<b>\$14.03</b>
<b>Regulation Down</b>	<b>\$7.48</b>	<b>-2.29</b>	<b>\$5.19</b>

Source: 2018 State of the Market Report for the ERCOT Electricity Markets, <https://www.potomaceconomics.com>.

## Networks – Transmission Infrastructure Development

Infrastructure has been the cornerstone of ERCOT's integration of renewable resources, and it continues to actively manage the grid infrastructure development. Each TSP, QSE and resource entity must coordinate with ERCOT the requirements for the following types of work for any addition to, replacement of, or change to or removal from the ERCOT transmission grid:

- Transmission lines
- Substation equipment including transformers, reactive devices, circuit breakers and disconnects
- Resource interconnections
- Protection and control schemes, including changes to remedial action plans (RAPs), supervisory control and data acquisition (SCADA) systems, energy management systems (EMS), automatic generation control (AGC), remedial action schemes (RAS) and automatic mitigation plans (AMP)

ERCOT and the TSPs evaluate the need for transmission system improvements and evaluate the relative value of alternative improvements based on established technical and economic criteria. The technical reliability criteria are established by the planning guide, operating guides and the NERC Reliability Standards. ERCOT attempts to meet these reliability criteria as economically as possible and actively identifies economic projects to meet this goal.

The generation interconnection process facilitates the interconnection of new generating units in the ERCOT region by assessing the transmission upgrades necessary for the new units to operate reliably. The process to study interconnecting new generation or modifying an existing generation interconnection to the ERCOT transmission grid is covered in the planning guide. The generation interconnection study process primarily addresses the direct connection of generation facilities to the ERCOT transmission grid and directly related projects. Projects identified through this process and are regional in nature may be reviewed through the regional planning group project review process upon recommendation by the TSP or ERCOT, subject to the confidentiality provisions of the generation interconnection procedure.

ERCOT performs an independent economic analysis of the transmission projects identified through this process that are expected to cost more than \$25 million. This economic analysis is performed only for informational purposes. No ERCOT endorsement is provided. The results of the economic analysis are included in the interconnection study posting.

## Outlook

ERCOT is constantly preparing for the future by developing and evaluating market rules, protocols and technologies to reliably manage a changing electric system. ERCOT serves as an information resource to the Public Utility Commission of Texas (PUCT) and stakeholder groups. In 2018, ERCOT performed studies and analyses related to the planning reserve margin and proposed market design changes. In early 2019, the PUCT directed ERCOT to move forward with the implementation of co-optimization in the ERCOT real-time market.

In the summer months, tight supplies in ERCOT lead to greater imports from SPP. ERCOT has 810 MW of DC ties with SPP. ERCOT is an energy island but there are DC transmission connections to SPP, plans for future connections, and a coordination agreement.<sup>14</sup>

In 2018, ERCOT worked with stakeholders to develop a standard approach for obtaining the data needed to map registered distributed energy resources (DERs) to their appropriate transmission loads. Mapping registered DER units to their locations will improve situational awareness and help grid operators more accurately assess the ERCOT system conditions.

In the future, energy storage technology will also be a significant resource in ERCOT. More than 2,300 MW of new battery capacity was under study as of December 2018. ERCOT has limited visibility into the operational status of these resources and is working with energy storage owners and developers to improve how information is shared with ERCOT.

Digital has clearly played a critical role in ERCOT's ability to integrate renewables, forecast loads, provide the appropriate signals and data and market information to participants, and manage its markets.



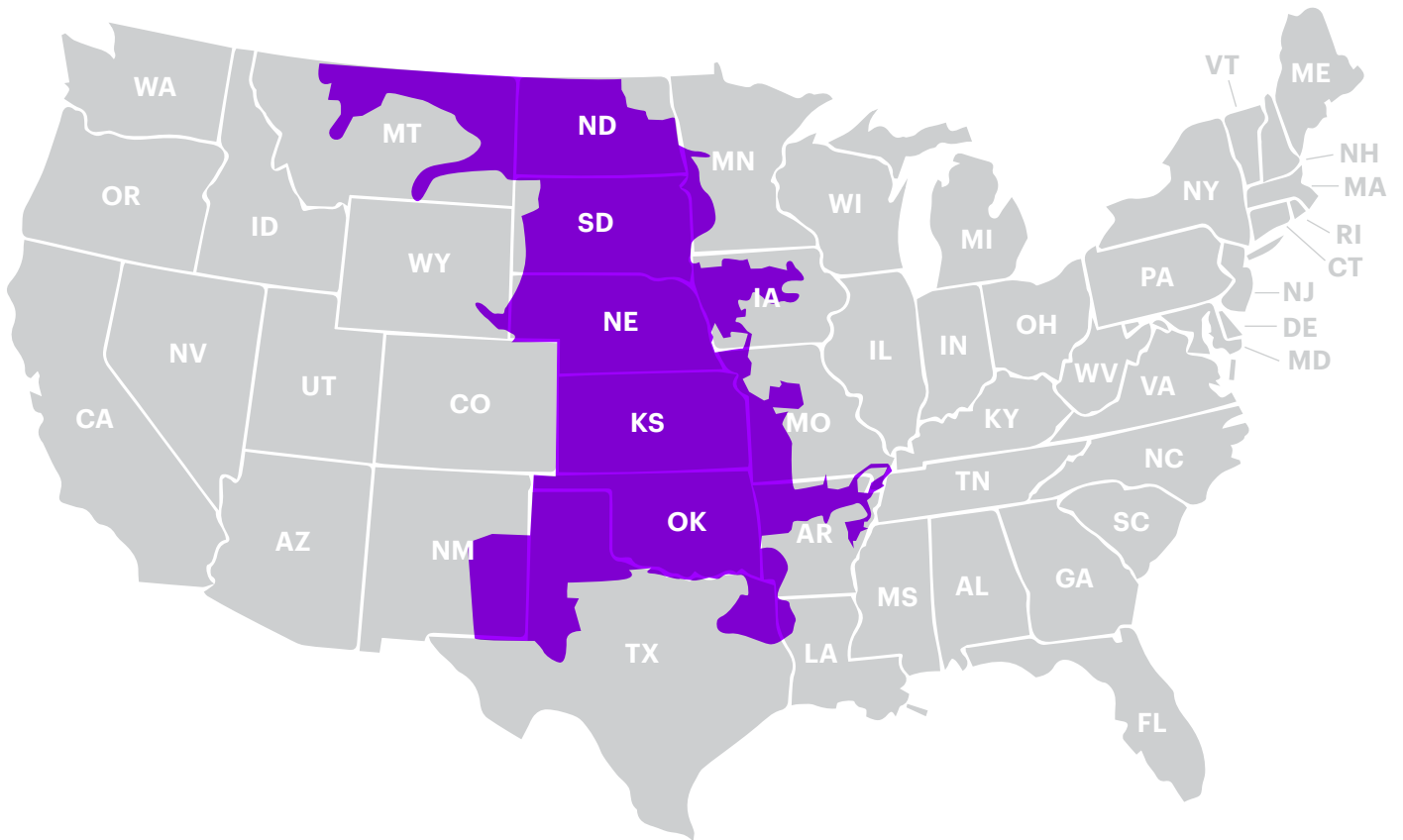


# 04

## **SPP: COMPETITIVE WIND RESOURCE WITH INCREASING MARKET INTERCONNECTIONS**

The SPP operating region spans 14 states from parts of Texas to North Dakota. For this large region, SPP acts as reliability coordinator managing the system operation and operating reserves, as balancing authority maintaining the balance of generation and load in real time, forecasting electricity demand and ensuring there is enough generation moment by moment to meet the actual load, and as TSP for the NERC Open Access Transmission Tariff (OATT), administering the provisions of the tariff and providing transmission service to the transmission customers under the applicable transmission service agreements.

**Figure 7. SPP footprint.**

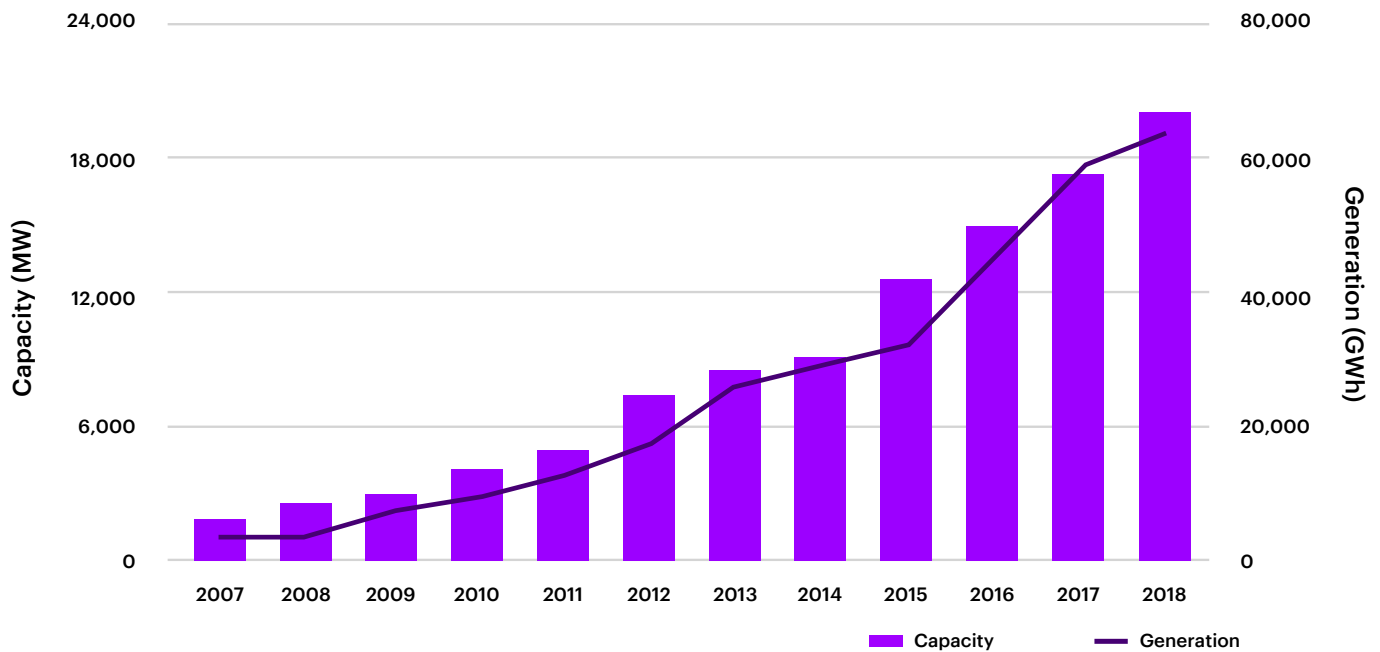


Source: Electric Power Markets: Southwest Power Pool (SPP), Federal Energy Regulatory Commission (FERC), [www.ferc.gov](http://www.ferc.gov).

SPP has interconnections with MISO, ERCOT, WECC, the Southwestern Power Administration (SPA), and the Associated Electric Cooperative (AECI). SPP manages the interconnections and seam agreements, including the development of tools that support interconnection-wide congestion management and seam coordination. SPP is a net exporter of low-cost wind to those markets.

SPP had the lowest average wholesale electricity prices nationwide in 2018 at \$30.34/MWh.<sup>15</sup> One of the main reasons is that SPP has some of the most competitive wind resources with the highest capacity factors in the U.S. The top six states by capacity factors are all in SPP: Kansas (42.1%), Nebraska (43.4%), New Mexico (40.9%), North Dakota (39%), Oklahoma (41.7%) and South Dakota (38.9%). The U.S. 2018 record low average wind CAPEX \$1,277/kW and LCOE \$31.7/MWh are in SPP (Kansas).<sup>16</sup> As a result, the total capacity of the wind generation assets in SPP has increased dramatically in the past decade to more than 23% of generation capacity to 20.6 GW in 2018.<sup>17</sup>

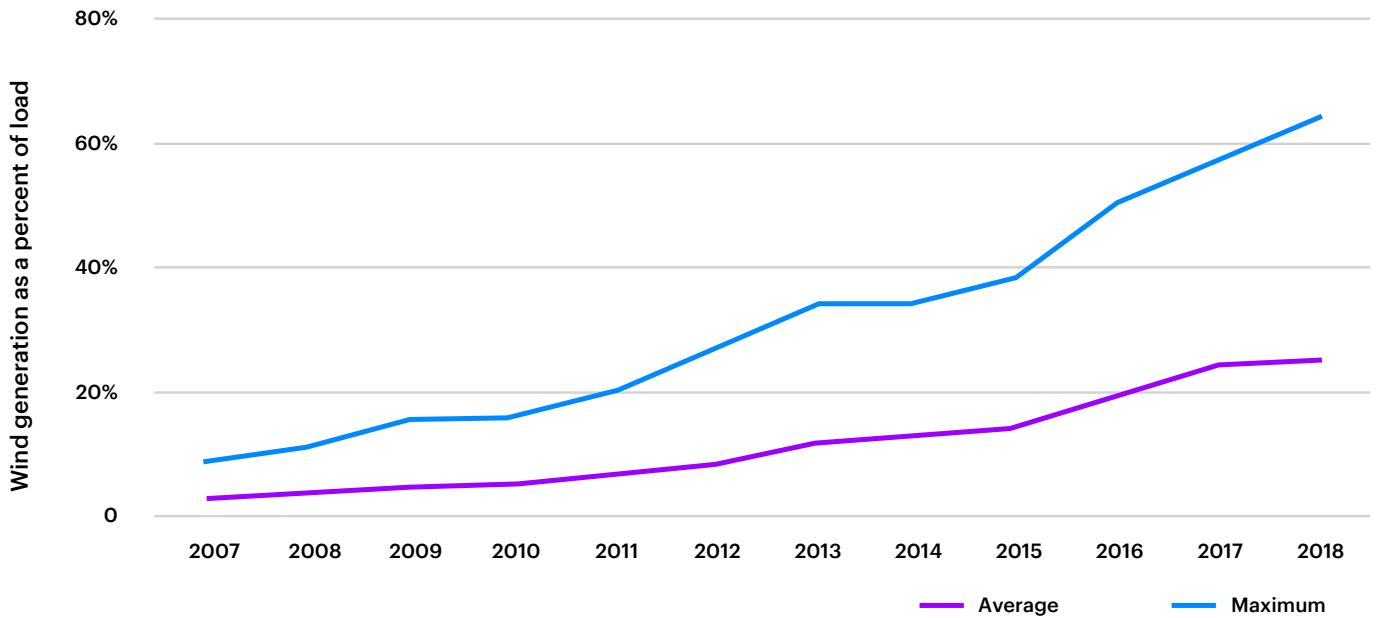
**Figure 8. Growth in wind capacity in SPP.**



Source: SPP State of the Market 2018, <https://www.spp.org>.

Since the start of the SPP market, the average and maximum annual wind generation as a percent of load have also increased rapidly as illustrated in Figure 9, to an average of 25% of load and a peak of 64% of load in 2018. In 2019, the peak load increased to 66.5%. Despite this high penetration, curtailment at SPP in 2018 was only 1.29%.<sup>18</sup> It is worth noting that wind is counter-cyclical in SPP.

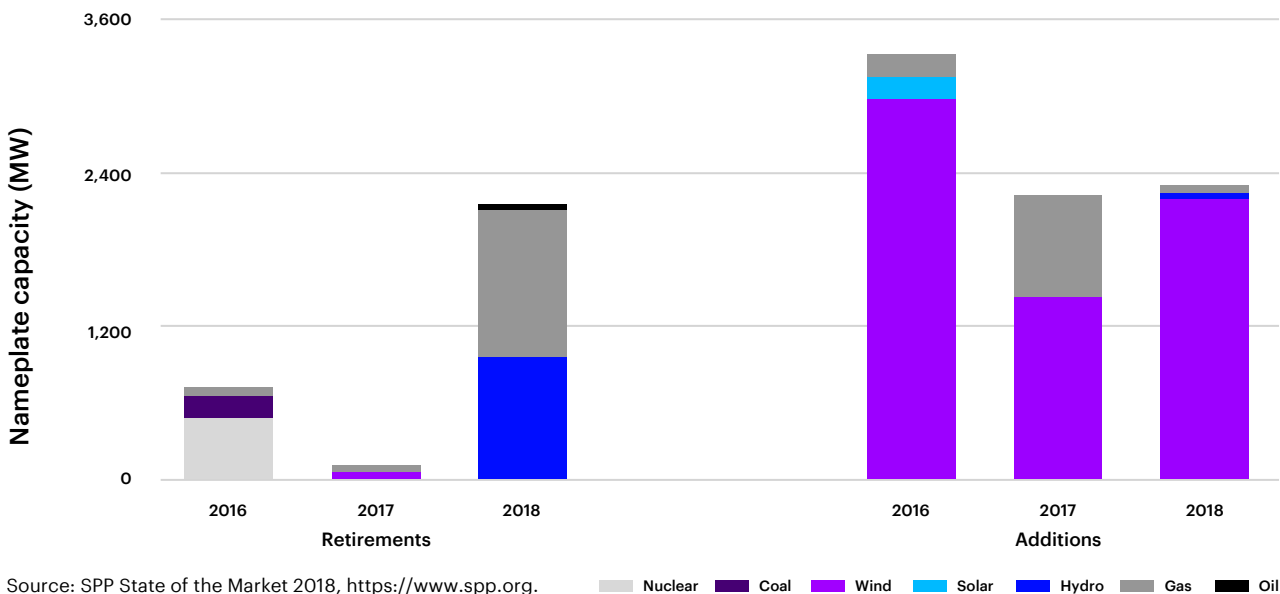
**Figure 9. Wind generation in SPP as a percentage of the load.**



Source: SPP State of the Market 2018, <https://www.spp.org>.

Wind and other renewables will grow in SPP as there is more than 83,000 MW of projects in the interconnection queue and only 312 MW is from fossil-fuel generation, with the remainder from renewables or storage resources.<sup>19</sup> As illustrated in Figure 10, this is consistent with the trend over the past few years.

**Figure 10. Capacity retirements and additions in SPP.**



Source: SPP State of the Market 2018, <https://www.spp.org>.

Legend: Nuclear (grey), Coal (dark purple), Wind (purple), Solar (cyan), Hydro (blue), Gas (grey), Oil (black)

The wind resources have also provided SPP with generation capacity compared to peak load, improving reliability. For 2018, the peak available capacity was 35%, nearly three times higher than SPP's minimum required planning reserve margin of 12%.

However, SPP has faced several operational challenges in dealing with substantial wind capacity. Wind energy output varies by season and time of day. This variability is estimated to be about three times more than the load when measured on an hour-to-hour basis. Moreover, wind is counter-cyclical to the load; i.e., as the load increases (both seasonally and daily), the wind production typically declines. One of the most significant challenges has been congestion, resulting in high congestion charges.

SPP began developing new energy markets in 2009 to address these operational challenges. The SPP Integrated Marketplace has successfully grown the wind capacity while keeping curtailment and wholesale electricity prices low. The SPP Integrated Marketplace was launched in 2014 and includes:

- A day-ahead market with transmission congestion rights.
- A Reliability Unit Commitment process.
- A real-time balancing market replacing the EIS market.
- Incorporation of price-based operating reserve procurement.
- Consolidation of the 16 legacy balancing authorities into one SPP balancing authority.

SPP has a Market Monitoring Unit (MMU) responsible for monitoring the SPP markets and services, including an evaluation of the market rules and market design features for market efficiency, fairness and effectiveness. Specific duties of the MMU include:

- Obtaining objective information about SPP's markets and services.
- Assessing the behavior of the market participants.
- Assessing the behavior of other markets and services that impact SPP.
- Detecting structural problems and design flaws in the operating rules, standards, procedures and practices in SPP's markets.
- Assessing the mechanism that governs the transmission markets independently or as a result of complaints or requests for an inquiry.

Selected key elements of SPP's approach to integrating renewables are outlined below.

## **System Operation – Import/Export Interconnection**

SPP is a net exporter of low-cost wind generation and this is expected to grow. SPP has deep experience managing the interface to neighboring markets, with greater than 15 GW of import/export interconnection capacity with neighboring balancing authorities expanding its balancing footprint.



**Table 3. Capacity of physical connections to SPP.**

Balancing Authority	Capacity (MW) of Intertie
MISO	6,000 (AC)
ERCOT	810 (DC)
WECC	>1,000 (DC)
Southwestern Power Administration (SPA)	>1,500
Associated Electric Cooperative (AECI)	5,000 (AC)

Source: SPP State of the Market 2018, <https://www.spp.org>.

SPP is a net exporter to ERCOT, MISO and AECI, with exports generally following the wind production curve with variations sometimes driven by ERCOT and MISO price differentials. SPP is a net importer of hydro power from SPA, particularly during on-peak hours but is scheduled day ahead. SPP also has a market-to-market process with MISO. Under the joint operating agreement, the RTOs collaborate to efficiently manage market-to-market constraints by exchanging information (shadow prices, relief request, control indicators, etc.) and using the RTO with the more economic redispatch to relieve congestion. The RTOs also work together on transmission planning and to address congestion volatility to better manage price and power swings.

### **System Operation – Dispatchable Wind Capacity**

An increase in dispatchable wind capacity has improved the ability of SPP to optimize variable resources. For example, lower wind output during the summer months means SPP does not need to reduce the dispatchable variable energy resource output during these times. This increase in

dispatchable wind capacity, coupled with an increase in transmission capacity, has helped in the management of congestion caused by high levels of wind generation.

There are further issues with non-dispatchable wind capacity, in particular, “price-chasing” behavior. Price chasing occurs when non-dispatchable variable energy resources or resources on manual control respond to prices by curtailing output in response to lower prices and increasing production when prices rise. This behavior increases volatility in market prices, oscillations on constraints, more regulation needs, and more output loss due to increased regulation. Additionally, some non-dispatchable resources are physically incapable of responding to dispatch signals or when they are acting as “price takers.” In these instances, the non-dispatchable variable energy resource is operating uneconomically and results in transmission congestion, creating greater price differences and volatility.

## Markets – Ancillary Services

The primary operating reserve products at SPP include the following:

- **Reg-Up and Reg-Down Services:** Generators increase or decrease output to ensure total generation matches the total load on a subinterval basis. Generators respond to regulation instructions within seconds.
- **Regulation mileage:** In addition to the regulation capacity payments, resources deployed for regulation also receive payments for costs incurred when moving from one setpoint instruction to another. These mileage payments are paid directly through Reg-Up and Reg-Down payments in the day-ahead market. The market calculates a mileage factor for both products each month that represents the percentage a unit is expected to be deployed compared to what it cleared. If a unit is deployed more than the expected percentage, then the unit is entitled to reimbursement for the excess at the regulation mileage marginal clearing price. If the unit is deployed less, the position must be bought back.
- **Spinning Reserve:** Increasing the power output of generators connected to the system, respond to instruction within 10 minutes.
- **Supplemental Reserve:** Reserved for contingency situations and respond to instructions within 10 minutes.

A few additional items to highlight in SPP's ancillary service markets:

- **Regulation mileage price inefficiency:** The MMU identified a mileage price inefficiency. Mileage prices are not set by the marginal cost of mileage like other products. Instead, units are cleared for regulation based on what are known as regulation service offers. These service offers are calculated by taking the competitive offer for regulation and adding the mileage offer to it after discounting the mileage offer by the mileage factor. The MMU has found that this process is open to manipulation.
- **Ramp product needed:** Ramp capability is needed to balance deviations between generation and load. Unlike capacity, the ramp service is not procured ahead of time. A resource's ramp rate is used to calculate its dispatch instruction. A resource will generally not be dispatched beyond the capability of the resource's ramp rate. The ramp rate is used only to calculate the current dispatch instruction. Unlike capacity, the market clearing engine does not specifically procure ramp ahead of time to meet these intra-hour net load changes, although committed capacity usually comes with incidental ramp capability. Because the committed capacity must have ramp capability, the market clearing engine should specifically procure and incentivize rampable capacity.

## **Markets – Congestion and Congestion Transmission Rights Market**

The congestion costs in SPP are significant. In 2018, the annual average day-ahead market prices ranged from around \$16/MWh on the western edge of Nebraska, to around \$36/MWh in the southcentral section of Oklahoma. About 75% of this price variation can be attributed to congestion and 25% to marginal losses, which is consistent with prior years. Because congestion is more volatile in the real-time market, the average geographic price range is slightly larger, from \$14/MWh to \$38/MWh.

Transmission upgrades and expansion have reduced congestion and more projects are planned. However, a key element to managing congestion is the transmission congestion rights market. Market participants take part in the congestion hedging market by obtaining auction revenue rights and/or transmission congestion rights. Auction revenue rights begin as entitlements associated with long-term, firm transmission service reservations. Transmission owners receive revenues from transmission customers for building and maintaining the transmission lines, and transmission customers pay the transmission owners for the use of the lines by way of the charges associated with transmission service reservations.

## **Networks – Transmission Infrastructure Development**

The biggest challenge is clearly congestion, so the annual integrated transmission planning assessment is critical. Increased transmission capability has reduced localized congestion, creating a more integrated grid with higher diversity and greater flexibility to manage high levels of wind generation, but with even more variable capacity planned, increased investment in transmission is critical.

In October 2019, the SPP board approved the 2019 Integrated Transmission Plan, requiring SPP members to construct 44 new transmission projects, including 166 miles of 345-kV lines. These upgrades are expected to reduce SPP's wholesale energy congestion costs by 21% on average, providing estimated future net savings of up to 23 cents on average monthly residential bills.<sup>20</sup>

## Outlook

The pipeline of wind (plus solar and storage) projects in the interconnection queue will continue SPP's transformation. Increased emphasis on improving the forecasting of wind resources (as price spikes and day-ahead and real-time price divergence are due to forecasting errors) and the development of new ancillary services products (e.g., ramp product) will be critical.

New products and modifications to grid operations will also be needed to accommodate increasing solar penetration, batteries and other storage assets, and hybrid plant technologies. The largest hybrid plant; i.e., NextEra's 700 MW wind, solar and battery project, is in Oklahoma (SPP).<sup>21</sup>

In December 2019, SPP launched a new strategic market roadmap development process that aims to enhance the process by which SPP and its stakeholders collaborate on proposed changes to its day-ahead and real-time electricity markets, the Integrated Marketplace.<sup>22</sup>

Additionally, as of December 2019, SPP is now also providing reliability coordination service to utilities in the West. This is separate from the Integrated Marketplace and it involved the establishment of data connections to new customers in the West, buildout of systems and processes to ensure a wide-area view of the entire Western Interconnection's bulk power system and working with new Western utilities customers.<sup>23</sup>

A big opportunity for SPP in the near future is the application of digital technologies, given the different stakeholders, interconnections and players. The use of digital will improve visibility on the efficiency of the power system, including advanced analytics to predict congestion and to support product development and automated management of the different markets.



**05**

## **IRELAND**

**Single Electricity Market (SEM) – world-leading levels of wind integration driven by policy, operations and market enhancements**

The Irish electricity system is undergoing transformative change driven by the integration of high volumes of wind energy, wholesale market reform and a supportive policy environment. Operating across both the Republic of Ireland and Northern Ireland, the Single Electricity Market (SEM) provides a wholesale electricity market and joint system operations for the All-Island market since its establishment in 2007. Over the past decade, there has been significant acceleration in renewable energy generation growth in the SEM. In the Republic of Ireland, renewable energy generation has grown from 7% to 33% between 2007 and 2018, primarily driven by 28% wind generation.<sup>24</sup> Similarly, renewable energy generation in Northern Ireland has grown from 8% to 38% between 2009 and 2018, with 32% from wind generation.<sup>25</sup>

EirGrid Group is the All-Island TSO and market operator. With responsibility for real-time operations, grid development and provision of competitive energy market arrangements, the grid operator plays a pivotal role in enabling the integration of very high levels of variable renewable energy generation. EirGrid Group has achieved world-leading levels of System Non-Synchronous Penetration (SNSP) increasing the limit from 50% to 65% over recent years.<sup>26</sup> In line with Ireland's renewable electricity ambitions, EirGrid Group continues to seek even higher levels of SNSP to enable the safe, secure integration of increasing variable renewable generation onto the All-Island transmission system.

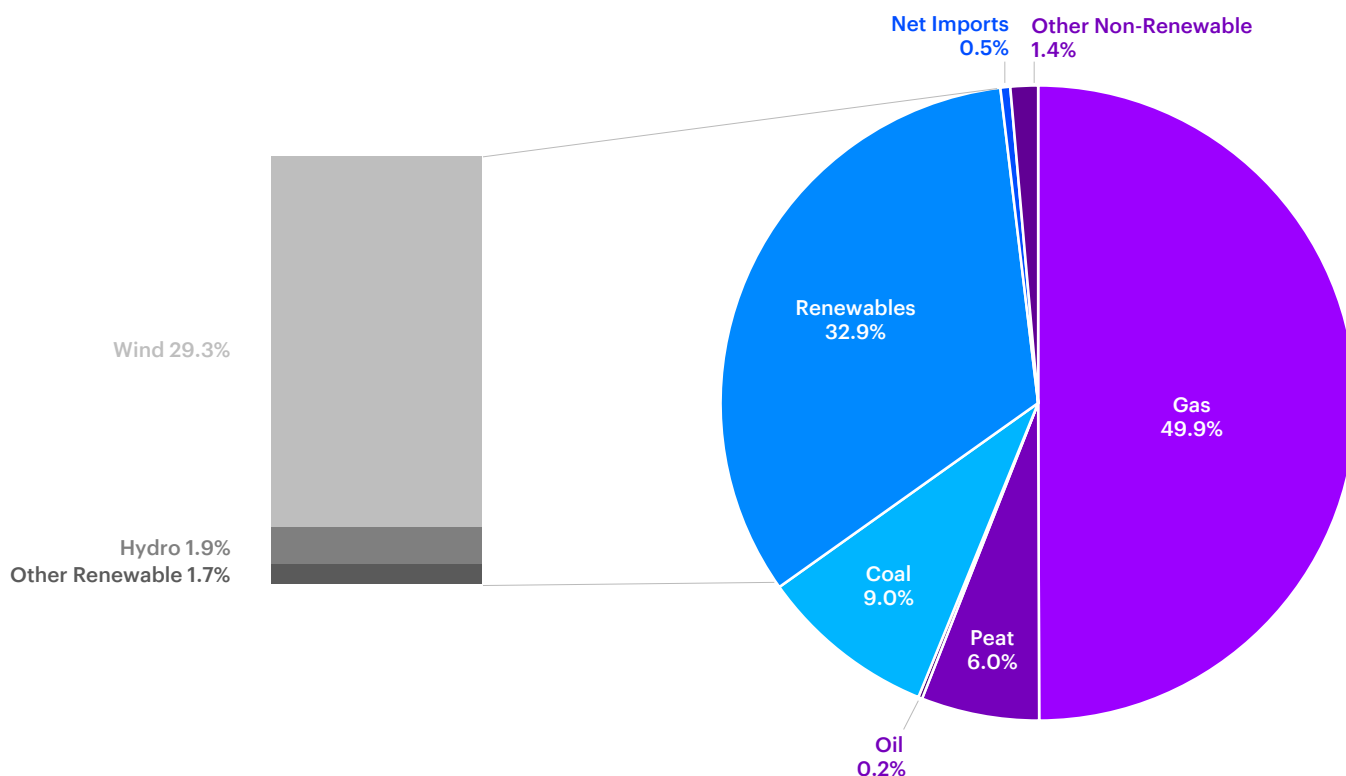
Policy and regulation continue to be the key energy transition enablers. In the recently published Climate Action Plan (CAP), the Republic of Ireland government set an ambitious target of 70% renewable electricity generation by 2030.<sup>27</sup> This is forecast to require an additional 12 GW of installed renewable energy capacity, which is indicatively expected to comprise at least 3.5 GW of offshore renewable energy, up to 1.5 GW of grid-scale solar energy and up to 8.2 GW of increased onshore wind capacity.<sup>28</sup> A similar target has not been set for Northern Ireland at this point, but it is expected that it will follow the same trajectory as the U.K., which sets out a net-zero emissions position by 2050.<sup>29</sup> To accommodate this level of variable renewable generation, the system will need to achieve a SNSP limit greater than 90%<sup>30</sup>—presenting a complex challenge for EirGrid Group in balancing system security, efficiency and flexibility.

The scale of the ambition contained in the CAP is even further amplified when considered in the context of projected demand increases, with EirGrid Group forecasting All-Island demand growth of between 28% to 55% across low to high-demand scenarios over the next decade.<sup>31</sup> Ireland's thriving ICT sector is alone forecast to account for 29% of the Republic of Ireland demand by 2028.<sup>32</sup> Aggressive CAP targets for electrification of heat and transport will also drive demand growth and modify the load shape. Urbanization will continue to intensify demand growth in the east of the country, and with most excess generation capacity available in the west of the country, significant grid constraints will need to be overcome to efficiently match generation and demand centers.

Unlike other countries targeting very high levels of renewable electricity penetration, Ireland has limited interconnection and limited diversity in its renewable generation portfolio. Ireland has two 500 MW HVDC interconnector links to the U.K.,<sup>33</sup> the Moyle and East-West interconnectors, with no other direct integration to mainland Europe. With low international and regional interconnectivity, Ireland's electricity system is exposed to the variability of wind, particularly as volumes increase. The diversity of the renewable electricity generation portfolio is also low with onshore wind energy accounting for almost 90% of renewable generation, more than 368 wind farms and a total installed capacity of greater than 4.92 GW (out of a total capacity of 14 GW<sup>34</sup>) across the island. While it is expected the portfolio will diversify somewhat over the timeframe to 2030 as projected within the CAP, wind is expected to continue to be the dominant source.

As a result of local system and operational constraints coupled with low interconnectivity, wind dispatch down is common. It should be noted that the definition of "dispatch down" can vary in different markets and, in some cases, all dispatch-down events are referred to as curtailment. In SEM, dispatch down includes both constraint and curtailment. Specifically, curtailment refers to dispatch down of wind for system-wide reasons (i.e., where reducing all wind generators across the system would overcome problems such as breaching SNSP). Constraint refers to dispatch down of wind for localized network reasons (i.e., where only wind generators in a particular network area or region are reduced to contribute to overcoming a problem on the network; i.e., congestion).

**Figure 11. All-Island fuel mix 2018.**



Source: EirGrid Group Annual Renewable Constraint and Curtailment Report 2018, <http://www.eirgridgroup.com>.

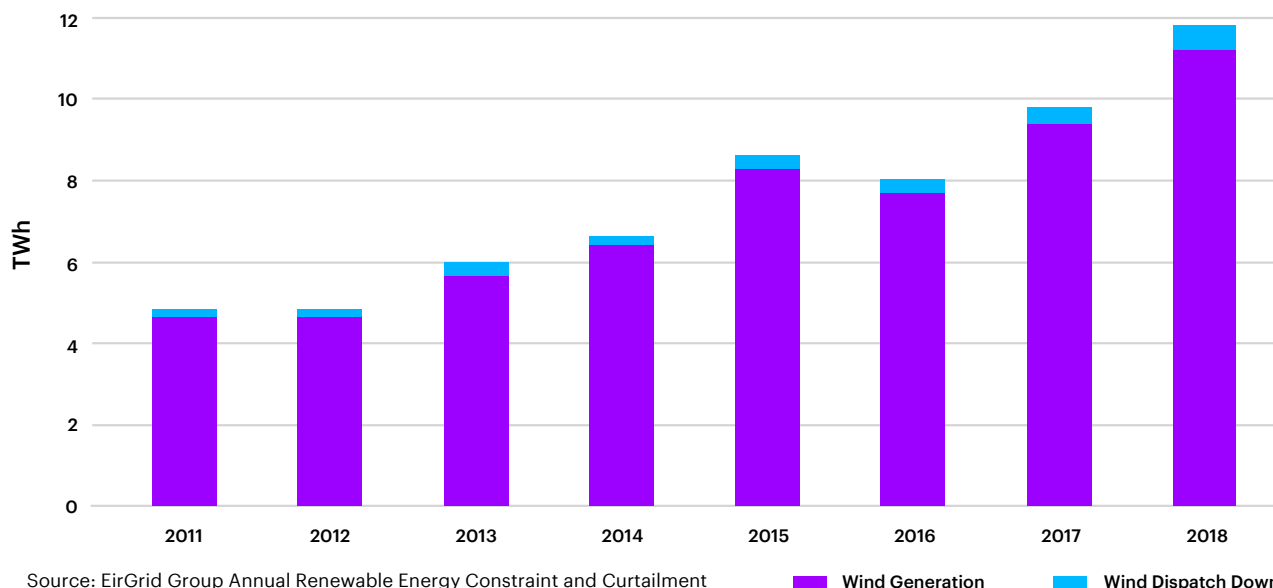
To ensure a safe, secure supply, EirGrid Group implements All-Island constraints for inertia/rate of change of frequency (RoCoF), along with localized stability constraints (e.g., minimum number of units per location). A single interconnector line links the Republic of Ireland and Northern Ireland electricity systems, "The North-South Tie Line," and it can be heavily constrained for system security reasons which often impacts the overall cost of energy. EirGrid Group reported that constraint and curtailment result in 6% wind generation dispatch down (707 GWh of 11,076 GWh) in 2018.<sup>35</sup>

Meeting Ireland’s renewable electricity targets and achieving a SNSP level of over 90% presents a significant challenge on an already congested grid with limited interconnection and a highly variable source of renewable generation prevailing. While a significant ramp up in renewable electricity generation is forecast over the next decade to meet targets in the Republic of Ireland and Northern Ireland, the parallel requirement to overcome SNSP limits means that overcoming curtailment and constraint challenges

will be key to ensuring targets can be achieved in an efficient, economic manner.

EirGrid Group is enabling world-leading levels of variable renewable generation through shaping market reforms, developing critical infrastructure and enhancing grid flexibility and control. Notably, EirGrid Group’s “Delivering a Secure Sustainable Electricity System (DS3)” program enabled advancements in policy, system services and system tools and contributed significantly to the SNSP increase from 50% to 65%. EirGrid Group’s recently announced new strategy, “Transform the power system for future generations,” positions it to be the key enabler of Ireland’s electricity sector transition. By implementing several multi-year programs, including the next phase DS3+ program and further market and infrastructure developments, EirGrid Group aims to continue to integrate world-leading levels of variable renewable electricity generation. Key elements underpinning EirGrid Group’s approach to date are highlighted in Table 4, along with an outlook for future considerations.

**Figure 12. All-Island wind generation and dispatch down volumes 2011 – 2018.**



Source: EirGrid Group Annual Renewable Energy Constraint and Curtailment Report 2018, May 2019, <http://www.eirgridgroup.com>.



## Markets – System Services

The system services component of DS3 has been and will continue to be a significant factor in supporting EirGrid Groups 90%+ SNSP ambition. In recent years, the number of services provided has grown from seven to a planned 14 by 2020, with an increased focus on system service remuneration. As well as energy and capacity payment mechanisms, there is now a large remuneration component for system services with the amount payable for these services rising from €60 million to €235 million. Proven technologies are eligible to provide services to the TSO, with services broadly grouped into Synchronous Inertia Response (SIR) and Steady State Reactive Power (SSRP), Reserve Services, Ramping Margin and Fast Post-fault Active Power Recovery (FPFAPR) and Dynamic Reactive Response (DRR).

- **Synchronous Inertia Response (SIR) and Steady State Reactive Power (SSRP):** These are services provided by a conventional unit once it is synchronized, regardless of operating output. SIR is the active power output response that a unit can provide, which has significant implications for rate of change of frequency (RoCoF) during power imbalances. SSRP is an important control for system voltages.
- **Reserve Services:** Both synchronous and non-synchronous generators can provide fast-acting responses to changes in frequency that supplements any inherent inertial response. In particular, FFR—MW response faster than the existing primary operating reserve times—may increase the time to reach the frequency nadir and mitigate the RoCoF in power imbalances.
- **Ramping Margin:** These system services are used to provide an increased MW output that can be delivered for a given time horizon. Ramping Margin is the guaranteed margin that a unit provides to the TSO at a point in time for a specific horizon and timeframe. The TSO has implemented three horizons of one, three and eight hours, respectively.
- **Fast Post-fault Active Power Recovery (FPFAPR) and Dynamic Reactive Response (DRR):** Units that can recover their MW output quickly following a voltage disturbance, including transmission faults, can mitigate the impact of such disturbances on the system frequency.

**Table 4. EirGrid Group System Services Overview.**

<b>Group</b>	<b>Service Name</b>	<b>Abbrev</b>	<b>Unit of Payment</b>	<b>Short Description</b>
<b>SIR &amp; SSRP</b>	Synchronous Inertial Respose	SIR	MWs <sup>2</sup> h	(Stored kinetic energy)* (SIR Factor-15)
	Steady State Reactive Power	SSRP	MVArh	(MVAr capability)* (% of capacity that MVAr capability is achievable)
<b>Reserve Services</b>	Fast Frequency Response	FFR	MWh	MW delivered between 2 and 10 seconds
	Primary Operating Reserve	POR	MWh	MW delivered between 5 and 15 seconds
	Secondary Operating Reserve	SOR	MWh	MW delivered between 15 and 90 seconds
	Tertiary Operating Reserve 1	TOR1	MWh	MW delivered between 90 seconds and 5 minutes
	Tertiary Operating Reserve 2	TOR2	MWh	MW delivered between 5 minutes to 20 minutes
	Replacement Reserve - Synchronised	RRS	MWh	MW delivered between 20 minutes to 1 hour
	Replacement Reserve - Desynchronised	RRD	MWh	MW delivered between 20 minutes to 1 hour
<b>Ramping Margin</b>	Ramping Margin 1	RM1	MWh	The increased MW output that can be delivered with a good degree of certainty for the given time hoizon.
	Ramping Margin 3	RM3	MWh	
	Ramping Margin 8	RM8	MWh	
<b>FPFAPR &amp; DRR</b>	Fast Post Fault Active Power Recovery	FPFAPR	MWh	MW delivered between 2 and 10 seconds
	Dynamic Reactive Response	DRR	MWh	MW delivered between 5 and 15 seconds

Source: DS3 System Services: Qualification Trails Process Outcomes and Learnings 2017, <http://www.eirgridgroup.com>.

## System Operation – Control Room Tools

EirGrid Group has delivered several advancements in tools and capabilities necessary to manage a large variable generation portfolio. With increased ability to detect, monitor and manage real-time situations, Ireland has been able to handle ever increasing levels of non-synchronous generation. To increase situational awareness, decision making, and control, key tools and mechanisms have been delivered or are planned for delivery, including:

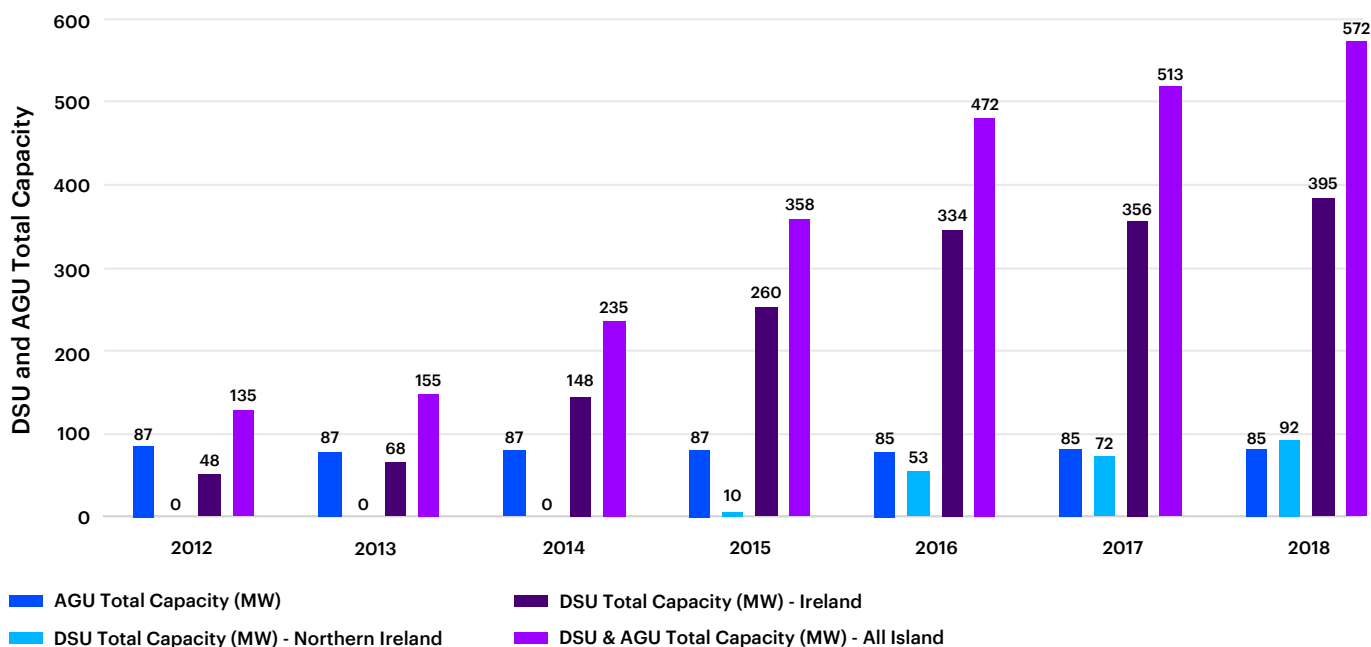
- **Wind Dispatch Tool:** The TSO can directly control wind farms in real time through a wind dispatch tool. This applies curtailment and/or constraint instructions to wind farms dependent on their current output, regional constraints and controllability levels.
- **Voltage Trajectory Tool:** This tool enables the TSO to assess the impact of varying sources of reactive power across the grid to ensure that local voltage management issues are monitored and managed correctly. Coupled with the interim ramping tool, this tool will provide the TSO with capability to reach 70% SNSP.
- **All-Island Wind Security Assessment Tool (WSAT):** WSAT provides the TSO with a real-time view of the transient and voltage stability of the grid, allowing for real-time correction and mitigation of instability. A further iteration of the tool (LSAT) is planned for autumn 2020, which will give the TSO a forecast of the future stability of the power system and offer guidance on potential mitigations for predicted instability which is needed to achieve SNSP up to 75%.

- **Scheduling and Dispatch:** The TSO uses algorithms within proprietary systems to produce an economically viable and secure schedule to meet demand as it nears real time. Three schedules are produced across a 30-hour time horizon, accounting for reserve requirements, system inertia, SNSP limitations and various forecasts such as load, demand and wind. Units are scheduled and dispatched in priority order, to ensure operational security, maximize priority dispatch generation (including renewables, interconnectors, peat and high-efficiency combined heat and power) and to minimize costs.
- **Ramping Tool (planned for 2020):** Provides the TSO with an ability to schedule and dispatch ramping margin services. This ramping capability is designed to ensure there is sufficient ramping ability in the system to withstand issues such as generator trips or forecasting errors of renewable generation.

## Load – Demand-side Management

- EirGrid Group primarily uses Demand-side Units (DSUs) and Aggregated Generating Units (AGUs) to provide flexible demand-side management through medium to large electricity customers. A DSU comprises one or more aggregated sites which can ramp down demand on instruction for a period of two hours or greater. To achieve this, DSUs use on-site generation, plant shut down or energy storage, or a combination of these options. AGUs are similar in nature but use on-site generation only to provide demand reduction. EirGrid Group has real-time visibility of these units' availability and will issue dispatch instructions to reduce demand, based on availability and cost. Ireland currently has 572 MW<sup>36</sup> of DSU and AGU nominal capacity (peak demand of 6,508 MW on December 4, 2018<sup>37</sup>).

**Figure 13. DSU and AGU capacity 2012 – 2018.**



Source: EirGrid DSM Industry Forum 2018, <http://www.eirgridgroup.com>.

- EirGrid Group also offers a scheme to large customers—Powersave—compensating customers for reducing consumption on days when system demand is close to available supply.
- Domestic customers can also provide flexibility by participating in tariff-based schemes which incentivize demand shifting to off-peak times; i.e., NightSaver (Ireland) and Economy 7 (Northern Ireland). It is expected that the planned rollout of smart meters in Ireland, coupled with increased deployment of distributed energy resources (DERs) and appropriately constructed tariffs, will stimulate increased demand-side participation. As a result, the DSO, ESB Networks, will play an increasingly important role in providing flexibility for the TSO.

## Markets – Market Design

In 2018, EirGrid Group implemented an integrated wholesale electricity market, I-SEM, which aimed to align the SEM with the European Target Operating Model and enable more efficient cross-border flows through pan-European trading.

I-SEM enabled closer integration of the All-Island market with the European electricity markets, optimized cross-border assets, produced downward pressure on prices and enabled increased granularity and transparency of market pricing signals. I-SEM is broadly made up of three different energy markets; the “ex-ante” day-ahead and the intraday markets, where electricity bought and sold before the market closes; and an enhanced balancing market, which takes place after trading has ceased. These markets have enabled wind assets to put downward pressure

on prices as wind farms are price takers in the market; i.e., they have zero marginal costs and will typically bid in with a price of zero, which ultimately drives down the overall cost of electricity bought and sold. Through closer integration with pan-European markets, I-SEM offers a pathway to greater cross-border balancing that may be used as a lever going forward for managing curtailment on a high-variable renewable system with +90% SNSP.

## **Networks – Transmission Infrastructure Development**

The greater Dublin region (eastern seaboard) is Ireland’s major transmission network load center, accounting for approximately one-third of total Irish demand.<sup>38</sup> Demand here continues to grow due to socio-economic drivers and a growing ICT sector. The region does not have a substantial excess of generation relative to demand. Regions in the west of the island have a significant and growing generation surplus relative to local demand (resulting in locational scalars for this region in the Capacity Auction). There is a considerable pipeline of renewable generators with connection agreements and live connection offers in the west of the country, where significant wind resource is located. There are also transmission constraints in some of these western regions with high volumes of renewable generation. To support increased penetration, EirGrid Group has planned significant development and reinforcement of the transmission network to cater for the export of excess generation from these regions toward high load areas such as the greater Dublin region.

In parallel with developing the local transmission network, EirGrid Group has planned to enhance Ireland’s interconnection with other markets to provide a route to market for excess renewable generation and to avoid large volumes of curtailed wind and solar. Increasing interconnection across the island of Ireland and into the U.K. will be important means of integrating increased renewables and ensuring energy security, particularly as the All-Island system faces forecast capacity constraints toward the mid-2020s.<sup>39</sup> Ireland is however closely geographically correlated to the U.K. in terms of availability of wind and solar resources, therefore interconnection to other jurisdictions such as mainland Europe will be an important mechanism to reduce curtailment.

Over the past several years, key infrastructure developments have been planned to further reinforce and position the All-Island electricity grid for world-leading levels of variable renewable energy generation. Key projects include:

- An additional 400 kV ROI – NI interconnector.<sup>40</sup> The “North South Interconnector” is required to enable increased power flow across the jurisdictions driven by market integration, security of supply and renewables integration.
- A new HVDC interconnection between Ireland and France. The “Celtic Interconnector,” which is designed to import/export approximately 700 MW and provide Ireland’s only direct connection to mainland Europe.<sup>41</sup>
- The Greenlink 500 MW interconnector,<sup>42</sup> further linking the electricity grids across the island of Ireland and the U.K.

## Outlook

EirGrid Group continues to prepare the All-Island grid to accommodate unprecedented levels of variable renewables and aim to achieve SNSP limits of +90% by 2030. This world-leading level of integration will require continued enhancements across market rules and policies, All-Island grid modernization and further integration with mainland Europe, and increased operational capability enabled through digitalization.

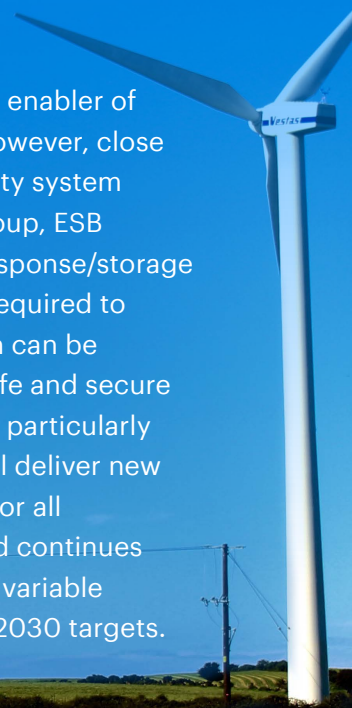
In 2019, EirGrid Group published indicative market development plans for 2019 to 2025 in their "Roadmap for Market Development."<sup>43</sup> The roadmap outlines further expansion of system and ancillary services to provide market participants additional financial incentives while also contributing to overall security and stability of the grid. Alignment to European standards such as the Common Grid Model Exchange Standard (CGMES) and European Balancing standards (e.g., Replacement Reserves (RR) – TERRE and Manual Frequency Restoration Reserves (mFRR) – MARI) will further integrate the All-Island market with Europe and enhance cross-border balancing and cooperation capability. Additionally, alignment with the European Clean Energy Package is hoped to bring further benefits and pan-European cooperation capability.

The timely rollout of the new Renewable Electricity Support Scheme (RESS) auctions will be fundamental to continued renewable capacity growth. In the absence of the expired Renewable Energy Feed-in Tariff (REFIT) scheme, this financial incentive scheme will be critical to ensure installed renewable generation targets will be met by 2030. As a technology-agnostic auction, it is intended that RESS will diversify Ireland's renewable generation portfolio and ensure competitive pricing.

In parallel with market enhancements, infrastructure development will be a key enabler of reducing constraint and curtailment on the island. Key projects like the Celtic Interconnector will provide new and diverse routes to market for renewable generation, while local grid reinforcement will ensure efficient integration of renewables and reduced curtailment.

Digitalization will provide EirGrid Group further opportunity to deliver flexibility on the grid. With the rollout of DERs, smart meter implementation, other behind-the-meter innovations and connected devices (intelligent end devices); data capture, analysis and response capabilities in real time become increasingly necessary. By continuing to enhance and develop control room tools, EirGrid Group will have improved capability to manage increasingly complex grid scenarios. Increased automation and digitalization of EirGrid's control systems, including real-time and predictive tools, will assist in achieving increased operational flexibility. Key next steps in this area include the rollout of the Ramping Margin tool in 2020, and the smart meter distribution network rollout, which will encourage energy demand reduction and load shifting at DSO level, providing opportunity to create new flexibilities at the DSO-TSO interface.

EirGrid Group as TSO will be a key enabler of the electricity sector transition; however, close collaboration between all electricity system stakeholders including EirGrid Group, ESB Networks, generators, demand-response/storage providers, and regulators will be required to ensure that system transformation can be achieved in a timely, least cost, safe and secure manner. Whole systems solutions, particularly unlocking TSO-DSO synergies, will deliver new flexibilities and create new value for all stakeholders, ensuring that Ireland continues to achieve world-leading levels of variable renewable integration to achieve 2030 targets.



**06**

## **UNITED KINGDOM**

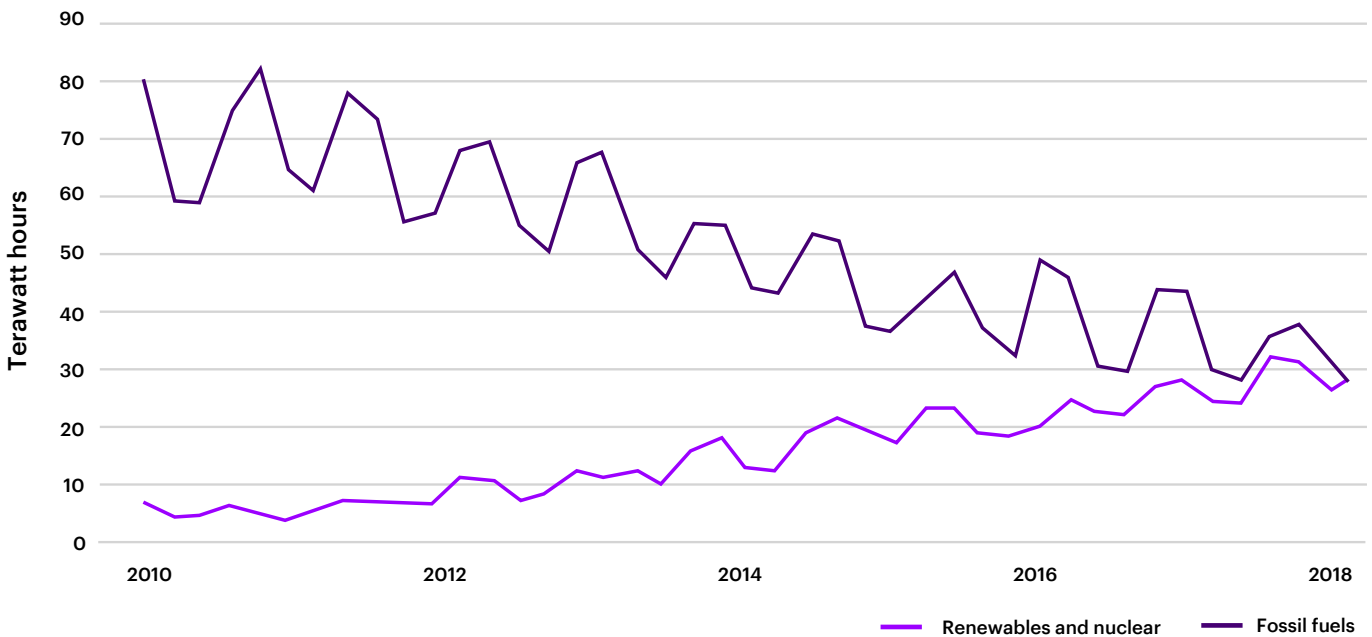
**Transforming the network  
to deliver net zero through  
market and product  
innovation, demand  
optimization and storage**



The U.K.'s electricity system is in the midst of complex, transformative changes as the trends of decarbonization, decentralization and digitization are creating a rapidly changing landscape. Operating across the U.K., the electricity system operator (ESO) facilitates the safe, efficient transportation of gas and electricity and seeks to ensure supply and demand are always balanced in real time. According to National Grid ESO, electricity generation mix data over the past decade highlights the increasing reliance of the U.K. on low-carbon and "green" power sources, with corresponding generation penetration rising as high as 47.9%.<sup>44</sup> More specifically, renewables' (including wind and solar) share of electricity generation grew from a low of 2% (quarterly TWh) in 2009 to 24.8% in 2019.

As owner and operator of the high-voltage transmission system, National Grid ESO plays a key role in the integration of renewable electricity generation and subsequent decarbonization of the energy system. The year 2019 marked a turning point in the U.K.'s journey toward a new era of clean energy with historic milestones being reached. For the first time since the Industrial Revolution, more electricity was generated from zero-carbon sources than fossil fuel while, in the summer of 2019, the electricity system operated coal-free for two weeks.<sup>45</sup>

**Figure 14. Fossil fuels vs. renewables and nuclear generation.**



Source: Carbon Brief - Analysis: UK renewables generate more electricity than fossil fuels for first time, <https://www.carbonbrief.org>.



## Summary of system operability challenges faced in the U.K.'s system:

The energy transition—the integration of renewables, storage and electric vehicles in particular—is changing the significance and nature of challenges faced in operating the electricity system.

In an operational strategy report<sup>46</sup> now published annually by National Grid ESO, the following key challenges to system operability and current activities underway to address them are highlighted:

- **Frequency volatility:** Faster-acting frequency response products are being developed in the U.K. because in a system with fewer traditional generators the frequency of the system is more volatile and moves away from target frequency (50Hz) more rapidly. The services used to manage this are both expanding and evolving to be more transparent, more dynamic (e.g., the Dynamic Firm Frequency Response product), better able to predict their response capability in near real time, able to respond more quickly (e.g., the sub-1 second response Enhanced Frequency Response product), and able to more accurately forecast their response capability in near real time.
- **Voltage constraints:** New and alternative solutions are being explored to manage the voltage performance of the U.K. system. Traditionally, reactive power services from large transmission-connected generation plants were sufficient to manage system voltage. However, there is now much greater complexity and volatility in the power flows on the transmission network. For example, in the U.K. the bulk supply points between the transmission and the distribution systems, traditionally modeled as loads, now regularly export power back into the transmission system. Reactive power services from non-traditional and embedded resources; i.e., generation within the distribution network, are now required and National Grid ESO is increasingly collaborating with DNOs to gain greater access to distributed providers.
- **Restoration:** The ability to restore the national electricity system from a complete or partial blackout is a complex operation, made more so by the decentralization of generation and the decreasing system inertia. To address this, the U.K. is currently consulting on a new restoration standard, placing new requirements on distribution operations and customers to better support the system restoration capability. National Grid is also expecting its first “embedded restoration service providers” to be configured and contracted in 2021 and 2022 respectively. This is working toward an aim of having a fully productized restart capability by 2025.
- **System Stability (inertia):** Increasing penetration of renewables and decreasing amounts of traditional power stations result in lower system inertia. A consequence of lower inertia is that changes in system frequency, which are increasingly common, may trigger generators’ protection systems throughout the network, which historically were set conservatively to prevent asset damage. This can result in rapidly cascading outages. As a result, National Grid ESO is undertaking a program of relaxing those protection systems. National Grid ESO is also consulting on establishing a new type of service called a virtual synchronous machine, to increase system inertia through artificial or through aggregated portfolios. In addition, National Grid ESO is in the process of deploying a new technology to accurately measure the power system inertia in real time. This platform will assist the system operators to procure frequency response services in a more efficient manner.
- **Thermal Network Constraints (post fault):** In the U.K., the ESO is responsible for conducting network options assessments that consider the optimum balance of investment in infrastructure, commercial services and system operation. Through this, National Grid ESO and the wider industry are currently exploring the development of new post-fault constraint management

products that will increasingly enable the more cost-effective commercial options needed in a less predictable system evolution. Such post-fault commercial services are intended to provide new ways of managing thermal constraints through increasing the visibility and control of embedded units, and by exploring more coordinated whole system optimized dispatch capability. This would increase network capacity and benefit providers by increasing system access, particularly by focusing on the key north-south transmission boundary between Scotland and Northern England.

## **Markets – New Participants, Products/Services**

The U.K. system operator currently runs a wide variety of services to balance grid demand and supply, governed by the singular aim to “ensure the security and quality of the electricity supply across Great Britain’s transmission system.” These services are going through a period of rapid change as the system and its operation evolve to enable the integration of renewables and address the operability challenges previously described.

The primary market activity used to balance the U.K. system is that of the balancing mechanism bids and offers made to the system operator by balancing mechanism participants. These bids and offers allow National Grid ESO to pay generators to move away from their wholesale market position where required to balance electricity supply and demand. This balancing mechanism is active between the close of wholesale market trading and real time (up to one hour before real time).

Historically, balancing mechanism participants were only transmission-connected or very large distribution-connected generators directly integrated into the operation of the U.K. electricity system. However, new legal requirements placed on the U.K. through the third European Energy Package, as well as the strategic need to increase participation and control of commercial services to enable renewables and the energy transition have prompted National Grid ESO to introduce a program of wider access that allows distribution connected assets as small as 1 MW to be direct providers of balancing services. This has greatly increased the range of services (and associated value) that can be provided by distributed energy assets, including renewables. It is also intended to ensure system operability while expanding the integration of renewables.

In addition to the wider access initiative, the third European Energy Package will also result in an increase of reserve providers available to National Grid ESO in the form of European system-connected providers under the Replacement Reserve product. These services will be traded over the electricity interconnectors and are coordinated through the European-wide project TERRE.

Along with balancing mechanism bids and offers, there are currently 15 additional balancing services available in the U.K. Largely these services can only be provided by balancing mechanism participants, though some may also be provided by non-balancing mechanism service providers, considered as ancillary service providers. Total expenditure in the U.K. on balancing mechanism services can vary significantly month to month. Since early 2019, monthly expenditure has ranged from approximately £60 million to approximately £150 million.

The balancing services are summarized in Table 5.

**Table 5. National Grid ESO's balancing services overview.**

<b>Service</b>	<b>Description</b>
<b>System Operator to System Operator</b>	System-operator-to-system-operator services are provided mutually with other transmission system operators connected to the U.K. transmission system via interconnectors.
<b>Super Stable Export Limit (SEL)</b>	The ability for synchronous generation to reduce their minimum generation level (SEL) in times of low demand on the system.
<b>Short-term Operating Reserve</b>	Short-term operating reserve is a service that provides additional active power from generation or demand reduction.
<b>Obligatory Reactive Power Support</b>	Provision of varying reactive power output. At any given output generators may be requested to produce or absorb reactive power to help manage system voltages.
<b>Transmission Constraint Management</b>	Required where the electricity transmission system is unable to transmit power to the location of demand due to congestion at one or more parts of the transmission network.
<b>Mandatory Response Services</b>	Mandatory Frequency Response is an automatic change in active power output in response to a frequency change and is a grid code requirement
<b>Intertrips</b>	Intertrip services are required as an automatic control arrangement where generation may be reduced or disconnected following a system fault event. Potential service providers would be approached directly by the grid if a specific requirement is identified.
<b>Firm Frequency Response</b>	Firm Frequency Response (FFR) is the firm provision of dynamic or non-dynamic response to changes in frequency.
<b>Fast Reserve</b>	Fast reserve provides rapid, reliable delivery of active power through increasing output from generation or reducing consumption from demand sources.
<b>Enhanced Reactive Power Services</b>	The enhanced reactive power service is suitable for generators which can provide reactive power over and above the grid code and obligatory reactive power service requirements
<b>Enhanced Frequency Response</b>	An innovative and recent product implicitly aimed at more fast-acting storage providers (e.g., lithium-ion battery assets) that utilizes frequency tracking to trigger response services. Separated into low frequency and dynamic services. Procured through a weekly live auction and has been credited with driving much of the current development interest in grid scale storage in the U.K.
<b>Demand-side Response</b>	Demand-side providers can deliver services by either reducing their demand or taking advantage of onsite generation. Refers to the delivery of reserve, response, and other services by non-balancing mechanism or demand-side units. Historically a minority share of balancing mechanism expenditure and, given the context of wider access, enabling more direct balancing mechanism participation may further reduce.
<b>Demand Turn Up</b>	The Demand Turn Up (DTU) service encourages large energy users and generators to either increase demand or reduce generation at times of high renewable output and low national demand. This typically occurs overnight and during weekend afternoons in the summer. No DTU services were procured in 2019, and potentially could be phased out following wider access rollout.
<b>Balancing Mechanism Start Up</b>	The Balancing Mechanism Start Up service provides on-the-day access to additional generation. The service is open to any balancing mechanism participants that expect to be unavailable within balancing mechanism timescales of 89 minutes, including both paid "hot standby" and accelerated Balancing Mechanism Start Up payments.
<b>Black Start</b>	Black Start is a procedure to recover from a total or partial shutdown of the national energy transmission system. Black start ensures that the grid is covered by contingency arrangements to restore the electricity supply in a timely, orderly manner. The Black Start service is procured from power stations that have the capability to start main blocks of generation onsite, without reliance on external supplies. Types of providers and services are expected to evolve to include distributed energy resources.

Source: National Grid ESO – list of all balancing services, <https://www.nationalgrideso.com>.

Regarding the curtailment of wind generation, this can and does occur for several reasons, including transmission constraint management, imbalance and system voltage. Because wind generation incurs no fuel cost and can even generate revenue through carbon subsidies (e.g. Renewable Obligation Certificates),<sup>47</sup> National Grid ESO may sometimes require operators to curtail a share of wind generation to reduce or constrain the amount of electricity produced. To deal with constraints, a range of mechanisms are used in U.K., including balancing mechanism bids and offers, pre-gate Balance Mechanism Units (BMU) transactions, trading, system-to-system (system operator to system operator) services and contracted services.

Despite the recent increases in wind generation, curtailment rate was down to just 3% between January and August 2018, from a respective figure of 4.5% in the same period of 2017 and annual average of 5.7% in 2016.<sup>48</sup> This significant improvement in wind curtailment came as a direct result of the development of new transmission links as part of the increased infrastructure network investment. Table 6 shows the total payments made to wind powered generation since the 2011/2012 financial year.

It is also worth noting that in the U.K., several services and actions are sometimes used to increase demand rather than curtail wind generation. These include repumping water at pumped hydro sites and utilizing the recent demand turn-up service.

**Table 6. National Grid ESO Monthly Balancing Services Summary 2019/2020 - January 2020.**

	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020
<b>Payments to wind powered generation [£m]</b>	34.1	7.6	49.7	65.3	96.8	83.2	108.0	173.2	124.3

Source: National Grid ESO – System balancing reports, <https://www.nationalgrideso.com>.

## System Operation - Forecasting and modernization

To enable and support these changes within the system operator, National Grid ESO is progressing with a variety of investments and improvements in its operational systems. As market products and services have evolved, investments have been required in the systems used to procure, dispatch, monitor and settle those new services. In the U.K., this has specifically involved investments in systems to support: wider access, TERRE and ancillary services.

### FORECASTING

- **Wind and solar forecasts:** Generation forecasts play a key role in system operations and the inherent unpredictability of these variable sources. National Grid ESO has continued to develop and refine its renewables forecasts, particularly through its innovation portfolio and several partnerships with academia. One additional aspect relevant to the successful integration of renewables is the improvement and exchange of the generator's own forecasts with the system operator. National Grid ESO is continuing to work with generators to expand and improve the forecast data provided to the system operator by the participant, which would increase system operator confidence in dispatching those generators for balancing or other services.
- More generally, a modern, agile overall forecasting capability is also required. With changes becoming more common and rapid in network connections, configuration and data sources, the system operator forecasting capability must keep up to pace and integrate modern tools and DevOps capabilities.

### MODERNIZATION

- **Inter-control room connection:** Operational connections and interfaces, especially with DNOs and interconnectors, have historically been limited to coordinating basic network switching schedules and operational safety. As both DNOs and interconnectors now play an increasing role in system balancing, these inter-control room connections are becoming more complex and essential. For example, National Grid ESO configured a direct control room link with a DNO on the south coast of England (UKPN): first to exchange more complex forecasting and contingency analysis data<sup>49</sup> and subsequently to coordinate the purchase of market services for transmission voltage management from the DNO acting as an aggregator.<sup>50</sup>
- **Energy Management System:** Finally, the core energy management system, with which the system operator runs the electricity system, is a long-term strategic asset and likely to require upgrading as system operation evolves and becomes more complex. This was recently true in the U.K. and resulted in a significant energy management system upgrade project.

## Load – Growing Demand-side Response

The U.K.'s energy transition to carbon net zero is further complicated when considering the projected demand growth, with National Grid ESO forecasting demand increases between 83% and 160% by 2050 across low- to high-demand scenarios.<sup>51</sup> The significant increase in electricity demand is largely driven by the expected aggressive electrification of heat and transport as risen by the U.K. government's targets of a complete ban of fossil fuel cars by 2040.<sup>52</sup> According to National Grid ESO's Future Energy

Scenarios, the number of EVs is forecast to rise to as many as 11 million by 2030 and 36 million by 2050.<sup>53</sup> This, alongside the changing generation mix, poses new challenges in maintaining system's balance and requires new ways to be found to deliver a reliable and efficient decarbonized energy system.

Recognizing the important role these demand-side assets can play in system balancing, National Grid ESO is growing its portfolio of demand-side response programs, which encourage consumers and businesses to manage their energy profile in support of the grid. Historically, National Grid ESO considers all distribution-level connections and assets to be demand- or load-side. However, initiatives are in place to increase participation in energy services to both demand and generation customers connected within the distribution network to market services by the system operator. This includes a market engagement campaign (Power Responsive), the introduction of the Demand Turn Up product, a range of demand-side friendly frequency services, and critically, allowing greater direct participation in the balancing mechanism by distribution connected customers through the wider access program.

Third-party aggregators have long played a significant part in the provision of services from load and/or distribution customers to the system operator, which is also expected to continue.

## Load – Increasing Flexibility of Distributed Generation

With the increasing decentralization of generation, in particular renewables, significant volumes of generation capacity are now being connected to the distribution networks rather than the transmission network. In the U.K., the six regional DNOs that operate the electricity system lower levels from 132 kV to low-voltage connection points are therefore also undergoing radical changes. As of 2019, more than 31 GW of generation capacity, representing 29% of total U.K. generation capacity, was connected to the distribution system or within distribution customers' networks,<sup>54</sup> rather than the transmission system.

In this context, two key developments have emerged regarding flexibility from generation assets:

1. **Flexible connections:** All U.K. DNOs now offer some form of flexible connection service, where a degree of export interruption instructed by the DNO is formalized in the generator's connection agreement in exchange for a faster and lower cost of grid connection. Typically, estimated curtailment figures of around 5% can result in an order of magnitude reduction in grid connection costs.
2. **Distribution flexibility programs:** U.K. DNOs are increasingly becoming buyers of flexibility services themselves to more cost effectively manage the distribution networks. This introduces a potential new revenue stream for distribution connected generators, although it does create conflicts and/or exclusions between local distribution and national system services.

## Flexible Generation – Natural Gas

In the U.K., natural gas plants have been one of the most significant sources of flexible generation, particularly among transmission-connected generation. This has continued to be the case, with gas plants currently making up 29% of U.K. generation capacity. Gas has only recently been surpassed by renewables in actual generation produced, with 38.9% of electricity generated in the third quarter of 2019, compared to 38.8% for gas).<sup>55</sup> Gas plants continue to be major players within the balancing mechanism.

## Networks – Delivering Wind to High-demand Areas and Increasing Interconnections

Aligned with the U.K. government's 2050 net-zero emissions ambitions, National Grid ESO continues to invest in innovative solutions in infrastructure and interconnectors to enable the efficient, secure integration of renewables and transition to a clean power system. Within U.K. transmission networks, enabling the integration of renewables shows three major drivers of network investment:

1. **Increasing the north-south transfer capacity**, to allow the greater volumes of renewable generation connected in Scotland and northern England to be transmitted to the southern load centers.
2. **Investments in the southern transmission network**, where significant offshore wind farm connections and increasing undersea interconnector connections are resulting in system constraints, particularly voltage related constraints.
3. **Increasing the number and system integration** of interconnectors with Ireland and Europe.

These areas have already seen significant investment. For example, in 2019, 64.5% of electricity imported to the U.K. via underwater cables came from zero-carbon sources.<sup>56</sup> The U.K. market currently has four interconnectors with a total capacity of 4 GW, but additional investment of more than £2 billion in new projects aims to bring the total number of interconnectors in operation to at least six by 2030.<sup>57</sup> Indicatively, National Grid has set targets for its interconnectors to provide electricity that will power 8 million homes via zero-carbon sources by 2025.<sup>58</sup> This network of European underwater cables is expected to enable the U.K. to increase the share of renewable imported electricity to 90% and consequently decrease the power sector emissions by 6 million tonnes, about 17%, by 2030.<sup>59</sup>

Overall, National Grid ESO's most recent Electricity Ten Year Statements report recommends continued investment in 25 schemes in a £5.4 billion network development program.<sup>60</sup>

## Storage – Growing Diverse Storage Technology Portfolio for Multiple Applications

The storage of electricity is widely recognized as a key solution to the intermittency of renewable generation sources. The U.K. has in total 3.6 GW of installed electricity storage capacity with the most significant source of energy storage being pumped hydro at 2.8 GW.<sup>61</sup> However, lack of suitable sites in the U.K. geography has prevented further development in this area. National Grid ESO expects an increase in grid-connected storage capacity in all U.K. energy scenarios. This growth expected to include a range of technologies, including grid-scale battery storage, enabled by the continued drop in battery costs and developments in other storage technologies.

National Grid ESO also cites a need for larger, longer duration storage to support decarbonization.

In the past year, around 50 storage projects have been commissioned in the U.K., providing around 500 MW of additional storage capacity. Many of these are short-duration batteries, in part driven by the increase in frequency management products procured by National Grid ESO (e.g., Enhanced and Dynamic Frequency Response products). However, they also include other technologies beyond batteries, such as a new liquid air facility. This is where off-peak electricity is used to cool air to a liquid state, which is later warmed and pumped to run a turbine. Around

80% of new storage connection projects are being connected on the distribution network or at a lower voltage; for example, alongside onsite generation.

There is steady growth in storage in all scenarios forecast by National Grid's Future Energy Scenarios with a greater, more rapid increase in the faster decarbonizing scenarios, as variable output from rising renewable generation increases the need for flexibility. There is particularly rapid storage growth in community-driven energy transition scenarios as both demand and renewable generation increases.<sup>62</sup>



## Outlook

Achieving the net-zero target is forecast to require about 540 TWh of low-carbon generation in 2050, an increase of about 250% from 155 TWh in 2017.<sup>63</sup>

As highlighted in the Committee on Climate Change Report, about 1 to 2 GW of low-carbon power capacity and 5 to 8 GW of renewable power capacity increase per year will be needed to reach such outputs by 2050.<sup>64</sup> The U.K. government, having focused its renewables funding primarily on offshore wind generation, suggests that offshore power capacity could increase from 8 GW today to 30 GW by 2030, accounting for about a third of electricity generation, and up to 75 GW by 2050.<sup>65</sup>

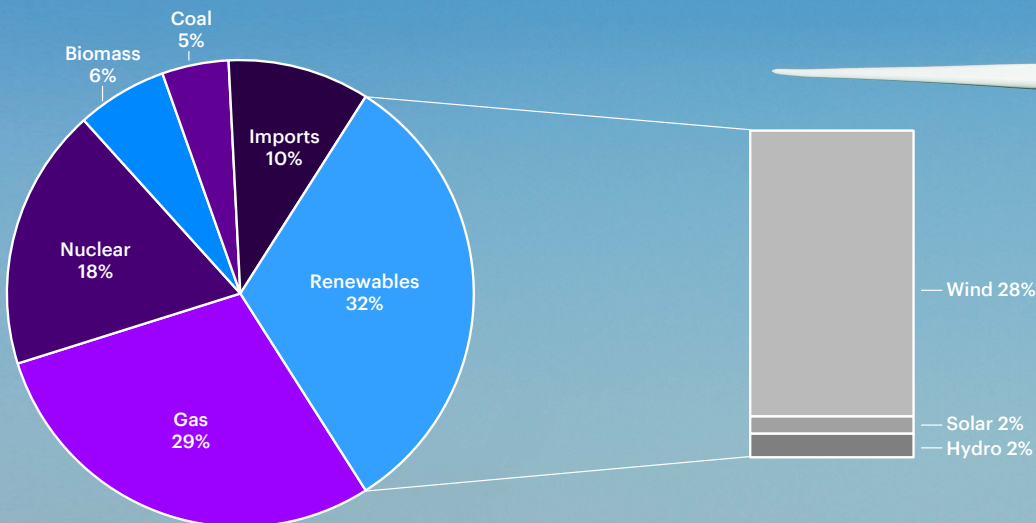
Meeting the U.K.'s decarbonization targets poses an ambitious yet highly complex challenge for National Grid ESO when considered in context of expected demand growth, ever-changing generation mix and market trends. As always, the lower and varying load factors shown by renewables, as compared to traditional generation, call for a much more flexible electricity system that can accommodate the variable supply from renewables. Increased

deployment of interconnectors, electricity storage, demand-side management and gas peaking plants can play a vital role in smoothing the system's operation and offer high levels of new flexibility.

The U.K. system operator has been pioneering in the development of ancillary services markets, widening participation not only for renewables (wind has been able to participate as a balancing mechanism for many years) but also to demand-side response and even water firms. New products like the Enhanced Frequency Response continue to be developed to leverage the characteristics of new technologies like batteries. Digital is also playing a critical role in system operations, particularly in forecasting wind and solar and in real-time visibility and operational control of the system integrity. Of the four markets in this report, the U.K. has the most activity in the distributed generation side, both an emphasis on demand-side response and distributed generation participation in the balancing markets. Finally, with the growth in offshore wind, there will be more investment in interconnections.

**Figure 15. February 2020 U.K. generation mix.**

Generation Mix Total 114 GW Capacity



Source: National Grid ESO, Great Britain's Electricity Explained, <https://www.nationalgrideso.com>.



**07**

# **COMPARISON OF MARKET APPROACHES TO WIND INTEGRATION**

The ERCOT, SPP, Ireland SEM, and the U.K. case studies illustrate how different markets are approaching the integration of renewables differently depending on their current situation, opportunities and constraints, market philosophy, and future targets. Table 7 highlights the key elements of each RTO's approach.

**Table 7. Comparison of renewable integration options across markets.**

<b>Integration Option</b>	<b>ERCOT</b>	<b>SPP</b>	<b>SEM</b>	<b>U.K.</b>
<b>System Operation</b>	<ul style="list-style-type: none"> <li>Integration of weather forecasting and demand management into grid operations.</li> </ul>	<ul style="list-style-type: none"> <li>Import/export markets.</li> <li>Expansion of balancing authority region.</li> </ul>	<ul style="list-style-type: none"> <li>Increase in control room tools to increase the ability to detect, monitor and manage real-time situations.</li> </ul>	<ul style="list-style-type: none"> <li>Improved forecasting.</li> <li>Modernization – control room and energy management system.</li> </ul>
<b>Markets</b>	<ul style="list-style-type: none"> <li>Advanced ancillary services products.</li> <li>Demand signals to manage reserve capacity below requirement.</li> <li>Volatile peaks managed by players reacting to prices.</li> </ul>	<ul style="list-style-type: none"> <li>Congestion rights market</li> <li>Reserve capacity exceeds peak requirement by more than 30%.</li> <li>Reducing volatility by increasing dispatchability of wind assets.</li> </ul>	<ul style="list-style-type: none"> <li>Increase in system services products from seven to 14, with remuneration for services rising from €60m to €235m.</li> <li>Introduction of I-SEM (integrated single electricity market) to enable closer integration of All-Island market with European electricity markets.</li> </ul>	<ul style="list-style-type: none"> <li>Widening balancing mechanism participation.</li> <li>New product and service. innovation and development.</li> </ul>
<b>Load</b>	<ul style="list-style-type: none"> <li>Advanced use of demand resources to manage load in ancillary services markets.</li> <li>Proactive pushing of information (e.g., requests to reduce demand and how) during tight conditions.</li> </ul>	<ul style="list-style-type: none"> <li>Supply exceeds demand by a significant margin, so less emphasis on load.</li> </ul>	<ul style="list-style-type: none"> <li>Use of DSUs and AGUs to provide flexible demand-side management through medium to large electricity customers.</li> </ul>	<ul style="list-style-type: none"> <li>Advanced use of demand resources to manage load in ancillary services markets.</li> <li>Growing demand-side response participation.</li> <li>Increasing participation of distributed generation resources.</li> </ul>
<b>Flexible Generation</b>	<ul style="list-style-type: none"> <li>Conventional plants participate in energy and ancillary services markets.</li> </ul>	<ul style="list-style-type: none"> <li>Conventional plants participate in energy and ancillary services markets.</li> <li>Hydro imports.</li> </ul>	<ul style="list-style-type: none"> <li>Conventional plants participate in markets.</li> </ul>	<ul style="list-style-type: none"> <li>Conventional plants, primarily natural gas, participate in markets.</li> </ul>
<b>Networks</b>	<ul style="list-style-type: none"> <li>CREZ – Transmission infrastructure is the foundation of market development.</li> <li>Cost of connectivity is the same for all generators, irrespective of the distance to the demand centers.</li> </ul>	<ul style="list-style-type: none"> <li>Congestion is a significant issue and cost.</li> <li>Incremental investments to ease congestion and will be increasingly important.</li> <li>Plan to implement 44 transmission projects to reduce congestion costs by 21%.</li> </ul>	<ul style="list-style-type: none"> <li>Planned development to cater for exporting excess electricity from low demand regions; e.g., West Ireland to high-load areas; e.g., Dublin and an additional North-South Interconnector.</li> <li>Plans to increase interconnection capacity to the U.K. and new interconnections with France.</li> </ul>	<ul style="list-style-type: none"> <li>Investment to move wind to high-demand centers.</li> <li>Investment increase interconnection to Ireland and Europe.</li> </ul>
<b>Storage</b>	<ul style="list-style-type: none"> <li>Few projects, just starting but expected to be increasingly important.</li> </ul>	<ul style="list-style-type: none"> <li>Few projects, just starting but expected to be increasingly important.</li> </ul>	<ul style="list-style-type: none"> <li>Just starting.</li> </ul>	<ul style="list-style-type: none"> <li>Investing in a wide portfolio of storage technologies for different applications.</li> </ul>

**08**

# **DIGITAL AND RENEWABLE INTEGRATION OPTIONS**

New ways to integrate high penetration of wind generation require new digital capabilities. Examples of the digital capabilities required for different integration options are shown Table 8.

**Table 8. Digital capabilities to support renewables integration.**

<b>Integration Option</b>	<b>Description</b>	<b>Examples</b>
<b>System Operation</b>	Change the rules for generation scheduling and dispatch; i.e., include wind forecasts, reliability requirements for participants and interconnections with external areas.	<ul style="list-style-type: none"> <li>• Machine-learning-based forecasting to improve predictive performance.</li> <li>• Increased automation of system operation decisions applied to a wider range of balancing mechanisms.</li> <li>• Enhanced situational awareness and decision support in the control room to augment human decision making.</li> </ul>
<b>Markets</b>	Change the rules on how the markets operate to better match variable renewable generation and increased connectivity across markets.	<ul style="list-style-type: none"> <li>• Industrializing new market constructs to enable a fair and efficient process in compliance with regulatory arrangements.</li> <li>• Increased data and commercial integration across markets.</li> </ul>
<b>Load</b>	Demand-side management with automated response times within seconds to minutes.	<ul style="list-style-type: none"> <li>• Platforms that enable low-latency visibility and dispatch of demand-side resources and the back-end settlement.</li> <li>• Virtual power plant aggregation of distributed energy resource.</li> </ul>
<b>Flexible Generation</b>	Use flexible renewable assets and conventional generation with flexibility to follow the load.	<ul style="list-style-type: none"> <li>• Digitalization of conventional generation operations to increase efficiency enabling conventional generation to remain economical as it shifts from provision of baseload to the provision of flexibility.</li> </ul>
<b>Networks</b>	Expansion of the transmission network and connectivity across markets.	<ul style="list-style-type: none"> <li>• Network digital twin combined with scenario-based simulation to assess different expansion options.</li> <li>• Digitalization of transmission network design (4D CAD, design standardization and automation) and construction (digital field worker) to reduce CAPEX unit cost.</li> </ul>
<b>Storage</b>	Technologies to absorb energy when its value is low and release energy when needed.	<ul style="list-style-type: none"> <li>• IT/OT integration to drive optimized usage of storage capacity by maximizing value stacking across localized network and system level needs.</li> </ul>

Additional details can be found in the comprehensive study published by the International Renewable Energy Agency (IRENA) “Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables.”<sup>66</sup>

For utilities, knowing what capabilities they will need as wind penetration levels rise is the easy bit. The real challenge is delivering these capabilities within a cost-minimizing regulatory framework in an industry riven with uncertainty and change. The digital technology end state for operating a fully renewable energy system looks very different from today’s often inflexible, monolithic and complex industry IT architecture. IT and OT are poorly integrated, data is siloed and hard to access and change is slow and expensive. The very antithesis of the required characteristics of a digital organization that needs to be agile and innovative in the face of change that is rapid and deep.

## Outlook

The underlying technologies required to manage the future energy system largely exist and are deployed and proven at scale. They underpin our internet-enabled lifestyles. But the combination of talent and digital operating model that turns generic enabling technology into industry-specific solutions is a tough ask for regulated utilities. Their businesses will have to fundamentally change. And they will have to take risks—and fail as they innovate. Technology investment will be stranded. This runs against ingrained behaviors and the regulatory framework under which most utilities operate.

Utilities are beginning to outline how they will digitalize to enable the transition to an increasingly renewable energy system. National Grid ESO has set a clear, compelling vision for digitalization of their business as a strategic imperative in their RIIO-T2 submission.<sup>67</sup> They recognize the key challenges with a focus on the need for new skills (product owners, data scientists, scrum masters) and a move to agile at scale.

The industry, policymakers and regulators will need to work together to make an industry digital revolution viable. And this will need to happen fast so that technology constraints do not act as a limiting factor to the pace of renewable integration.



# Batteries and Renewables Integration

**Many markets have reached over 20% to 30% renewables integration, often by relying on hydropower or conventional generation (coal, gas, biomass) to balance the variability of wind and solar. However, it is widely recognized that batteries can support renewables penetration.**

In addition to absorbing energy when the demand is low and releasing energy when it is needed (peak shaving, energy arbitrage), batteries are changing system operations as new rules will be required to manage batteries in the system (e.g., state of charge management). New ancillary service products that take advantage of batteries will be developed (e.g., U.K.- Enhanced Frequency Response product), and batteries can also be used to firm up parts of the grid (more efficiently than transmission investment).

The most common configuration of batteries has been of four-hour duration, so while batteries have replaced gas peaking plants or conventional generation providing ancillary services, current battery technology (primarily lithium-ion chemistries) are not suited for days or weeks of energy storage.

The following are three examples of how batteries are changing markets and markets are changing to support batteries.

## **National Grid Case: New products that leverage battery characteristics**

National Grid U.K. must maintain system frequency within  $\pm 1\%$  of the target value of 50 Hz. In-built system inertia has reduced as conventional thermal generation comes off-line while increasing amounts of variable renewables are being connected. The resultant increase in frequency volatility has increased the requirement for faster response times by the company. National Grid UK's fastest ancillary service tool has been FFR, with response times for primary and secondary FFR of 10 seconds and 30 seconds respectively.

In 2016, National Grid had an auction for a new EFR product, with sub-second response time to provide the company with greater control over frequency deviations, resulting in potential cost savings of £200 million.

There were eight tenders accepted, 201 MW of EFR at a total cost of £65.95 million with an average price of £9.44/MW of EFR/h. In more than 200 bids, the weighted average tender prices for thermal generation and demand reduction were £35.20 and £28.56/MW/hour against the weighted average tender price of £17.39/MW/hour for storage technologies.<sup>68</sup>



## FERC Order 841: Market rules being adapted for batteries

FERC Order 841 directs the regional grid operators to establish rules that open capacity, energy and ancillary services markets to energy storage. Order 841 creates a clear legal framework for storage resources to operate in all wholesale electricity markets.

Figure 16 is the Energy Storage Association’s (ESA) assessment made of the progress of the regional grid operators against the FERC order 841 requirements.<sup>69</sup> It shows that with the exception of CAISO, while progress has been made, there is still work to do in many of the markets before batteries can participate fully in existing energy and ancillary services markets.

**Figure 16. FERC Order 841 – Compliance by ISO.**

■ Likely compliant   
 ■ Potentially non-compliant   
 ■ Non-compliant

Topic/RTO/ISO	CAISO*	ISO-NE	MISO*	NYISO	PJM*	SPP*
<b>B</b> 1. Participation model 2. Qualification criteria 3. Existing market rules	Likely compliant	Potentially non-compliant	Potentially non-compliant	Potentially non-compliant	Potentially non-compliant	Potentially non-compliant
<b>C</b> 1. Eligibility to provide all services	Likely compliant	Non-compliant	Likely compliant	Potentially non-compliant	Potentially non-compliant	Potentially non-compliant
2. Ability to de-rate capacity	Likely compliant	Likely compliant	Likely compliant	Likely compliant	Likely compliant	Likely compliant
<b>D</b> 1. Participate as a seller and buyer 2. Prevent conflicting dispatch 3. Make whole payments	Likely compliant	Likely compliant	Likely compliant	Potentially non-compliant	Likely compliant	Likely compliant
<b>E</b> 1. Bidding parameters	Likely compliant	Non-compliant	Likely compliant	Non-compliant	Non-compliant	Likely compliant
<b>F</b> 1. SOC management	Likely compliant	Potentially non-compliant	Likely compliant	Potentially non-compliant	Potentially non-compliant	Likely compliant
<b>G</b> 1. Minimum size	Likely compliant	Likely compliant	Potentially non-compliant	Likely compliant	Likely compliant	Likely compliant
<b>H</b> 1. Price for charging energy 2. Metering & accounting	Likely compliant	Likely compliant	Likely compliant	Likely compliant	Potentially non-compliant	Likely compliant

Source: “Energy Storage Association Unveils Initial Assessment of Regional Grid Operator Compliance with Federal Energy Regulatory Commission Order 841,” Energy Storage Association press release, [www.energystorage.org](http://www.energystorage.org).



## **Australia Case: Batteries will change markets**

New ancillary services products are being created and market rules adapted for the characteristics of batteries. Those characteristics also mean the way a battery participates in the market is different from other plants connected to the grid. Battery participation will change how the market operates and they will impact the pricing of ancillary services in the market.

For example, five months after it went live, the 100 MW Tesla battery implemented in South Australia had already taken a 55% share in the state's frequency and ancillary services market, and lowered prices in that market by 90%.<sup>70</sup> The Tesla battery is able to charge and discharge much more quickly and frequently than fossil alternatives. This bidding approach changes how the market operates and how other bidders bid.

In summary, batteries are becoming an important asset to provide flexible capacity and grid services. However, batteries are still relatively expensive. The IEA's 2019 investment report estimated grid-scale battery cost at \$400/KWh (average duration of four hours),<sup>71</sup> although costs are falling fast. FERC Order 841 mandates that RTOs/ISOs modify their rules to allow batteries to participate in existing markets but practically it makes sense for the RTO/ISO to first maximize what can be done in system operation, markets, and load to support integration of renewables. Batteries, like transmission expansions, are critical but are more expensive measures.

To justify the higher price, batteries must be operated to derive maximum revenue from multiple stacked revenue streams. This revenue stacking approach is illustrated in Table 9. A combination of software tools involving planning, optimization and analytics will be needed to maximize these benefits.

In this inset, we have focused on batteries to support the grid activities. Batteries have a much wider application. Generators are using batteries to build hybrid plants (mix of solar, wind and battery) to replace gas peakers to improve load profiles, to access ancillary services revenue streams, to improve forecasting, and to reduce curtailment.

On the demand side, we see behind-the-meter batteries to support demand-side technologies and control and to support the creation of virtual power plants (VPPs). We expect to see batteries at every point in the utilities value chain—integrated with generation, transmission-connected, distribution-connected and behind-the-meter. They will become a key part of the energy system infrastructure.

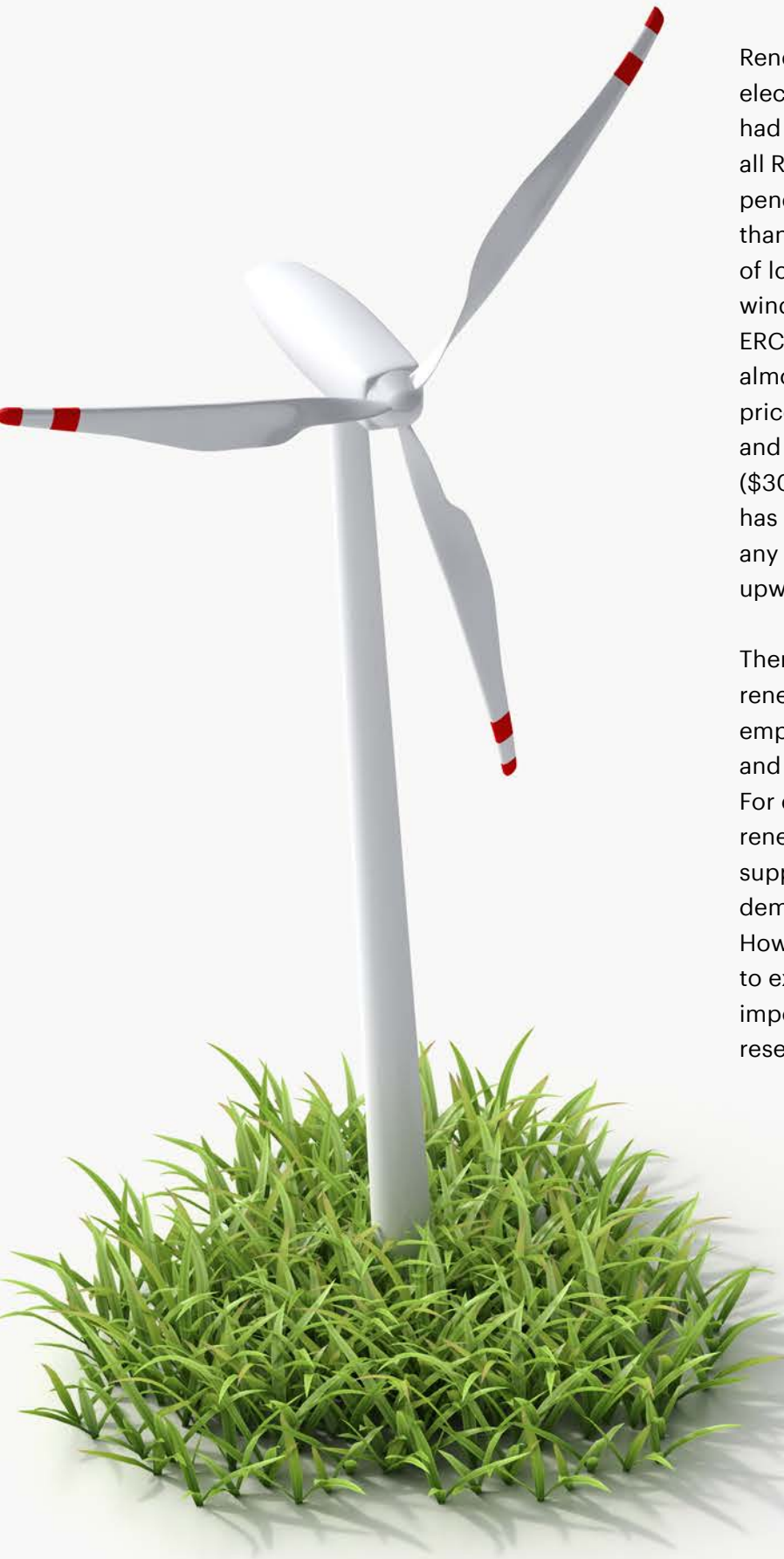
**Table 9. Battery storage revenue stacking.**

Domain	Service
Customer	<ul style="list-style-type: none"> <li>• Time-of-use bill management</li> <li>• Demand charge management</li> <li>• Increased self-consumption of on-site generation</li> <li>• Backup power</li> <li>• Demand-response program participation</li> </ul>
Distribution	<ul style="list-style-type: none"> <li>• Distribution capacity/deferral</li> <li>• Reliability (back-tie) services</li> <li>• Voltage support</li> <li>• Resiliency/microgrid/islanding</li> </ul>
Transmission	<ul style="list-style-type: none"> <li>• Transmission deferral</li> <li>• Black Start</li> <li>• Voltage support</li> <li>• Inertia</li> <li>• Primary frequency response</li> </ul>
Wholesale market	<ul style="list-style-type: none"> <li>• Frequency regulation</li> <li>• Imbalance energy</li> <li>• Spinning reserves</li> <li>• Non-spinning reserves</li> <li>• Flexible ramping product</li> </ul>
Resource adequacy	<ul style="list-style-type: none"> <li>• System resource adequacy capacity</li> <li>• Local resource adequacy capacity</li> <li>• Flexible resource adequacy capacity</li> </ul>

Source: "Order Instituting Rulemaking to consider policy and implementation refinements to the Energy Storage Procurement Framework and Design Program (D.13-10-040, D.14-10-045) and related Action Plan of the California Energy Storage Roadmap." California Public Utility Commission, January 11, 2018. <http://docs.cpuc.ca.gov>.

**09**

# **IMPLICATIONS FOR GRID OPERATORS**



Renewables have not increased the wholesale electricity prices in SPP and ERCOT. In 2018, SPP had the lowest wholesale electricity price among all RTOs (\$30.43/MWh) despite having the highest penetration of wind in its electricity mix (more than 23%) with max wind reaching a peak of 64% of load in 2018. Despite this high penetration, wind curtailment at SPP in 2018 was only 1.29%. ERCOT has more volatility in its prices but it has almost 20% wind penetration and a wholesale price comparable to many markets (\$41.61/MWh) and in the mid-range of wholesale U.S. prices (\$30.43 to \$47.53). Ireland, on the other hand, has much higher curtailment (6% higher than any RTO in the US), and curtailment is trending upward.

There are several options for integrating renewables and which to use/what to emphasize will differ by the current situation and targets/opportunities of each market. For example: Is there access to low-cost renewables and will this drive a situation where supply is expected to significantly exceed demand? Where is demand relative to supply? How flexible is demand? Is there an opportunity to expand the size of the market through imports/exports? How robust can the operating reserves/ancillary services market be?

There are six main implications for grid operators planning to integrate larger share of renewables:

1. **Understand the current sources of flexibility in the existing network.** In addition to understanding the supply and demand locations, the on- and off-peak volumes, the quality of production forecasts and load forecasts, and the existing long/short position, understand what existing sources of flexibility the network currently has access to; e.g., pumped storage hydro, interconnections with other markets, demand resources that can vary the load.
2. **Reliability requirements and participation of renewable resources in operating reserve/ancillary services markets:** Current wind and solar assets can be dispatched and designed to provide frequency and voltage support. Retrofitting is expensive. Ensure the markets are designed to reward a firm electron from renewable producers.
3. **Connectivity and congestion:** Understand where supply is (and is expected to be) relative to demand, what is the policy and cost of accessing transmission, where will congestion happen (or expected to happen) and have a plan, whether it be transmission expansion or congestion rights markets, to deal with this.
4. **What is the supply/peak demand ratio** that the market is comfortable with and what is the best (safest, lowest cost, most reliable) way to manage this; e.g., capacity market, capacity reserve, specialized contracting, etc.
5. **Review the renewable integration options** (system operation, markets, load, flexible generation, networks, storage) and be clear on the activities in each area and whether this makes sense given the current situation, renewables plans and targets, and integration costs.
6. **Invest in digital.** Much can be done to optimize the current situation, particularly if digital can be used to increase visibility of system operation and load, improve production forecasting, and predict network congestion. There is flexibility in existing systems and markets can be effective in quickly responding to signals. The visibility that ERCOT provides to energy consumers is just one example of leveraging digital to manage tight system conditions.

Renewable generation assets are transforming the grids, and we are seeing innovations in market and product design. But what we are also seeing is that these transformations can be implemented incrementally and pragmatically.

# Whole-systems thinking

**Whole-systems thinking will be needed to unlock value and to achieve decarbonization and renewable penetration aims in a lowest-cost, secure manner.**

Collaboration among all system players including generators, TSO, DSO, demand-response/storage providers, electricity consumers and regulators will be required to unlock all potential system solutions. For example, Accenture is working with grid operators to explore value-stacking opportunities to identify ways in which the same assets or services can be used to provide multiple solutions to one or more parties requiring flexibility. Unlocking this opportunity could offer previously unrealized capacity options for TSOs.

There is an increasing focus on the opportunity presented by sector coupling. An integrated systems approach across electricity and gas grids offers the opportunity to deliver new flexibility mechanisms. For instance, Power-to-X provides a way to harness variable renewable electricity resources and convert them to hydrogen (green hydrogen) and other gases, such as ammonia, which can be used directly in heat and transport alongside electrification, or to transport hydrogen to industrial regions for direct use in high-temperature processes. Hydrogen as an energy vector can enable variable renewable energy sources to meet energy demand at scale and across a wide variety of applications, offering a new flexibility opportunity for electricity TSOs.

Interest in Power-to-X is growing globally particularly as countries consider solutions for difficult-to-decarbonize sectors like heavy transport and large industry. Offshore wind growth is also encouraging industry stakeholders to consider large energy storage and complementary value streams, particularly so in the case of floating wind farms that are far from shore. The economics of HVDC and other cable solutions for far-from-shore assets may make Power-to-X a very attractive complementary value stream, enabling asset owners to hedge their route to market across both electricity and hydrogen for transport/heat. The intermittent nature in which wind is curtailed may reduce the extent to which all this energy can be economically captured for Power-to-X; however, the sector-coupling opportunity will afford another source of energy system flexibility and efficiency in future.

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