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INNOVATIVE ANCILLARY SERVICES

INNOVATION LANDSCAPE BRIEF

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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Disclaimer

1 NEW ANCILLARY SERVICE PRODUCTS AND MARKET PARTICIPANTS

New products
- Ramping products
- Fast response frequency reserve

New market participants
- Wind turbines providing inertial response
- Solar PV and batteries providing voltage support
- Distributed energy resources providing frequency and voltage control

→ **Increased flexibility for VRE integration**

2 KEY ENABLING FACTORS

- Defining performance-based products
- Separating capacity and energy products, and contracting periods
- Separating upwards and downwards balancing products

3 SNAPSHOT

- Batteries can provide ancillary services in Australia, Belgium, Germany, Netherlands, UK and USA
- Wind power generators can provide balancing services in nine European countries
- A US system operator uses separated ramping products to help the system meet ramping needs
- The exchange of balancing services across borders in Europe is increasing
- Local flexibility markets emerge in Germany and UK, where ancillary services are procured by the DSOs

WHAT ARE ANCILLARY SERVICES?

Ancillary services are vital to support power system operation. There are two types: frequency and non-frequency services (voltage control, black start).
Innovative ancillary services can address the variability and uncertainty of the VRE.

INNOVATIVE ANCILLARY SERVICES

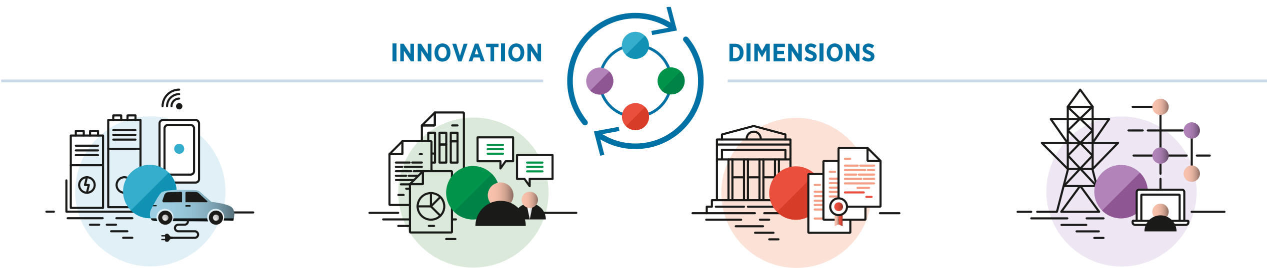
Ancillary services need to be adapted to increase system flexibility.
The ancillary service market should be open to all participants.

ABOUT THIS BRIEF

This brief forms part of the IRENA project "Innovation landscape for a renewable-powered future", which maps the relevant innovations, identifies the synergies and formulates solutions for integrating high shares of variable renewable energy (VRE) into power systems.

The synthesis report, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables* (IRENA, 2019a), illustrates the need for synergies between different innovations to create actual flexibility solutions for power systems. Solutions to drive the uptake of solar and wind power span four broad dimensions of innovation: enabling technologies, business models, market design and system operation.

Along with the synthesis report, the project includes a series of briefs, each covering one of 30 key innovations identified across those four dimensions. The 30 innovations are listed in the figure below.



ENABLING TECHNOLOGIES

1 Utility-scale batteries
2 Behind-the-meter batteries

3 Electric-vehicle smart charging
4 Renewable power-to-heat
5 Renewable power-to-hydrogen

6 Internet of things
7 Artificial intelligence and big data
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9 Renewable mini-grids
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11 Flexibility in conventional power plants

BUSINESS MODELS

12 Aggregators
13 Peer-to-peer electricity trading
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17 Increasing time granularity in electricity markets
18 Increasing space granularity in electricity markets
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SYSTEM OPERATION

25 Future role of distribution system operators
26 Co-operation between transmission and distribution system operators

27 Advanced forecasting of variable renewable power generation
28 Innovative operation of pumped hydropower storage

29 Virtual power lines
30 Dynamic line rating

This innovation landscape brief examines innovations in ancillary services – a key market design innovation that addresses the variability and uncertainty of the VRE share in the grid. Ancillary services need to be adapted to increase system flexibility by remunerating new services needed in a high-variability scenario. Moreover, in addition to being open to conventional generation units, the ancillary service market should be open to new participants, such as large-scale renewable generators and battery storage, and to providers of distributed energy resources (DERs), including demand response, small-scale battery storage, and distributed VRE generation.

The brief is structured as follows:

I Description

II Contribution to power sector transformation

III Key factors to enable deployment

IV Current status and examples of ongoing initiatives

V Implementation requirements: Checklist

I. DESCRIPTION

The increased deployment of VRE generation sources introduces variability and uncertainty into power system operation. To address these issues, transmission system operators (TSOs) and distribution system operators (DSOs) procure system services: the deployment of flexible on-demand generation, storage or demand-side response to help maintain grid reliability and security. This brief discusses how the design of ancillary service markets can evolve to help system operators integrate VRE by addressing the introduced variability and uncertainty. To ensure a reliable and stable system, the power supply must meet demand at all times to maintain the nominal grid characteristics in terms of frequency and voltage.

"Ancillary services" are services necessary for the operation of a transmission or distribution system. Typical ancillary services are procured by TSOs and can be clustered into frequency ancillary services (balancing of the system[1]) and non-frequency ancillary services (voltage control and black-start capability). Conventionally, TSOs have utilised power from generating resources, storage resources (such as pumped hydro storage or capacitors) or reactive power control equipment (such as synchronous or static compensators or capacitor banks) to obtain ancillary services (Singh & Papalexopoulos, 1999). These strategies help system operators maintain grid frequency and voltage at desired levels while provisioning some generation capacity as reserves for contingency events (Stoft, 2002).

To address the variability and uncertainty of increasing VRE in the grid, ancillary services need to be adapted to increase system flexibility, incentivise fast response and ramping ability, and remunerate each of the services accordingly. Moreover, the definitions and measurement schemes of some conventional ancillary services do not provide a proper basis for evaluating the performance of different resources. As a consequence, some resources may not receive the right incentives to provide flexibility, thus limiting the flexibility available to system operators. To address variability and uncertainty in the grid, there is a need to redesign the existing ancillary service products and create new ones. For instance, Pennsylvania Jersey Maryland (PJM) Interconnection, an independent regional transmission operator in the United States, has developed different frequency regulation products for slower conventional resources and for faster battery storage resources.

Moreover, in addition to being open to conventional generation units, the ancillary service market should be open to new participants, such as large-scale renewable generators and battery storage, and to providers of DERs, including demand response, small-scale battery storage and distributed VRE generation.

Table 1 briefly describes traditional and new ancillary services, as well as new players allowed to provide these services. The innovative ancillary services are highlighted.

1 Supply may vary with unexpected increases or decreases in power supply.

Table 1 Types of ancillary service and associated products

Ancillary service	Product	Description	Typical response time
Frequency regulation	**Primary regulation**	The automatic local regulation provided by generating unit speed regulators. This level of regulation sustains frequency levels, preventing large deviations from the scheduled value.	Sub-seconds to seconds
		Innovations: • Fast frequency response is a new product designed to remunerate the provision of fast response[1]. Batteries are great providers of such services, creating the possibility of additional revenue streams for battery operators/owners. • Wind turbines can provide inertial response through power electronic converters. • Photovoltaic (PV) installations, direct current systems and batteries can also provide synthetic inertial response if the inverter is programmed to do so. However, as inverters are not stuck with characteristics of large spinning masses and have more options to provide system stability, this might not be the best use of them. • If regulation allows, DERs can provide this service.	
	Secondary regulation	The automatic regional regulation provided by automatic generation control (AGC), which sends signals from the control centre to certain generators to re-establish the nominal frequency value and restore the primary reserve capacity.	5–15 minutes
		• If regulation allows, DERs can provide this service.	
	Tertiary regulation	The manual regional regulation provided by generating units and controlled by the system operator.	>15 minutes
Non-frequency regulation	**Voltage support**	The injection of reactive power to maintain system voltage within a prescribed range.	Seconds
		Innovations: • Voltage control through reactive power provided by resources connected to the power system through inverters, such as solar photovoltaic and battery storage. • If regulation allows, DERs can provide this service.	
	Black start	The ability to restart a grid after a blackout.	Minutes
	Innovations: • Ramping products	Fast ramping resources that can respond to large net load variations in a short time. This product properly remunerates the fast ramping capability of generators and incentivises flexibility.	Minutes

Innovations in ancillary services

Note: *The nomenclature and the definitions of different types of ancillary service used in this table are not standardised and can vary significantly from country to country. Historically, the nomenclature and definitions have been based on the services provided by energy resources for reliable grid operations. However, different types of ancillary service are increasingly being categorised as specialised products, catering to specific grid requirements. For example, "Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation" specifies how TSOs across the European Union should manage their network, taking into account that the power system is integrating more renewables and that markets are increasingly interconnected (European Commission, 2017a).*

[1] Sometimes, the inertial response of wind turbines is also classified under the category of fast frequency response.

(Based on: Banshwara et al., 2017; Batlle, 2013; Kirby, 2004)

Trading ancillary services with neighbouring TSOs within a regional market is also key to increasing the overall flexibility of the transmission system and reducing balancing costs. Several stakeholders in the European Union (EU), including the Agency for the Cooperation of Energy Regulators (ACER), national regulatory authorities, and TSOs within the European Network of Transmission System Operators for Electricity (ENTSO-E), have developed a set of rules on the operation of balancing markets, which entered into force via "Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing".

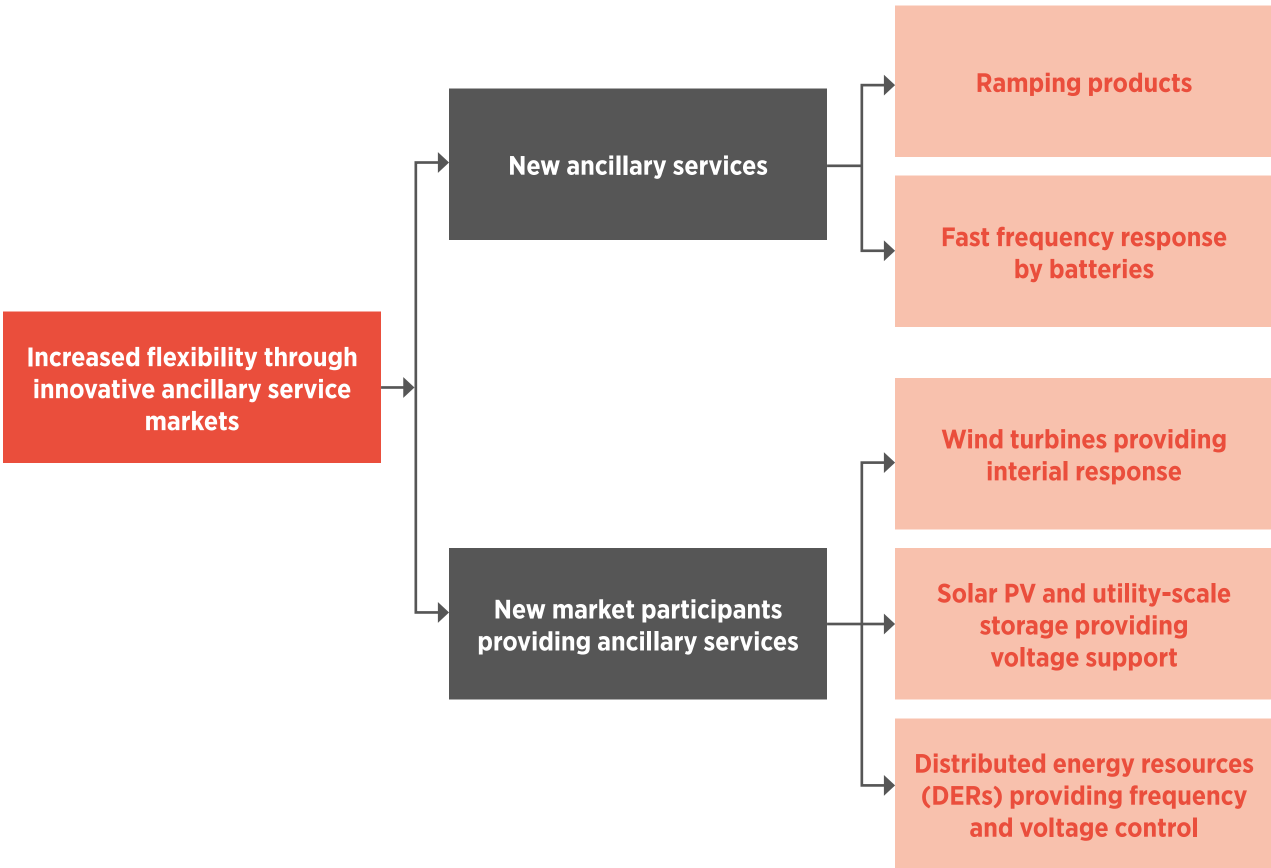
The European balancing guideline sets down rules on the operation of balancing markets throughout the EU, referring to those markets that TSOs use to procure balancing services (either balancing energy or balancing capacity[2]) to keep the system balanced in real time. This regulation provides opportunities for cross-border trading within such balancing markets (European Commission, 2017b). As such, this framework enables a greater cross-border availability of resources for balancing the system and, in turn, lowers costs for procuring these services. (See also Innovation Landscape Brief: Regional Markets. [IRENA, 2019b])

2 Commission Regulation (EU) 2017/2195 defines "balancing energy" as the energy used by TSOs to perform balancing and provided by a balancing service provider; "balancing capacity" is defined as the volume of reserve capacity that a balancing service provider has agreed to hold and in respect to which the balancing service provider has agreed to submit bids for a corresponding volume of balancing energy to the TSO for the duration of the contract (European Commission, 2017b).

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

To increase system flexibility and integrate a high share of VRE, while keeping the system in balance, several innovative products are being developed in different markets. One set of innovative ancillary services addresses flexibility issues, remunerating those services related to rapid ramping requirements, frequency regulation, and so on. Another set of innovative ancillary products allows new market participants to offer such services: wind turbines can be utilised to provide inertial response, solar photovoltaic (PV) can offer reactive power support, and other DERs can help increase market liquidity across different trading time frames and reduce ancillary service procurement costs.

Figure 1: Innovations in ancillary services and examples



New ancillary services

Ramping products

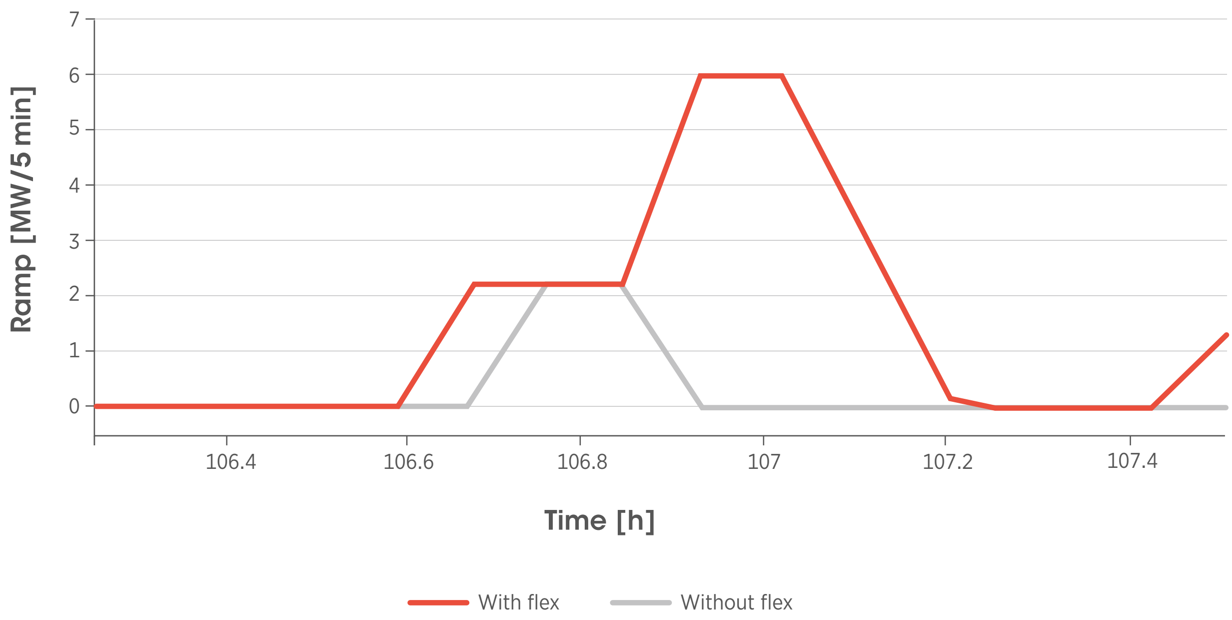
With an increase in the VRE share, the net load[3] curve becomes increasingly volatile (Kirby & Milligan, 2008). Conventional generation, with a controllable generation profile, is expected to be increasingly displaced by low marginal cost VRE generators and is instead expected to be used to provide back-up power.

System operators would need reserves that can provide fast ramping capabilities to address such net load volatility. Conventionally, net load ramping requirements have been served by conventional generators. In most markets, such ramping by conventional generators is not identified as a separate ancillary service and is only compensated based on the marginal cost of electricity production. When such ramping is procured through energy markets, steep ramping requirements can lead to increased prices in the energy market, thereby distorting the market for participants who are not providing ramping services (Ela *et al*., 2012).

To address this issue, a separate ramping or flexibility product is created as part of the balancing market to serve the net load ramping requirements. For example, California Independent System Operator (CAISO) in the United States was among the first independent system operators in North America to implement a separate flexibility ramping product. In November 2016, CAISO implemented Flexible Ramp Up and Flexible Ramp Down Uncertainty Awards, which are ancillary service market products to procure ramp-up and ramp-down capability for 15 minute (min) and 5 min time intervals. The product is procured in terms of megawatts (MW) of ramping required in a 5 min duration, and any resource capable of fulfilling the ramping requirement can participate. Market participants do not provide bids for this product but are instead compensated according to their lost opportunity cost of providing other services in the ancillary service market. The price for providing ramp-up service is capped at USD 247 per megawatt-hour (/MWh), while the price for providing ramp-down service is capped at USD 152/MWh (CAISO, 2018).

Furthermore, when such ramping products are traded in the ancillary service market, the availability of fast ramping capacity increases, which in turn reduces the price spikes associated with ramping shortfall (Krad, Ibanez & Ela, 2015a). This is depicted in Figure 2.

Figure 2: Available ramping capacity with and without flexibility reserve products



Source: IRENA (2017), adapted from Krad, Ibanez & Ela (2015a)

3 "Net load" is the difference between the load and the electricity production from variable renewable generation.

Fast frequency response provided by batteries

Grid frequency must be kept in the system within a prescribed range for secure system operations. In cases of sudden variation in demand and supply in the system, grid frequency can suddenly go out of range, thus affecting the reliability and security of the system. Conventionally, quick restoration of frequency within a few seconds to minutes has been enabled by increased output by conventional generators through autonomous governor control. However, with increased VRE penetration, autonomous response offered by the remaining conventional generators may not be sufficient to address frequency drops. Batteries are well suited to providing balancing services and fast frequency response because of their short response times.

The fall in costs of battery storage technologies has led to their increased deployment by system operators as well as generators for various purposes. Battery storage technology has a sub-second response capability that makes it suitable for use by system operators as a rapid response frequency reserve. A separate ancillary service market product can be created to procure such services from battery storage systems. For instance, National Grid in the United Kingdom has added a new product to contract with battery storage providers for fast frequency reserve services. In 2016, National Grid conducted an enhanced frequency response (EFR) tender under which it contracted eight battery storage facilities for four years to provide sub-second rapid response frequency reserves (KPMG, 2016).

Similarly, Australia's energy market operator contracted Tesla's 100 MW/129 MWh lithium-ion battery in South Australia. The battery, known as Hornsdale Power Reserve, provides accurate response to the frequency control and ancillary services market at a lower rate than conventional sources of energy. In its first four months of operation, the price of frequency ancillary services was reduced by 90 % (Gabbatiss, 2018; Vorrath & Parkinson, 2018).

In Japan, as opposed to the TSO procuring the ancillary service directly, some utilities require that large solar PV projects control their feed-in of electricity by using battery storage to meet grid frequency requirements. For example, the 38 MW Tomakomai solar PV project includes a 20 MW lithium-ion battery, one of the world's biggest at the time of construction in 2017. The sole application of the battery is to meet the frequency requirements of the local energy utility, Hokkaido Electric Power Company.

New market participants providing ancillary services

Wind turbines providing inertial response

"Inertial response" refers to the ability of synchronous generators to speed up or speed down to overcome immediate frequency disturbances. Inertial response has been traditionally provided by large thermal generators and large hydropower plants. Although such frequency disturbances can be addressed using fast frequency response services, inertial response can provide faster response times and more reliable response because it is an inherent feature of generators.

VRE technologies have been exempted from balancing responsibilities in many countries. However, some VRE technologies can offer balancing services. Wind turbines connected to the power system through a power electronic converter can provide inertial response (also known as synthetic inertia) during frequency disturbances. During a frequency surge, the power electronic controller can apply a retarding torque on the turbine to reduce generation, whereas during frequency drops (Ela et al., 2012), the controller can utilise the kinetic energy of the turbine to increase power output (Morrena, Pierikb & Haana, 2006). This can also be achieved by reducing or increasing the blade angle to decrease or increase the power supply (Miao et al., 2010). For instance, Hydro-Québec TransÉnergie, a TSO in Canada, requested an inertia emulation function in the wind turbines as a part of its 2 000 MW wind energy procurement tender (Brisebois & Aubut, 2011).

Inverters can be programmed to help control frequency as well, and the way that PV plants are operated can be a factor in the ability to provide frequency response. However, a question is whether it is best to use inverters this way. Inverters are not stuck with the characteristics of large spinning masses and have more options to provide system stability (Roselund, 2019).

Obtaining system services from VRE requires various policy measures, such as specific grid codes and upgrades to the system services procurement mechanism (IRENA/IEA/REN21, 2018).

PV power plants and utility-scale storage providing reactive power

Reactive power helps maintain voltages in the network within prescribed limits (Kirby & Hirst, 1997). However, reactive power flowing for long distances in the transmission and distribution grid causes a number of problems, which include inadmissible voltage excursions and increased losses. Therefore, reactive power must be supplied, when needed, from a nearby source. This has conventionally limited market mechanisms for procuring reactive power, as there may be limited alternative sources of reactive power at a given location.

Devices such as solar PV or battery storage, which have a solid-state electronics interface with the power system, can provide reactive power support (Ela *et al*., 2012). Reactive power support from large-scale wind and solar generation connected to the grid via inverters is also important in some jurisdictions – notably, where high-quality primary energetic resources are in areas far from main load centres and connect to main load centres via "weak" networks. Designing proper mechanisms to ensure that these assets contribute to reactive power control is also relevant. Such mechanisms can include:

- adequately designed connection requirements in grid codes, which may slightly increase capital expenditure requirements for generators and thus guide investment decisions

- incentives oriented specifically to the procurement of reactive power as a separate product, which have been less common so far.

Distributed energy resources

DERs, such as rooftop solar systems, behind-the-meter battery storage systems, plug-in electric vehicles, and commercial and industrial loads, can provide ancillary services to system operators through price-based incentives, often referred to as "explicit demand response". By increasing liquidity and competition in the ancillary service markets, DERs can also help lower ancillary service procurement costs. DERs may be allowed to participate independently or through aggregators or retailers, depending on the market design in place.

For instance, in December 2017, the New York Independent System Operator (NYISO) released a concept proposal of market design to enable DERs to participate in wholesale as well as ancillary service markets. Under this proposal, DERs would be treated on a par with other market players and would be able to participate in capacity reserve markets, regulation service markets, and so on, either directly or via aggregators of small-scale DERs (<100 kilowatts) (NYISO, 2017).

Also, DERs can participate in local flexibility markets, if established. Local flexibility markets are platforms that centralise local flexibility offers to allow system operators to reliably and economically relieve physical congestions and bottlenecks from the grid (EPEX SPOT, 2019). Being connected to the distribution grid, DERs are potentially problematic for network stability and reliability in the distribution network. In addition to central utilisation of DER flexibility services in traditional markets, decentralised management of DERs by DSOs could be possible. The interest in this type of management is rising, especially because of upcoming risks for, among other things, over-voltage and congestion with the penetration of distributed generation. DSOs could then procure local system services from DERs to solve issues related to voltage regulation, power quality and distribution network congestion. (See also: Innovation Landscape Brief: Market Integration of distributed energy resources [IRENA, 2019c])

Potential impact on power sector transformation

- In Germany, renewable energy generators, battery storage systems and industrial loads were allowed – alongside conventional generators – to participate in the balancing markets in 2009. In the period from 2009 to 2015, the balancing **market size in gigawatts (GW) decreased by 20 % and ancillary service procurement costs by TSOs decreased by 70 %**. During the same period, **system stability increased and the installed capacity of VRE increased by 200 %**. This experience indicates that allowing new resources to participate in ancillary service markets can help increase system stability while reducing costs (Wang, 2017).

- The deployment of the sub-second EFR by National Grid in the United Kingdom is expected to result in **costs savings of approximately USD 262 million**[4] over four years compared with alternative ways of providing frequency response (KPMG, 2016).

- According to a study by Krad, Ibanez and Ela (2015b), the deployment of flexibility reserve products, such as CAISO's flexibility ramping product (Flexible Ramp Up and Flexible Ramp Down Uncertainty Awards), **can offer value in managing uncertainty introduced by VRE** (i.e. real-time prices that exceed USD 1000/MWh).

4 Original figure of GBP 200 million converted to USD using the prevailing exchange rate as per Bloomberg on 24 July 2018 (www.bloomberg.com/quote/GBPUSD:CUR).

III. KEY FACTORS TO ENABLE DEPLOYMENT

Introduction of innovative products and new market participants requires revision of rules on how these services should be procured are also needed (e.g. more frequent contracting periods, local markets, cross-border sharing of reserves).

Defining performance-based products

Conventionally, different energy resources providing frequency regulation services have been compensated at the same remuneration, irrespective of their performance (IRENA, 2017). However, battery storage-based resources can provide much faster regulation service than conventional generators. Therefore, the compensation mechanism must appropriately value the performance characteristics of different resources. This will incentivise greater deployment of battery storage technology in providing ancillary services.

For instance, in 2011 the Federal Electricity Regulatory Commission's Order 755 mandated compensation to resources providing frequency regulation based on their performance (FERC, 2011). Following this order, PJM Interconnection implemented a new product to remunerate resources based on how fast they are able to respond to the system operator signals. The compensation is proportional to the response time, thereby incentivising battery storage systems in providing such services. Two different signals were created – a conventional signal and a fast response signal – so that fast responsive resources such as batteries have an advantage over conventional resources and can be remunerated for this service (PJM Interconnection, 2018).

Separating capacity and energy products, as well as contracting period

In many ancillary service markets, balancing capacity and balancing energy are jointly procured. Balancing capacity gives TSOs the possibility of activating a certain amount of balancing energy in real time. For instance, automatic frequency restoration reserve (FRR) markets in Denmark and Spain and manual and automatic FRR markets in Germany follow this approach (IRENA, 2017). However, only those generators that can offer balancing capacity can offer balancing energy in real time. This method does not reveal the most cost-effective resources in real time. It also restricts the participation of various DERs, including VRE, because such products are procured well in advance and most VRE resources or DERs cannot commit capacity earlier than in real time.

For instance, the Netherlands' automatic and manual FRR markets, as well as Belgium and Denmark's manual FRR market, procure balancing capacity and energy as separate products (IRENA, 2017). For Belgium and the Netherlands, two options are available: capacity and energy in one product or as separate energy products (free bids).

Separating balancing capacity products from balancing energy products can help discover cost-effective resources in real time while allowing VRE resources and other DERs to offer their energy flexibility in such markets. For this, the acquisition of balancing energy has to shift from yearly to monthly, or even daily, procurement. This will increase VRE resources and DER participation in ancillary service markets, thereby increasing system flexibility while leading to increased deployment of such resources.

The US National Renewable Energy Laboratory has conducted studies to analyse the changes required to operate reserve requirements due to the introduction of up to 30 % solar PV and wind energy resources on large portions of the western and eastern interconnections of the US grid. Studies concluded that the reserve requirements should not be static, as they have conventionally been, but instead should change according to the system conditions on a shorter time scale, such as on an hourly basis (EnerNex Corporation, 2011; GE Energy, 2010).

However, in systems where the short-term signals are, for whatever reason (e.g. volatility, lack of credibility), insufficient to incentivise investments in resources capable of providing ancillary services in real time, contracting them in advance can be a way to enable or unlock investments.

Separating upwards and downwards balancing products

In many ancillary service markets, frequency regulation service is procured as a single product that includes both frequency regulation up and frequency regulation down services. For instance, in Denmark, Italy and Spain system operators procure such a unified frequency regulation service under FRR requirements (IRENA, 2017).

Procuring frequency regulation up and down as a single product limits the amount of capacity and the types of resources that can participate in the ancillary service market. For instance, a combined-cycle plant operating at its minimum generation point could provide only regulation up, whereas a wind plant operating at its maximum generation could provide only regulation down. However, neither resource would be able to participate in the ancillary service market, which procures regulation up and down as a single service. Therefore, frequency up and down regulations should be procured as separate products. This will enable VRE resources, as well as DERs, to participate in ancillary service markets, thereby increasing system flexibility and resource deployment. For example, Elia, the Belgium TSO, has defined two asymmetrical products for frequency containment reserves (FCRs, also called R1): “R1- down” and “R1- up”, for which the supplier needs to react to any frequency deviation bigger than 100 mHz (separated for the positive and negative deviations) (Elia, 2018). CAISO implemented Flexible Ramp Up and Flexible Ramp Down Uncertainty Awards.

IV. CURRENT STATUS AND EXAMPLES OF ONGOING INITIATIVES

Some of the key indicators of an innovative ancillary service market are described in the table below. Case studies of innovative ancillary services follow.

Table 2 Innovative ancillary service market: Key indicators

Key indicator	Examples
VREs are able to participate in the existing ancillary service markets	• Wind power generators are allowed to provide balancing services in Belgium, Denmark, Estonia, Finland, the Netherlands, Poland, Spain, Sweden, and the United Kingdom. • In Chile, the first pilot was implemented to enable a PV power plant to provide ancillary service to the utility grid and ensure grid stability.
New ancillary service products have been designed for VRE integration	• In the United Kingdom, a new product was introduced for battery storage: enhanced frequency response. • Ramping products introduced in the United States. • EirGrid, the Irish TSO, has defined several additional system service products to cope with wind energy fluctuations. • PJM Interconnection, a system operator in the United States, has developed different frequency regulation products for slower conventional resources and for faster battery storage ones.
Battery storage can participate in ancillary service markets	• Australia, Belgium, Germany, the Netherlands, the United Kingdom, and the United States.
Reforms are made to ongoing ancillary service market or balancing market	• The EU-wide development and implementation of network codes for balancing markets and system operation, including the procurement of ancillary services by TSOs (applicable in all EU member states). • In Denmark, wind turbine operators now face charges for incorrect forecasts, the same way as conventional generators. • In the United Kingdom, recent reforms have increased charges in general for incorrect forecasts and rewarded generators and suppliers that can plug these gaps.

Examples of new ancillary services

National Grid's enhanced frequency response tender (United Kingdom)

National Grid, the TSO in the United Kingdom, has the obligation to maintain system frequency within ±1% of the target value of 50 hertz. The rising share of renewables and declining share of conventional generators in the energy mix in the recent years had led to decreased system inertia and an increase in frequency volatility. This resulted in the need for faster frequency response than the existing options could provide.

Until August 2016, National Grid was procuring fast frequency response, which was its fastest tool, with a primary response time of 30 seconds (s) and a secondary response time of 60 s. Then National Grid introduced an enhanced frequency response (EFR) to provide sub-second rapid response frequency reserves. The tender to procure EFR contracted eight battery storage facilities for four years at prices between USD 9.21/MW/h and USD 15.74/MW/h.[5] The tender was oversubscribed by seven times, with 1.2 GW of battery capacity being unsuccessful in the tender, which indicated a large interest and appetite by battery storage developers to provide these services (KPMG, 2016).

Midcontinent Independent System Operator's ramping product (United States)

To prevent pricing spikes in the energy market, Midcontinent Independent System Operator (MISO) in the United States has implemented a separate ramping product to help the system meet ramping needs. The product is procured on a day-ahead as well as a real-time basis. Resources can provide ramp up, ramp down or both, and the output in MW they can attain within 10 min counts towards the ramp up or ramp down. All dispatchable resources can participate in offering this product, which is procured by MISO across its territory and does not vary by location or zone within MISO's territory. The resources providing ramping services are compensated for the lost opportunity cost, calculated from the clearing price of other products in the market (NYISO, 2018).

New York Independent System Operator's proposed flexibility ramping product (United States)

After the successful implementation of the flexibility ramping product by CAISO and MISO, the NYISO proposed a similar flexible ramping product in its 2018 master plan. The NYISO expects that the product would be procured in both day-ahead and real-time markets. Moreover, the ramping requirement is expected to be specified in terms of the MW of response a resource can provide in a given time interval. The resources providing the ramping service are expected to be compensated at the lost opportunity cost of a resource participating in the energy market (NYISO, 2018).

Pan-European guidelines on electricity balancing and electricity transmission system operation (European Union)

As part of the EU's so-called third legislative energy package, Regulation (EC) No 714/2009 sets out the rules governing access to the network for cross-border exchanges in electricity, with a view to ensuring the proper functioning of the EU's internal market in electricity (Council of the European Union, 2009). This package created ENTSO-E, which together with the Agency for the Cooperation of Energy Regulators (ACER), develops the European network codes and guidelines (i.e. the rules for the operation of the electricity sector), which are then adopted by the European Commission. Within this framework, several network codes have been adopted, including "Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation" and "Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing" (European Commission, 2017a, 2017b). The former lays down detailed guidelines on operational planning for ancillary services, as well as load-frequency control and reserve rules, including operational agreements, frequency quality, load-frequency control structure, operation of load-frequency control, FCRs, FRRs, replacement reserves, exchange and sharing of reserves, time control process, co-operation with DSOs, and transparency of information. The balancing capacity products can be defined as follows:

- **Frequency containment reserves (FCR)**: Active power reserves available to contain system frequency after the occurrence of an imbalance.
- **Frequency restoration reserves (FRR)**: Active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one load-frequency control area, to restore power balance to the scheduled value. A distinction is made between automatic FRRs and manual FRRs.
- **Replacement reserves**: Active power reserves available to restore or support the required level of FRRs to be prepared for additional system imbalances, including generation reserves.

5 Original figure of GBP 7/MW/h and GBP 11.97/MW/h converted to USD using the prevailing exchange rate as per Bloomberg as on 26 July 2018 (www.bloomberg.com/quote/GBPUSD:CUR).

Local flexibility markets

Piclo flexibility market (United Kingdom)

Open Utility is developing an online marketplace, called Piclo Flex, to enable DSOs to access location-specific flexible resources. These local flexibility markets will play a critical role in balancing local smart grids and facilitating the rollout of distributed generation, storage and electric vehicles. It acts as a marketplace for DSOs to procure services from DERs that can provide flexibility at times when the network is becoming more congested. This market is open to aggregators, suppliers, battery operators, electric vehicle charge points, industrial consumers or any other flexibility provider.

Piclo Flex allows network operators to see what is available in their regions; they can then plan how to meet their needs accordingly. It also allows them to provide greater transparency to flexibility providers seeking to determine the opportunities for additional revenues. DSOs can hold auctions to procure services in flexible capacity from a range of providers that have uploaded their capabilities to the platform.

A smart and flexible network could reduce the United Kingdom's emissions from electricity generation, but only if the DSOs can quickly and easily access flexible assets on the grid. Open Utility's resource optimisation algorithms, delivered via an intuitive online service, lower the barriers to entry and manage the deployment of localised flexibility in a highly efficient and scalable way.

Flexibility platform for congestion management (Germany)

The grid operators Avacon Netz, EWE NETZ and TenneT, and the European power exchange EPEX SPOT, have developed a clear and transparent market mechanism for flexibility providers that want to participate in market-based congestion management. By introducing local order books, flexibility offers based on network topological information will be recorded. These offers can then be accessed by system operators, who can use them to avoid grid congestions. EPEX SPOT acts as a neutral intermediary between system operators and flexibility providers.

In Germany, there is growing input from wind power plants in the north, while the main consumption areas are in the south. As a result, grid congestion at all voltage levels is increasingly occurring. This has caused substantial expenditure on grid-stabilising measures, such as feed-in management and redispatch. The transmission grid is particularly concerned by this, but congestion is also increasingly occurring at the distribution grid level.

This flexibility platform is demonstrating that a voluntary market-based instrument can prevent forecasted grid congestion by enabling better matching of generation and consumption, while taking into account local flexibility assets. In addition to other providers of local flexibilities, the automobile manufacturer Audi is participating in this flexibility market with its power-to-gas plant in Werlte, Lower Saxony.

Ancillary services trading across borders

Pan-European pilot projects for trading ancillary services across borders (European Union)

As of 2017, several European projects that aim to increase the exchange of balancing services across borders had been initiated and had started to show results. For example, the International Frequency Containment Reserve co-operation is a common market for the procurement and exchange of balancing capacity and involves ten TSOs in seven countries: Austria (APG), Belgium (Elia), Denmark (Energinet), France (RTE), Germany (50Hertz, Amprion, TenneT DE, TransnetBW), the Netherlands (TenneT NL) and Switzerland (Swissgrid). As a result of this project, where FCRs are procured through a common merit order list, FCR capacity prices have been steadily decreasing and converging across the participating countries. Other initiatives in Europe aim to net imbalances or exchange balancing energy across TSO scheduling areas, such as the project to exchange energy from automatic FRRs between Austria and Germany. As a result, the overall cross-zonal exchange of balancing energy (including imbalance netting) almost doubled between 2015 and 2017 (ACER/CEER, 2018).

Other pan-European pilot projects for trading ancillary services include:

- **International Grid Control Cooperation**: A regional project operating the imbalance netting process that involves 11 TSOs in eight countries: Austria (APG), Belgium (Elia), Czech Republic (ČEPS), Denmark (Energinet.dk), France (RTE), Germany (50Hertz, Amprion, TenneT DE, TransnetBW), the Netherlands (TenneT NL) and Switzerland (Swissgrid).

- **e-GCC**: A regional project operating the imbalance netting process that involves Czech Republic (ČEPS), Hungary (MAVIR) and Slovakia (SEPS).

- **Imbalance Netting Cooperation**: A regional project operating the imbalance netting process that involves Austria (APG), Croatia (HOPS) and Slovenia (ELES).

- **Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation**: Starting point for the implementation and operation of a platform for automatically activated FRRs, in compliance with the European network codes.

- **Manually Activated Reserves Initiative**: An initiative to design a platform for exchanging balancing energy from manually activated FRRs, launched in 2017 by 19 European TSOs.

- **Trans European Replacement Reserves Exchange**: A project selected by ENTSO-E to become the European platform for the exchange of balancing energy from replacement reserves pursuant to the network codes, in which nine TSOs participate: Czech Republic (ČEPS), France (RTE), Italy (Terna), Poland (PSE), Portugal (REN), Romania (Transelectrica), Spain (RED), Switzerland (Swissgrid) and the United Kingdom (National Grid).

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS

Hardware:
- Power electronic converters and control devices to enable inertial response by wind turbines
- Inverters enabling PV, battery storage to provide ancillary services

Software:
- Extension of existing software applications or development of dedicated software applications for trading of new products in the ancillary service markets
- Data analytics software to record and analyse ancillary service market transactions

REGULATORY REQUIREMENTS

Retail market:
- Allowing DERs to participate in ancillary service markets

Wholesale market:
- Regulatory mandates for new ancillary service products that can enable better integration of VRE into the system, as well as in recognition of the services VRE generators can provide to the grid

Distribution and transmission system:
- Regional, national, federal or sub-national roadmap for integration of VRE generation into the grid, encompassing role of ancillary service providers and including the design of dedicated ancillary service markets at DSO or TSO level
- Permission for DSOs to procure ancillary services
- Strong co-operation frameworks between DSOs, TSOs and ancillary service providers

STAKEHOLDER ROLES AND RESPONSIBILITIES

TSOs:
- Conducting studies to evaluate development of new ancillary services for better VRE integration
- Conducting pilots for new ancillary service products (including regional projects, where applicable)
- Introducing specific grid codes and upgrading the system services procurement mechanism

DSOs:
- Forecasting ancillary services that could be provided by DERs, based on historical data and advanced weather forecasts
- Securely storing and sharing grid-related data with TSOs and other ancillary service providers, according to applicable data privacy and sharing norms

New ancillary service providers (utility-scale VRE and DERs):
- Participating in ancillary service markets, where established
- Complying with existent regulation and technical requirements of the ancillary service market, including information exchange with DSOs and TSOs (*e.g.* capacity, location, type of DER)

Regulators:
- Defining and mandating new ancillary service products in collaboration with TSOs and DSOs to enable better VRE integrationasts

ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
CAISO	California Independent System Operator
CEER	Council of European Energy Regulators
DER	distributed energy resource
DSO	distribution system operator
EFR	enhanced frequency response
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
FCR	frequency containment reserve
FERC	Federal Electricity Regulatory Commission
FRR	frequency restoration reserve
GW	gigawatts
min	minutes
MISO	Midcontinent Independent System Operator
MW	megawatts
MWh	megawatt-hour
NYISO	New York Independent System Operator
PJM	Pennsylvania Jersey Maryland
PV	photovoltaic
s	seconds
TSO	transmission system operator
VRE	variable renewable energy

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