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Contributions of renewables to ancillary services and system stability

Review of experiences made in Germany

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Contents

List of abbreviations

AbLaV	*Verordnung zu abschaltbaren Lasten* (Regulation on Interruptible Loads)
ACER	European Union Agency for the Cooperation of Energy Regulators
AS	Ancillary services
BDEW	*Bundesverband der Energie- und Wasserwirtschaft e.V.* (German Association of Energy and Water Industries)
BESS	Battery energy storage systems
BMWK	*Bundesministerium für Wirtschaft und Klimaschutz* (Ministry for Economic Affairs and Climate Action)
BNetzA	*Bundesnetzagentur* (Federal Networks Agency)
CEER	Council of European Energy Regulators
CHP	Combined heat and power plants
DE	*Deutschland* (Germany)
DSO	Distribution system operator
EEG	*Erneuerbare-Energien-Gesetz* (The Renewable Energy Sources Act)
ENTSO-E	Association of European Transmission System Operators
EnWG	*Energiewirtschaftsgesetz* (Energy Industry Act)
EU	European Union
FACTS	Flexible alternating current transmission system
FFR	Fast frequency response
FINC	Fully integrated network components
FRT	Fault ride-through
Hz	Hertz
kW	Kilowatt
LFSM-O	Limited frequency sensitive mode at overfrequency
LFSM-U	Limited frequency sensitive mode at underfrequency
NC DC	Network Code on Demand Connection
NC RfG	Network Code on Requirements for Generators
nf-AS	Non-frequency ancillary services
PV	Photovoltaic
RE	Renewable energy

RES Renewable energy sources

RfG Requirements for Generators

SDL *Systemdienstleistungen* (ancillary services)

SINTEG Smart Energy Showcases projects

SysStabV System Stability Ordinance

TCR Technical Connection Rules

TSO Transmission system operator

VDE FNN *Forum Netztechnik/Netzbetrieb im VDE* (Network technology/network operation forum in the VDE)

VDE *Verband der Elektrotechnik Elektronik Informationstechnik e.V.* (Association of Electrical, Electronic & Information Technologies)

Editorial

As the energy transition in Germany progresses, the proportion of decentralised and inverter-connected plants in the system is increasing. To be able to continue ensuring secure system operation, the provision of ancillary services must be ensured through renewable energies, storage and flexible consumers in the future. Many renewable energy plants are already technically capable of providing a large number of ancillary services, or can be equipped with corresponding capabilities. These developments, together with advancing digitalisation and the use of innovative technologies, are changing the electricity system fundamentally.

Grid operators are responsible for the efficient, safe and reliable operation of the grids; with an average interruption time of 12.20 minutes in 2019,[1] "keeping the lights on" remains a top priority for German grid operators, despite the increasing challenges observed in grid operations. The fact that the energy system will also become more integrated in the future – with interfaces between the electricity, gas, heating and hydrogen networks – only adds to the complexity of coordination tasks.

Naturally, grid operators should be able to prevent violations of threshold values – i.e. voltage, frequency and current – as well as power failures from occurring. If they do occur, then immediate grid restoration after power outages or disturbances is required. All of this is possible through so-called ancillary services.

The provision of ancillary services has been discussed in Germany for years. Depending on the voltage level, both transmission and distribution grid operators have to provide various ancillary services for the safe and reliable operation of their grids. These contributions have been traditionally provided by large thermal power plants. These plants will gradually leave the system or run less frequently. Even though they might still be able to provide individual ancillary services – black start capability can also be provided from a standstill – this responsibility will mainly shift to renewable energy (RE) power plants. As most of these plants are connected to the distribution grid, an increasing proportion of ancillary services will be provided by plants in the distribution grid in the future.

When also taking the increase of e-mobility and other decentralised assets (battery storage, heat pumps) into account, this will only become more pronounced and will translate into greater system responsibility on the part of distribution network operators. In the future design of ancillary services, there will be a lot of room for manoeuvre, which must be used sensibly. This also applies to areas that do not already fall directly under the classic scope of ancillary services. Probably the most important example here is the issue of inertia.

The discussion on the further development of ancillary services is still high on the agenda, especially against the background of large fluctuations in load flow, the increasing distances over which electricity must be transported in Germany, as well as the reduced operating times of conventional power plants. This radically changes the demand for ancillary services and ways of providing them.

The operation of a large number of decentralised generation plants must be orchestrated and harmonised with the requirements of the system. In addition, cross-grid cooperation is gaining in importance because potential providers of ancillary services are increasingly being connected to the distribution grids. Accordingly, it is necessary to lay the foundations today for RE plants to provide all technical capabilities so that the system can continue to be operated in a safe and stable manner in the future.

This report may provide the basis upon which a bilateral exchange between German and Chinese actors could take place. With the largest installed renewable energy capacity worldwide, China will at some point need to actively employ ancillary services for a smooth integration of RE. Germany, on the other hand, is not at the end of the road regarding its ancillary services development; it can therefore greatly profit at a later stage from corresponding insights into the Chinese experiences.

Sincerely,

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Executive summary

An omnipresent challenge of any system with a high proportion of RE is ensuring security and stability of the electricity grids. Today, many of these services are inherently – and usually cost-effectively – provided by conventional power plants. However, the penetration of those plants, especially in Germany, will continue to decline in the short term. This gap must be closed and the system must be redesigned in such a way that sufficient providers are able to cover the demand for ancillary services in an economically efficient manner in the future.

This report outlines the current status of the development of ancillary services in Germany. It summarises key definitions of ancillary services that contribute to the sustainable operation of the grid, namely:

- Operational management
- Frequency control
- Voltage control
- Restoration of supply

In addition, it provides an overview of the broader actor landscape, as well as relevant technical regulations that govern the requirements that RE power plants must fulfil in order to provide the necessary ancillary services. The currently applicable regulatory framework in Germany for the provision of ancillary services is largely determined at European level and implemented at national level.

The report also describes the different procurement options and criteria for the individual ancillary services. The question of whether the provision of ancillary services products is most efficient via binding connection guidelines, markets or the grid operator can only be evaluated on a case-by-case basis, depending on actor structures and market design.

A look into issues that are going to define future discussions on the development of ancillary services is another crucial aspect. The focus here is especially on current discussions and long-term perspectives for frequency control, flexibility, inertia and voltage control. Experiences made along the way which led to temporary regulatory adjustments are also addressed. The key take-away is that it is important to correctly estimate and anticipate changes in the system, so that plants can be equipped appropriately and relevant processes can be adapted in a timely manner.

To deepen the research, part of this report also includes interviews with relevant actors in this field, providing practical insights into the German experiences with the growth of renewable energy and corresponding development of ancillary services; these interviews also depict current needs for further improvements of the regulatory system. Among the interviewed actors are German network operators, power plant and battery operators and industry representatives. The interviews were conducted by the consultant DNV.

All in all, this report sets out to present the past, the current state of development as well as the need for future action in the area of ancillary services in Germany. As this topic is still constantly evolving, this report can be seen as a momentary snapshot. It aims to provide national and international players in the field with orientation on how this topic has evolved over the years in Germany and the relevant discussion points around it.

1 Ancillary services and system stability: fundamentals and definitions

1.1 What are ancillary services?

The most important goal of energy policy is to ensure a reliable energy supply. The power system must therefore be able to meet the demand of consumers for electricity at any time, as well as ensuring safe operation of the power system.

Due to the large number of participants and complex relationships in the operation of electrical networks, deviations and errors in the system can occur, such as load or supply fluctuations, as well as equipment failure and generation failures. To avoid these errors and failures in the system, there are services that are constantly working to keep the frequency and voltage within acceptable values or return them to normal range after a deviation or failure. Services that guarantee these technical processes are called ancillary services.[2]

Ancillary services Normal operation and normal operational fluctuations			
Frequency control	**Voltage control**	**System restoration**	**Operational Management**

▪ Control power
  ▪ mFRR
  ▪ aFRR
  ▪ FCR
  ▪ Interruptible loads
  ▪ Fast Frequency reserve *
	▪ Direct voltage control
	▪ Switching operation
	▪ Transformer tap
	▪ Reactive power control
	  ▪ (quasi)stationary**
	▪ STATCOM or phase shifter
		▪ Black start capability**
		  ▪ Energy reserve
		  ▪ Islanding capability**
		▪ Transition to auxiliary load
		▪ Coordination
			▪ ICT and data exchange
			▪ Operational planning
			▪ Network security management
			▪ Adaptation of the operation mode for active power control
			  ▪ System automatics (e.g. intertripping)

Ancillary services products		* As new products of ancillary services or changes to the primary control reserve ** Defined as so-called non-frequency-bound ancillary services	

Table 1: Primary ancillary services products. Source: dena (2020)

In European jurisprudence under Article 2(48) of Directive 2019/944 on common rules for the internal market of electricity, the term “ancillary service” implies a service necessary for the operation of a transmission or distribution system, including balancing and non-frequency ancillary services (AS). Even though congestion management is not explicitly addressed in this directive, it still remains an important tool that transmission system operators (TSOs) frequently employ in operational management.

There are four main categories of ancillary services: operational management, frequency control, system restoration and voltage control (see Table 1). To provide the four ancillary services, the grid operators have established a large number of processes and use several ancillary services products. These products are provided from network operators’ resources, but also from network users. Among the different ancillary services products, a distinction must be made between technical capabilities that ensure the robustness of the individual facility and the system, products that must always be active (e.g. the ability to fault ride-through), and products that are only requested when necessary (e.g. control reserve).

Operational management

As part of the operational management, the grid operator is faced with the task of organising the safe and reliable operation of the grid – specifically, continuous monitoring and control by the TSO and network management by the distribution grid operator (DSO). Since operational management forms the basis for the provision of other ancillary services, it is central to the operation of the system. The most important operational management activities include:

- Control of equipment and compliance with permissible limit values
- Data collection, aggregation and exchange
- Network congestion management to avoid physical overload of power lines in the network
- Operational and shutdown planning to support the necessary maintenance, transformation or expansion of the network[3]

Frequency control

The system operator balances power generation and power consumption, ensuring a standard frequency of 50 Hz. Frequency control serves as the central pillar for balancing supply and demand. So, for example, if electricity generation is higher than consumption, excess energy speeds up the system. Thus, the frequency increases, which poses a danger to the connected loads and generators attached to the grid. The same applies for frequency drops and a power shortfall. If the electricity demand is higher than the supply, the frequency drops. Compliance with the rated frequency of 50 Hz can be ensured through the following sequence of measures:

- Balancing power, which is offered by flexible power plants, consumers or storage systems by adapting their generation or consumption to the requirements within a certain framework and carrying out switching specifications from the grid operator for this purpose. In return, the providers of balancing power receive a financial payment from the network operator. Balancing power is offered in three timed stages: primary balancing power (automatic full activation within 30 seconds as soon as the grid frequency setpoints deviate by a certain value), secondary balancing power (full activation within 5 minutes of being called up by the grid operator), and minute reserve power (complete activation within 15 minutes after being called up by the network operator).
- Loads that can be switched off can be activated immediately within 350 milliseconds or within 15 minutes (e.g. can be implemented in the melting process of steelworks). The switch-off is voluntary, occurs after consultation and is reimbursed. Reimbursement happens, in contrast to shutdowns, within the framework of the system protection plan in the next item.
- Automatic frequency relief (or switching off districts) as an emergency measure if the control capacity is not sufficient. In contrast to the previous point, these shutdowns occur within the framework of the system protection plan.[4]

System restoration

If the frequency rises above 51.5 Hz or falls below 47.5 Hz, power plants are shut down for protective purposes. After a shutdown of the complete system (blackout), the objective of system restoration is to first restore the network and then to provide for consumers again in the shortest possible time. Power plants can be restarted from a completely blacked-out state in order to restore the extra-high voltage network.

The power restoration ancillary service is a complex collaborative task that can only be carried out in stages, since the already activated part of the power system must remain in balance all the time. In the event of a large-scale power outage, this task is coordinated by the responsible TSO in conjunction with the operators of the connected distribution system and in consultation with the neighbouring transmission system and power plant operators. The voltage is first rebuilt in individual “islands”, then the frequencies of these subnetworks are synchronised with each other again.

Voltage control

The mains voltage is the electrical voltage provided by the energy suppliers in the power grids, which is used for the transmission of electrical power. In Europe, the mains voltage for alternating current is 230 volts at 50 Hz almost everywhere. It can vary in other parts of the world, but the devices must be adapted to the respective mains voltage.

The grid operator ensures that the operating voltage of the system is maintained at an appropriate level to comply with the voltage limits. Even though the voltage may change within the given boundary conditions, the voltage in the network must be maintained within a given voltage range. Otherwise, devices that are connected to the network may be damaged if the network voltage is too high.

The network operator has various voltage stabilisation options.

- Consideration in planning process: When planning a network project, the focus is initially on the transportation of active power. However, aspects of voltage stability can already be taken into account when choosing a favourable network topology and the technical design of networks.
- Load flow control equipment: When the system is running, switching operations can change the network topology or the turn ratio of the switched transformers and thus affect the voltage.
- Control of the plant itself: Finally, voltage can be influenced by specifically influencing the reactive power behaviour of connected systems or network components.[5]

1.2 The importance of stability

In order to guarantee a secure power system in the long term, ancillary services are needed to comply with operational limits in normal operation. However, as soon as existing safety reserves are exhausted and technical limits are exceeded, other mechanisms come into play. To avoid failures and the spread of disruptions, the network operators resort to so-called stability measures.

Stability measures serve to control incidents. The effects of errors should be limited and the system should be returned to normal operation from faulty operation without further limit violations, as indicated in the system protection plan.[6]

To evaluate system stability, it is common practice to divide stability phenomena into three categories: frequency stability, voltage stability and angular stability.

Depending on the relevance of the cases, the needs for the ancillary services or the stability can determine the dimensioning. Inertia is crucial to maintaining the frequency in normal operation as well as in the event of a fault. Partial network operability is also an important prerequisite for network restoration and for frequency stability. A clear distinction between ancillary services and stability is therefore often not expedient.

According to the previous view of the TSOs, ancillary services are limited to frequency control, voltage control, network restoration and operational management. Stability is seen as an additional area.

Table 2 provides an overview of which products are to be assigned to the individual stability objectives. It should be noted that further requirements for robustness, network disruptions and system and network protection must also be taken into account for the system design.[7]

Stability **Control of interference**			
Frequency stability	**Voltage stability**	**Angular stability**	**Resonance and controller stability**

■ Instantaneous reserve **
■ Islanding capability
■ Automatic disconnection of interruptible loads
■ System protection plan
■ LFSM-O/LFSM-U
■ Generation shedding
■ Load shedding
	■ Dynamic grid support**
	■ Impulse excitation
	■ Short-circuit current **
	■ Direct Voltage control
	■ Reactive power control
	  ■ Dynamic/fast
	■ System protection plan
	  ■ Load shedding
	  ■ Blocking of transformer taps
		■ Instantaneous reserve
		■ Fast power adjustment ("fast valving")
			■ Grid forming
			■ Damping of harmonics
			■ Islanding capability
			■ PSS and POD controllers***

Products of stability	* As new products of ancillary services or changes to the primary control reserve ** Defined as so-called non-frequency-bound ancillary services *** Power System Stabilizer (PSS) and Power Oscillation Damping (POD)		

Table 2: Primary products of stability. Source: dena (2020)

1.3 Harmonisation of requirements for grid connection

With the proportion of conventional power plants decreasing, renewable power plants need to contribute to power grid stability during power outages and normal operation. Network connection codes (NC) require that all devices connected to a system conform to the specifications set out in the NC from the time of connection and throughout their lifetime. Network codes are a set of rules drafted by ENTSO-E, with guidance from the Agency for the Cooperation of Energy Regulators (ACER), to facilitate the harmonisation, integration and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market.[8]

In April 2016, the European Commission published new regulations that set out a network code with requirements for connecting generators to the grid (RfG). The connection conditions of this ordinance apply to new power plants. On 17 May 2018, the European requirements for generators officially came into force.

The Network Code on Requirements for Generators (RfG) harmonises the standards that generators must respect to connect to the grid. These (Europe-wide) harmonised standards are intended to stimulate the market for generation technologies and increase competitiveness.

The regulations cover aspects such as capabilities for frequency stabilisation, provision of reactive power, through to black start capacity of large installations. [9]

The RfG Regulation:

- creates a clear legal framework for grid connection.
- facilitates electricity trading across the Union.
- ensures system security.
- supports the integration of renewable energy sources.
- promotes competition and thus creates advantages for consumers.[10]

The Technical Connection Rules (TCR) is part of the definition of the European Network Code for Germany developed further to meet European standards by the VDE Association for Electrical, Electronic & Information Technologies (VDE FNN). It signifies the secure integration of renewable energies into the grid, grid interoperability, as well as investment and planning security.

The Technical Connection Rules:

- outline the essential requirements for the connection of customer systems to the public utility grid.
- provide important information for the operation of equipment.

- determine the duties of the grid operator, plant operator, planner and customer.

FNN is currently revising all four TCR (one per voltage level). The main focus of the revision is the implementation of the European Network Codes.[11]

2 A look back – ancillary services in Germany

2.1 Historical background

Germany was a fossil-dominated system with integrated companies, where the synchronous generators of conventional power plants with their inherent characteristics (induced voltage, inertia) predominantly provided for the stability of the power system. With the energy transition starting with the first Renewables Act (EEG) in 2000, it quickly impacted system operations at various levels.

Historically, renewables were only seen as an add-on in the system. As long as they did not interfere with the system's stability, they remained connected and, in case of doubt, disconnected. With the increasing phase-out of conventional generation, this approach was increasingly challenged.

Moreover and as a parallel development, the unbundling and liberalisation of the electricity markets accelerated the emergence of new players and resulted in the first electricity markets. The establishment of electricity markets was a process which occurred in most European countries in the 1990s and 2000s. The German electricity market liberalisation was a result of several efforts, starting at the end of the 1990s[12] with the revision of the Energy Industry Act (EnWG).[13]

A key feature of today's electricity markets is the balancing market. Looking at the development of the balancing market, the following milestones stand out:

- As part of the available ancillary services, balancing services (also known as control reserves) include balancing capacity and balancing energy. While the trading of balancing capacity is taking place in the balancing capacity market, recently the **balancing energy market** was introduced as an accompanying measure.[14] In the balancing energy market, all prequalified balancing service providers with available capacities at short notice are admitted who have not taken part in the balancing capacity market.[15] Additional balancing bids, which are closer to real-time, can thus be accessed by the TSOs.
- As of recently, the prequalification criteria for the provision of balancing energy as well as product definition have been designed to mainly accommodate a conventional power plant fleet.[16] In view of the rise of RE, **product specifications** were partly re-selected. This ensures non-discriminatory access for RE to the balancing market.
- **Cooperation in the control areas** – there are four in Germany – was improved to avoid counteracting activation of control power.

Another important milestone achieved with the liberalisation of the energy markets is the **participation of interruptible loads**, a means to ensure frequency stability, via the Regulation on Interruptible Loads (AbLaV). These loads must be able to reduce or switch off their consumption at short notice if they are called upon to do so by the responsible TSO.

An additional measure was the **reduction of the lead time**, i.e. the time span during which the product is open for trading before delivery. This was reduced in Germany's intraday market from 45 minutes to 30 minutes in 2015 and down to 5 minutes in 2017.[17] This reduction represents an important step towards a precise resolution of imbalances in the intraday power exchange.[18]

With regard to voltage maintenance, the grid operator has different measures at its disposal. Among those, reactive power control and fault ride-through (FRT) have become more widespread over the years. In order to influence the voltage, the grid operator can use the reactive power of connected plants or grid components. Conventional power plants react much faster due to their automatic voltage regulation and cover a large proportion of today's reactive power demand. If RE in the distribution grid are to increasingly replace part of the functionality of large power plants that are phased out, significantly faster reaction times for these plants may also be required.[19] This results in different requirements for the provision of reactive power within the distribution grid itself and for the additional provision of reactive power for the transmission grid.

A distinction between the different "speeds" of reactive power is made today: a faster form and a rather slower form of reactive power provision. The (quasi-)stationary reactive power is used for static voltage maintenance in case of slow voltage changes, whereas in the context of dynamic grid support, a faster reactive power is to be fed into the grid to balance rapid voltage changes. Due to faster voltage changes in normal operation by RE, there will be more demand for fast reactive power in the future.[20]

The requirements for dynamic support in the event of a grid failure and the associated voltage support to limit a voltage drop (also known as fault ride-through) are not affected by this fast form of reactive power. In principle, systems connected via converters are capable of handling the fast reactive power. A prerequisite though is that converters have sufficiently fast control.

In order to manage congestions, a future-oriented regulatory reform was introduced a year ago: With the introduction of **Redispatch 2.0**, the redispatch procedure has essentially been opened for RE by also addressing all electricity generation units down to 100 kW. RE and conventional power plants are also in a common merit order. The overarching goal of Redispatch 2.0 is the cost-effective and non-discriminatory elimination of scheduled and non-scheduled network bottlenecks.[21] This measure ultimately optimises network management and reduces the costs for the elimination of network bottlenecks. Redispatch has traditionally been performed by TSOs, but since October 2021, DSOs and the connected customers and plants in the low-, medium- and high-voltage grid will also be included in the redispatch scheme.

These legislative changes are expected to reduce the high costs caused by redispatch measures, as decentralised RE plants might be closer to a congestion point and can thus resolve the problem quite efficiently.[22] However, the feed-in priority still prevails: Conventional power plants will be prioritised for the redispatch measures, and only RE that offer prices 10 times cheaper than those of conventional power plants will be considered.[23] Current proposals by the German Federal Network Agency (BNetzA) provide for a minimum factor of 10 for RE and a minimum factor of 5 for combined heat and power (CHP) plants.

A look back at the costs by the German TSOs for ancillary services provides a good indication of their increasing expenditures for balancing and stabilising the grid (see Figure 1).[24] According to BNetzA's monitoring report, the costs for ancillary services have risen from EUR 1,211 million in 2014 to EUR 2,018.3 million in 2020, representing an increase of approximately 67% in four years. This trend is expected to continue and will now be counter-balanced by the recent legislative revisions. However, more changes might become necessary in the future.

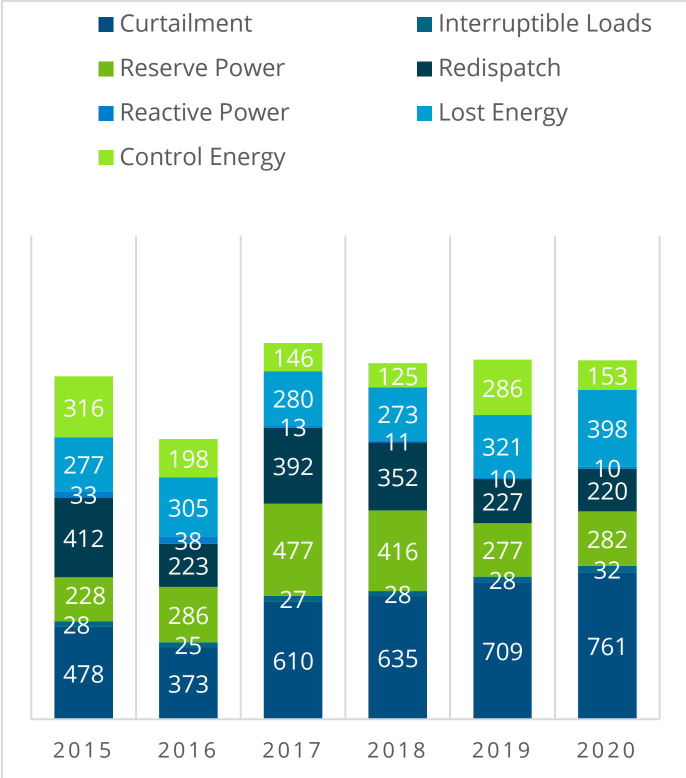

Figure 1: Cost development according to ancillary service. Source: Federal Network Agency (2021)

2.2 Actor landscape and regulatory environment

The continuous developments in the field of ancillary services affect a large number of actors that are involved in various implementation steps. In June 2019, the amendment of the "Directive on common rules for the internal market in electricity" (2019/944/EU) was adopted at European level. This amendment was part of the so-called "Clean Energy Package".

According to this directive, grid operators are to procure ancillary services primarily on the market, as long as this is found to be economically efficient. Specifically, six "non-frequency ancillary services" must be procured. These include voltage regulation, local grid stability inertia, short circuit current, dynamic reactive current support, island capability and black start capability. To this end, a transparent, non-discriminatory and market-based procurement for these ancillary services is to be introduced at national level.

The aforementioned requirements from the directive had to be anchored in national legislation of the Member States by the end of 2020. In Germany, the Federal Ministry for Economic Affairs and Climate Action (BMWK) took the lead and defined the basic principles on the basis of an expert opinion, formed by an expert consortium, namely SDL-Zukunft. It was left to the national regulatory authorities' discretion to decide on what economically efficient ancillary services meant. In case no market-based approach was chosen, the authorities had to prove that their alternative option was more efficient for all stakeholders.

Member States will have to consider concrete legislative measures, which will include both the amendment of existing laws and the adoption of new regulations. In Germany, amendments to the Energy Industry Act (EnWG) were necessary. A prominent amendment was the revision of Art. 12(h) EnWG, which intended to create the authorisation basis for the BNetzA to determine procurement models for ancillary services. The law entered into force on 27 November 2020.[25]

The Federal Network Agency (BNetzA) defines the specifications and requirements for the procurement of non-frequency-based AS. Alternatively, it may request that the network operators jointly develop appropriate specifications and requirements with the involvement of all relevant network users and approve them.[26] If market-based procurement of an ancillary service is not economically efficient, the BNetzA may provide for an exemption. Exemptions will be reviewed at least every three years. The BNetzA participated in the expert review process initiated by the BMWK, but it is not bound by the results of this process in its decisions.[27]

TSOs are generally responsible for ensuring system security, but they must increasingly rely on the provision of the necessary AS from lower grid levels and plant operators.[28]

Operational management is the responsibility of the respective grid operator, who must take into account the necessary requirements of the respective upstream grid operators. The overriding responsibility for system stability lies with the TSOs, who also need to coordinate their actions with other European TSOs.

Frequency maintenance is carried out by the TSOs by maintaining a balance between electricity generation and consumption. In connection with voltage regulation, the transmission and distribution grid operators have the task of maintaining the grid voltage in their respective grid area in a permissible band with regard to voltage quality. This is done for their own grid level, taking into account the requirements in upstream and downstream grid levels.

In the event of a large-scale power blackout, the TSO, with the cooperation of the distribution system operators, must be able to restore the supply of electrical energy within the shortest possible time (system restoration).

The network operators are supported in their activities by the “technical regulator” VDE FNN, an association that defines systemic requirements, taking into account the political framework conditions, in concrete technical guidelines for the connection and operation of the technical facilities. The legislator requires a guarantee of technical safety for the construction and operation of energy plants (Art. 49 EnWG). Here, the legislator limits itself to defining a protection target and leaves the technical specification to the VDE FNN. The legislator recognises this set of rules and presumes that technical safety is guaranteed if the technical rules of the VDE FNN are complied with.[29]

On the basis of these specifications, plant manufacturers design their plants and plant operators make the decision to offer ancillary services. Only if all players are provided with reliable framework conditions and sufficient planning certainty can system security be guaranteed.[30]

In the Transmission Code from 2007, access conditions to the grid in all four German TSOs zones is defined. This set of rules was first drawn up in 1998 by VDE FNN, in response to the liberalisation of the electricity market and corresponding revision of the Energy Industry Act (EnWG).[31] Network codes covering the entire European market are developed by the Association of European Transmission System Operators (ENTSO-E).

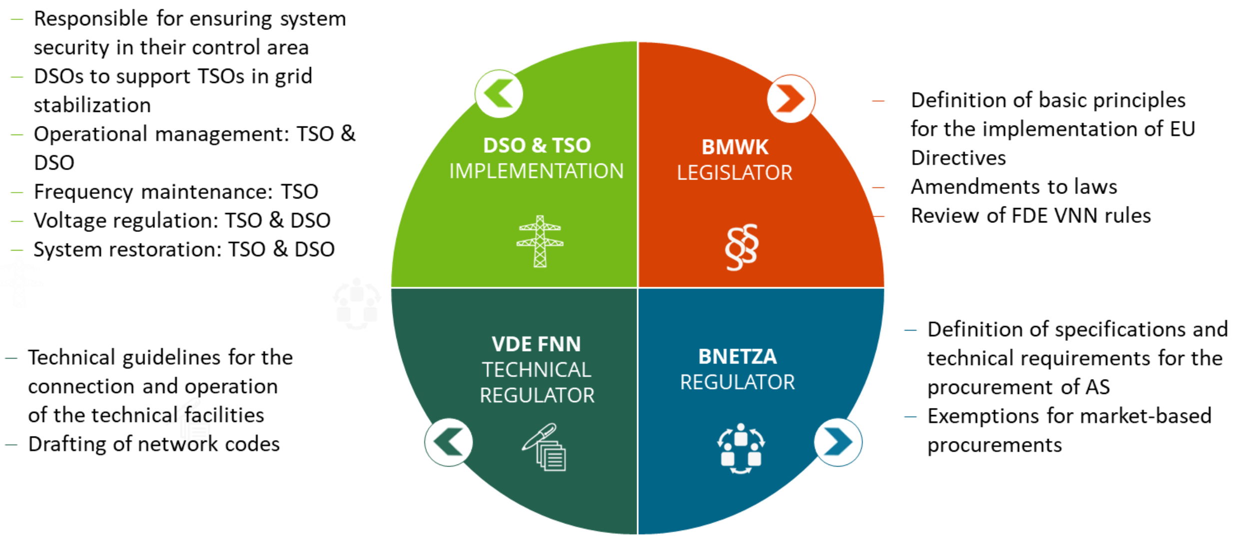

Figure 2: Overview of actors and their activities

It can be seen that new regulations, directives, resolutions and standards are constantly being drawn up at European level and must then be implemented in Germany. However, the flow of information is not one-sided. When setting technical rules for Germany, VDE FNN, for example, may contain more detailed provisions – without contradicting European regulation; additionally, it may also influence upcoming European regulation through relevant consultations.[32]

3 Procurement options and criteria – regulatory decisions

The change in the electricity supply system and European legal requirements necessitates further developments in the procurement of ancillary services products. The available procurement options include market-based procurement, the binding requirement in the technical grid connection guidelines, and provision by the grid operator. This is done on the basis of three decision-making stages that must be fulfilled, and which are examined at the beginning of this chapter.

3.1 Regulatory background

As mentioned above, in June 2019, the amendment of the "Directive on common rules for the internal market for electricity" (2019/944/EU) was adopted by the European Commission. Among other things, it describes how the provision of so-called "non-frequency ancillary services" (nf-AS) is to be fundamentally organised in future.

According to the provisions of the directive, ancillary services are to be procured in a transparent, non-discriminatory and market-based manner in future, unless they are provided by the grid operators themselves from grid operating equipment.[33] An exception to this rule is granted if the regulatory authority has come to the conclusion that the market-based procurement of non-frequency-based ancillary services is not economically efficient. The obligation does not apply to fully integrated network components (FINC, for further explanation, see sub-chapter 3.3 below).

The directive affects a significant number of national laws and regulations and requires Member States to take various measures to implement it. To this end, amendments to the EnWG were necessary in Germany and a law regulating the market-based procurement of ancillary services was passed in October 2020.[34] Similar to the European directive, the aim of the regulation was to open up the provision of ancillary services to all market participants, i.e. generators, storage facilities or consumers, by introducing transparent and non-discriminatory market-based procedures. Apart from stimulating competition, this makes it possible to leverage additional technical potential for the provision of ancillary services in order to improve the overall security of system operations.[35]

The specific procurement systems are defined by the BNetzA. If market-based procurement of an ancillary services product is not economically efficient, the BnetzA may grant an exemption for the respective AS; the law came into force on 27 November 2020.[36]

To further support the introduction of market-based procurement systems, BMWK has launched the SDL-Zukunft project (implemented by the consultant ef.Ruhr), whereby the ministry is working closely with BnetzA with the involvement of relevant stakeholders such as network operators, industry associations and researchers to investigate – among other things – for which ancillary services market-based procurement is recommended.[37]

The efficiency assessment of market-based procurement is completed for the time being after the BnetzA followed the recommendations from the SDL-Zukunft report – however, the report is not binding for BnetzA and does not in any way pre-empt its decisions.[38] Currently, the process for formally defining the procurement models lies again at the BnetzA. The initial efficiency assessment in 2020 within the framework of SDL-Zukunft was only the prelude. As already mentioned, within the framework of a regular evaluation, the BnetzA will review its exemption decisions every three years at the latest.

3.2 Different stages of ancillary services procurement

When procuring AS products, there are three decision stages that must be fulfilled:

1. **Provision of technical capabilities**: As a first step, the technical capabilities of the facility must be fundamentally defined so that the plants are capable of providing the required ancillary services products. These technical capabilities may be specified in the respective network codes and guidelines and, where applicable, in conjunction with technical connection requirements or other national regulations.
2. **Provision of capacities**: Next, it must be ensured that the facility is available and that the network operator can access it.
3. **Provision of services**: The actual provision of the AS product is then the final step in the process.

Besides direct provision by the grid operator, the system requirements can in principle also be covered by the market participants. There are three different variants in which procurement may be organised:

1. Obligatory and not remunerated
2. Obligatory and remunerated
3. Voluntary on the basis of incentives and remunerated

In the case of the first two **obligatory models**, the provision of AS products is stipulated in the technical connection requirements. Then, depending on the decision stage as well as the different AS products, the remuneration may be regulated differently.[39]

On the other hand, **voluntary procurement models are generally market-based**. According to the interpretation of the BMWK, market-based procurement requires that at least one of the parameters price or quantity can be freely determined by the provider of AS products. AS products that are remunerated in a regulated manner can therefore be defined as market-based, as long as the provider side is free to react to this with a corresponding quantity offer.

In total, there are four different options for the market-based procurement of AS products:

- Regulated remuneration
- Bilateral contracts
- Invitation to tender
- Auction

In the end, when faced with the procurement of different AS products, the following questions must be addressed:

- Should the AS product be provided by the grid operator or a grid user?
- Should the provision be mandatory or voluntary?
- Should the ancillary service be remunerated?
- If so, through which remuneration model?

A comprehensive overview of these issues is provided in Figure 3. The questions are sometimes quite complex, as a large number of factors (e.g. transaction costs, market failures, effects, system needs) have to be taken into account.

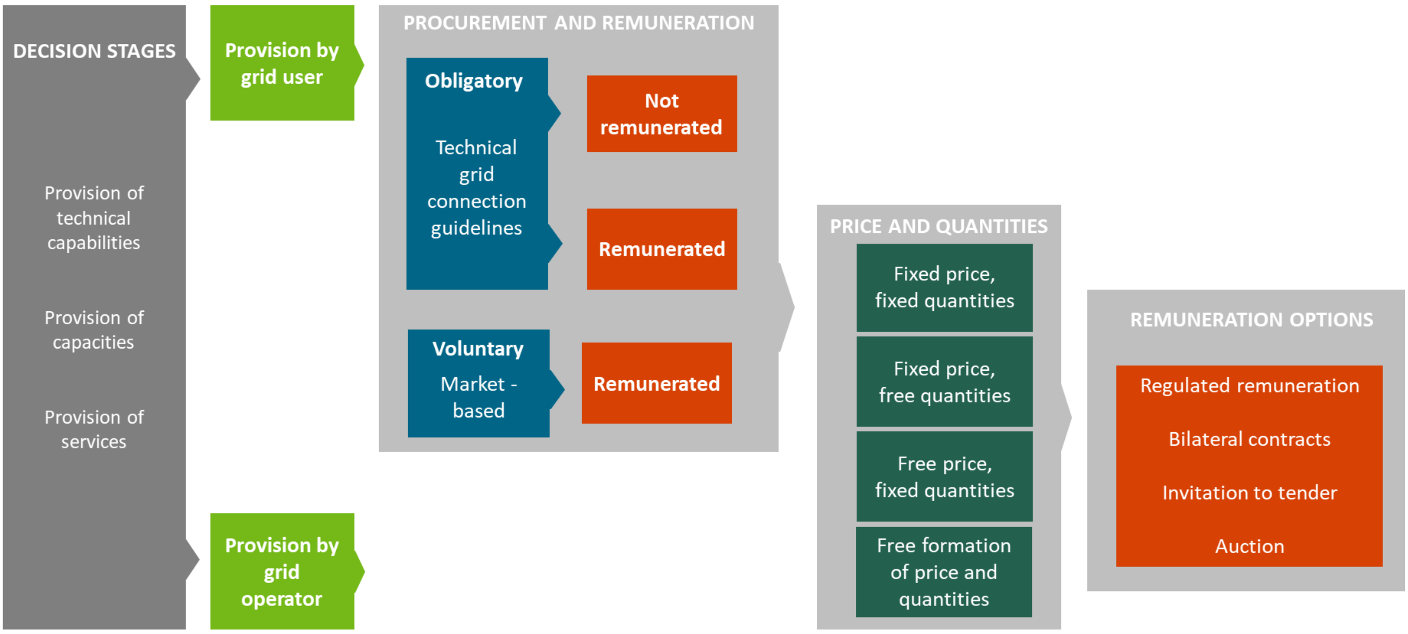

Figure 3: Levels of ancillary services procurement.

3.3 Specification in the technical grid connection guidelines

The currently applicable technical requirements for grid users in terms of ancillary services are formulated by the European Union and implemented at national level. Exemplary network codes are the “Requirements for Generators”, the “Demand Connection Code” and the “System Operation Guideline”.[40] Based on these technical requirements and the regulatory restrictions, it can be assessed to what extent the different network assets and plants are suitable for the provision of AS.

In Germany, these requirements are implemented by the corresponding technical connection guidelines, as developed by VDE FNN.[41] When defining the requirements for generation plants in terms of the provision of AS, the VDE FNN application rules make a fundamental distinction between type 1 and type 2 electrical energy generation plants. In general, type 1 plants – providing electrical energy with the help of synchronous generators – are subject to stricter requirements with regard to the provision of AS; all other plants are defined as type 2 energy generation plants – i.e. inverter-coupled RE systems.[42]

Energy storage systems are subject to additional restrictions with regard to their ownership. These result from Directive 2019/944, which is being transposed into national law in Germany. According to the requirements of this directive, energy storage facilities may in principle not be owned by a network operator.

This does not apply to so-called “fully integrated network components” (FINC). According to the definition of the directive, these are network components that are integrated into the transmission or distribution network and serve solely to ensure the secure and reliable operation of the network.[43] FINC may neither be used for system balancing (provision of control reserve) nor for congestion management (redispatch). According to article 54 paragraph 2 of the directive, the recognition of an energy storage facility as a FINC takes place through approval by the regulatory authority.

3.4 Market-based procurement

Taking a more detailed look at market-based procurement, this sub-chapter explains the criteria used in Germany to assess the efficiency of this specific procurement option. There are different ways to examine whether the added value of market-based procurement outweighs the transaction costs of the market. The listed criteria are evaluated separately for each decision stage (capacity, technical capabilities, service provision) and, if necessary, by network level. Each of the present criteria is a necessary criterion for efficiency to be met. If only one of the criteria is not fulfilled, a market procurement is considered non-efficient.

An important criterion in this regard is the **market size versus the anticipated transaction costs** resulting from a market procurement of AS products. Under market size, an estimation of the volume of the economic costs of the AS products on the basis of specific supply costs and technical parameters is understood. On the other hand, transaction costs translate to a qualitative estimate of the additional costs arising from the introduction of AS products in the market; here, costs for the introduction and market ramp-up as well as ongoing costs for the operation of the market are taken into account.[44] In this criterion, the **number of potential providers** is another decisive factor. This indicator provides for the risk that arises when there are not enough potential providers. It also takes into account how many new providers could enter the market in the short and medium term. If there are not enough providers, this could lead to the small number of providers having too much market power. The regional distribution of potential providers can also be relevant if the provision of NF-AS has to be locally differentiated for technical reasons.

Incentives also have an important role to play when assessing the efficiency of market-based procurement. It is crucial here to consider the operational and investment efficiency. In the case of **operational efficiency**, it is analysed qualitatively whether market-based procurement creates an incentive to choose the most favourable option for provision in a technology-neutral manner. For **investment efficiency**, a qualitative assessment of whether market-based procurement creates sufficient incentives to invest in the most efficient technologies for the provision of the respective NF-AS is performed. Another qualitative assessment is also carried out, comparing the benefits of market-based procurement with provision from the grid operator’s own resources.

Another indicator to be considered is the **impact** that market-based procurement may have **on electricity markets and prices**. With this criterion, the impact and interactions with other electricity markets (e.g. balancing market) are taken into account. The possibilities of strategic bidding behaviour that is harmful to the system (“gaming”) falls under this indicator. Investigating **distribution effects** is another important aspect; distribution effects can occur, among other things, through rising grid fees ultimately causing greater burdens for consumers. In addition, new remuneration models for generation plants may arise.

System security and environmental compatibility belong to the fourth pillar of assessment criteria for market-based procurement. First of all, it is investigated whether fundamental characteristics of market-based procurement conflict with secure operation. Regionally distributed non-frequency based AS in particular pose a challenge here. Additionally, with the larger goal of climate neutrality, effects on relevant environmental goals, i.e. CO2 emissions and resource consumption, are also examined.

Ultimately, a liquid market is an important precondition for the market-based procurement of AS and is often associated with significant costs and effort. In the end, if market-based procurement is not possible at the given time, the existing system demand must be fulfilled directly by the grid operator, such as in the form of FINC, reserves or through grid connection conditions in the Technical Connection Rules that are binding for all market participants.[45] If market-based procurement is deemed possible, a corresponding procurement procedure is started. If, contrary to the ex-ante assessment, the local system demand cannot be met efficiently by the market participants, the grid operators will secure the remaining demand.

According to paragraph 12h of the EnWG, BNetzA has issued an exemption decision for the following non-frequency-based AS in December 2020, meaning that they are not to be procured on the market:

- Fast reactive current injections
- Provision of short circuit current
- Inertia for local grid stability
- Island operation capability

On the other hand, the following are to be procured on the market:

- Steady state voltage control
- Black start capability [46]

A proposal for a procurement system for black start capability has already been developed on behalf of the BMWK within the context of the project "SDL-Zukunft".

3.5 Costs for ancillary services

In BNetzA's monitoring reports, the costs for ancillary services are regularly published. In the years 2018 and 2019, the costs remained quite constant, that is EUR 1,933.2 and EUR 1,931.2 million respectively.[47] In 2020, however, the net costs for ancillary services, which are passed on to end consumers, increased to around EUR 2,018.3 million. When looking at the cost structure, the main cost blocks in this year were:[48]

- the provision and use of the network reserve power plants amounting to approx. EUR 282.8 million (2019: EUR 278.1 million),
- national and cross-border redispatch amounting to EUR 220.5 million (2019: EUR 227.2 million),
- estimated compensation claims for feed-in management measures amounting to EUR 761.2 million (2019: EUR 709.5 million),
- and loss energy amounting to approx. EUR 398.8 million (2019: EUR 321.2 million).

The use of ancillary services products entails costs for both grid and plant operators. If, for example, the provision of a non-frequency-based ancillary service has so far been based on the technical grid connection guidelines without remuneration, there are no immediate costs for the network operator; however, costs will generally arise for network users.[49] Up to now, these have been borne by the providers themselves, who pass them on to the electricity consumers in other forms – for example, through stricter requirements for contribution margins in their investment decisions or, in the case of renewable auctions, in the form of higher bid prices.[50] Under market-based procurement, such supplier-side costs would be included in the network charges and thus be more "visible". In general, however, ancillary services are covered via network charges.

3.6 Future procurement – stakeholder opinions

The interviews conducted by DNV also provide a more in-depth look into the further evolution of ancillary services procurement. The most relevant stakeholder opinions with regard to the future procurement of ancillary services are summarised in this sub-chapter. In an interview with a wind power plant operator, it was mentioned that the potential of wind turbines for system stability still needs to be given more attention by the relevant authorities and policymakers. This includes the consolidation of policies that promote the wider substitution of the conventional power plants through renewables in the field of ancillary services. To harness this potential, different ideas can be pursued. A collaboration project was mentioned in the interview, in which the operation of the wind farm is assessed for the provision of short circuit capability. Moreover, there is no question that enhanced utilisation of flexible alternating current transmission systems (FACTS) is beneficial for more efficient reactive power compensation; this also constitutes one of the constant considerations of the interviewee.

On the other hand, the contribution of wind generation to harmonic filter services has not been a requirement yet. Finally, fast frequency response will likely be included in the service contribution in the future as new types of wind turbines are gradually put into operation. These statements were also confirmed by another plant operator, highlighting the gap between the current regulatory framework and the market potential that can result from the technological capabilities of renewable energy sources.

When asked under what circumstances the plant operators would imagine additional ancillary services, it was again stressed that the whole portfolio of services could be implemented. As regards the integration of FACTS (STATCOM, grid-forming inverters, etc.), additional investment is needed. The promotion of battery energy storage systems (BESS) is key, as it will encourage the application of hybrid solutions. As for the way in which services are provided, this must be clear (either mandatory or remunerated). Regarding short circuit capability services as well as filtering of harmonics, these possibilities are not that mature yet.

All in all, from the responses given by plant operators, there seems to be a divergence between the scope of network regulations and the desire of plant owners to expand their business planning. Among other things, there is a feeling that the design of the systems is to a certain extent restrictive in order for synergies to emerge. The area in which plant operators are therefore called upon to push the boundaries of their business in terms of the provision of ancillary services is characterised by a considerable degree of complexity. This, combined with bureaucratic constraints, if not discouraging, introduces ambiguities and delays on the road towards holistic exploitation of decentralised units.

Finally, an additional parameter was noted, which will be considered by the stakeholders in the next period. The development of wind farms (offshore and onshore) needs to take into account the corresponding extensions to the grid to which they will be linked. Therefore, if the approval of the connection of a decentralised unit relates to a connection system for which either an extension or reinforcement of the grid is required and at the same time the compensation of reactive power is mandatory, this implies an increase in costs. On this point, the planning of the generation must therefore go hand in hand with the planning of the network.

When looking at the actions undertaken in the past at country level, an interviewed battery and power plant operator mentioned that some possibilities for more efficient implementation have been identified. In particular, the certification procedures were not sufficient to promote new network technologies and especially hybrid solutions. In addition, there are still economic barriers to market activation. All in all, the interviewee concluded that an environment of greater flexibility and more direct decision-making would have been more supportive of the whole process.

In another interview with TSO representatives, it was pointed out – in agreement with the views of the wind power plant operator – that the market for ancillary services should not be treated as one. In this sense, the needs and criteria of TSOs differ in some respects from those of DSOs. According to the interviewees, the market needs to be strengthened as regards DSOs, since at this level there is increasing integration of renewable energy sources. The closure of conventional generation units makes it necessary to approach and promote new solutions where decentralised renewable energy generation units will provide these services. Inertia in particular has become a big issue. However, at TSO level, the development of this market is proceeding more slowly, as the interviewees believe the process of transitioning to the full replacement of conventional generation units can proceed quickly, but as far as ancillary services are concerned a more cautious approach is needed.

At DSO network level, the following ancillary services are typically required: congestion management (curtailment/redispatch), provision of reactive power by all connected plant operators, and primary control (FCR) provision through BESS. According to the network code, reactive power provision is described as a binding ancillary service. Redispatch services are not requested by the grid code but need to be provided by law with remuneration.

According to the DSO-interviewee, the discussion for acquiring further ancillary services from the decentralised units is always open (e.g. inertia, redispatch studies). From their perspective, the first priority is to verify the technical feasibility and the beneficial impact of such a development. However, if the capability of individual producers is deemed necessary for grid support, then bilateral and remunerated agreements between the two parties can be established.

At the end of each interview, the interviewees were called to give their personal views on how different ancillary services should be procured. The different options were:

- mandatory (not remunerated)
- bilateral agreements (voluntary, remunerated)
- market procurement/exclusion (voluntary, remunerated)

These personal views were given based on the available capacity and commitment of the different stakeholders for providing these services (see Table 3). One can derive from this heterogenous group of stakeholders that there are different viewpoints on how different ancillary services should be procured. However, most stakeholder groups expressed a preference for moving towards a future procurement of ancillary services through bilateral contracts. These considerations should be included in stakeholder-wide dialogues, as the discussions on the procurement of additional ancillary services are not expected to end any time soon. A detailed summary of the interviews can be found in the annex of this report.

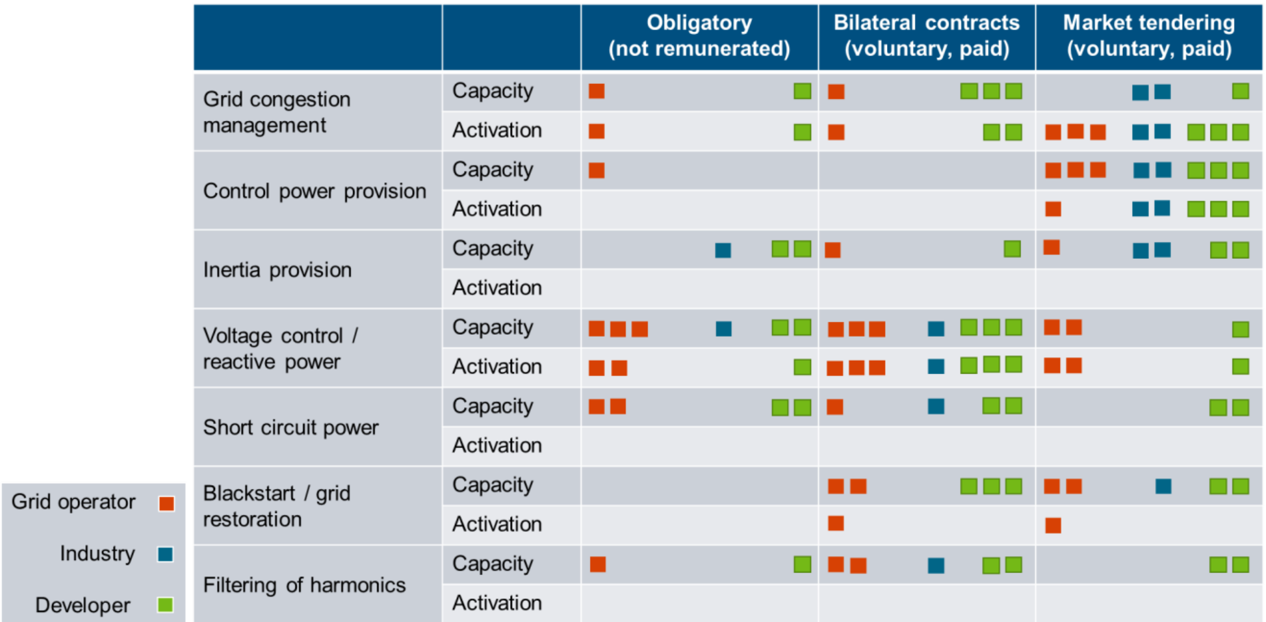

Figure 4: Overview of classification of ancillary services from RE units according to interviewees. Source: DNV

3.7 Open issues – stakeholder opinions

In this sub-chapter, open regulatory issues are addressed. Some interesting statements were provided by operators of power plants as well as BESS. The interviewed wind power plant operator elaborated more on the nature of boundary conditions that limit the utilisation of wind turbines. It can be concluded that, despite the available technology and consequently the existence of the market, the regulatory authorities need to encourage the creation of the required legal framework that would exploit this potential. This framework is not yet clearly defined.

The inadequacy of the regulatory framework and its divergence from current technological capabilities were identified as the main obstacles to taking this case forward by another power plant and storage operator. This is particularly true when looking at the inconsistency of regulatory rules for storage technologies. From a technical point of view, system operators face particular challenges in identifying appropriate and available points of connection to the grid.

When looking at BESS, this effort becomes even more difficult because battery systems today are still treated within the framework of the grid codes, either as producers or as consumers. This cannot be viable and in no sense compatible with the current technological capabilities of these systems. The battery is not just a power absorption or power output element – above all, it is a storage device and should be treated as such. A direct consequence of this situation is the reluctance of developers to carry out new projects that could theoretically contribute to ancillary services. In other words, unlocking the market cannot be possible if advanced technologies are significantly limited in the number of benefits they can offer.

The management of the available electricity in grid power flows could be optimised by consolidating the contribution of storage technologies and ultimately defining them in the regulatory framework. Such a development would encourage the identification and regulation of existing markets and thus facilitate the development of the widespread use of renewable energy sources and storage technologies for the provision of ancillary services. An important step in the development of the market would also be the further specification of compliance rules. In addition, more economic incentives need to be created so that the ancillary services of the renewables can be extended, for example to include the provision of power reserves.

These views are also shared by grid operators, as the current market conditions do not allow the utilisation of renewables for integrating further services that are technically feasible (e.g. secondary, tertiary regulation). The interviewed TSO stressed that the ongoing transition with the closure of conventional plants has an actual impact on the system stability (loss of inertia, lower short circuit capability, dynamic control, redesign of protection schemes, etc.), giving rise to challenges (frequency balance) that must be tackled with the assessment and promotion of new solutions. The critical question that needs to be answered is how the promoted business model can be aligned with the technologies such as grid forming converters, hybrid systems of STATCOM. Another interviewed TSO mentioned that the identification of the points where the grid needs to be reinforced alongside the extension of the grid itself to manage fluctuating renewable power flows is slowing down the maturation of the market for ancillary services from renewables.

When looking at the interviewed industrial stakeholders, the interviews showed a mixed picture: on the one hand, an industrial player with a strong focus on the provision of ancillary services versus another industrial player with a pure focus on the core production business and all required measures to prevent own losses in case of loss of supply. Both interviewees agreed however on one thing: the existence of regulatory barriers for the provision of ancillary services. The recent abolishment (June 2022) of the markets and regulation for quickly and immediately available interruptible loads for example, has been identified as particularly counterproductive. Further regulatory barriers may be found on page 16 of the interview summary.

4 Looking ahead – technological developments

4.1 Inertia

With the phasing out of synchronous machines, the available inertia in the grid is decreasing. Today, instantaneous reserves are provided by the inertia of rotating masses, which is supplied by energy plants synchronously coupled to the grid: mostly large conventional power plants, which inherently possess this capability.[51] Replacing this effect in future grids will prove a considerable task. While failures can still be controlled in the foreseeable future, additional inertia is already needed today to safely handle system splits.

Inverters can eventually imitate this behaviour, but the integration of so-called grid-forming inverters into the European transmission grid has not yet been evaluated conclusively. In most grids, inertia is still provided from fossil- or water-driven power plants. Apart from the obvious redispatching of large thermal power plants, some new technical concepts exist that can be utilised for increasing inertia:

- **Rotating phase shifters**: Another possibility to increase inertia in the electricity supply system is the use of rotating or synchronous phase shifters. Existing decommissioned power plants can be converted accordingly or new phase shifters can be built. Rotating phase shifters are essentially synchronous machines in idle mode. They are not yet widespread in Germany. Since the primary use for rotating phase shifters is currently not the provision of inertia, phase shifters have a relatively small rotating mass; this could, however, be increased by simple measures.

- **Grid-forming inverters:** Grid-forming inverters can react instantaneously to frequency changes and thus provide inertia by adjusting the active power feed-in. The main reason for using inverters for the provision of inertia is that they are needed anyway for the connection of generators, loads and storage units. Part of the investment costs could be allocated according to the primary purpose of the plants, e.g. the feed-in of active power. The use of inverters could thus represent an economic alternative to rotating masses. However, grid-forming inverters are currently not applied in interconnected grids at transmission and distribution grid level due to the technical connection guidelines. They will only be allowed with the next revision of the requirements for generators and grid connection guidelines. In addition, central technical as well as economic questions have not yet been conclusively investigated, meaning that the actual technical and economic potential is difficult to quantify today.[52] In the medium term, the TSOs foresee in any case a considerable demand for grid-forming inverters in RE.

An increasing number of grid users are being connected to the grid via inverters (e.g. decentralised generation plants such as wind turbines and photovoltaics, large loads such as power-to-X plants and storage systems). These plants can adjust their active and reactive power feed-in and thus contribute to voltage and frequency maintenance. The upgrading of inverter-connected plants for an instantaneous reaction to disturbances (e.g. contribution to inertia or to the short-circuit current) requires a modified inverter concept, which, on the one hand, can mean greater technical complexity and, on the other hand, challenges in other areas of operational management.

The European regulatory agency ACER and the Council of European Energy Regulators (CEER) intend to revise the regulations governing the connection of power generation plants and consumer devices to the electricity grids, the grid codes "Requirements for Generators" (NC RfG) and "Demand Connection" (NC DC) in the next few years.[53] An initial draft was presented in May of this year.[54] Due to the much discussed nature of the draft, it is not likely to pass unchanged. At the same time, market-based procurement of inertia is being considered in DE.

4.2 Fast frequency response (FFR)

Nowadays, battery storage systems can technically react much faster than the requirements for primary control power demand. Based on this, some stakeholders (especially manufacturers and operators of battery storage systems) advocate that another very fast control reserve should be introduced to utilise this additional technical potential. For example, a new AS product is being created along the framework of the Irish DS3 programme, a multi-year programme aimed at meeting Ireland's 2020 RE targets.[55] The goal is to get financial incentives to make inertia available to the system by means of directly coupled synchronous machines. [56]

However, in the view of German TSOs, there is currently no need for this, since, on the one hand, the requirements are lower due to the large interconnected systems [57]and, on the other hand, similar requirements for emergencies can be found in the network code on "Requirements for Generators" (NC RfG). Specifically, Articles 13(2) and 15(2)(c) on limited frequency sensitive mode at overfrequency (LFSM-O) and underfrequency (LFSM-U) stipulate that both of these modes must be activated when the system is in an emergency state of overfrequency or underfrequency.[58] LFSM-O thus provides the system with a fast reduction of active power production, and LFSM-U with a fast increase in active power production.[59]

4.3 Flexibility

As an addition to the expansion of the grid and the use of redispatch, grid operators must be given the opportunity to procure and call up flexibility from decentralised RE plants on the market; the same goes for prosumers, which apart from consuming their self-produced energy should also be able to provide their flexibility to third parties.[60] BNetzA defines flexibility in the electricity system as "the change in feed-in or withdrawal in response to an external signal (price signal or activation) with the aim of providing a service in the energy system".[61]

With regard to the regulatory framework, EU law and specifically the directive on the internal market for electricity stipulates market-based procurement of flexibilities as a fundamentally binding principle – reference is made to "market-based incentives for investments in sources of flexibility" as well as to the structure of the grid charges.[62] In German law, this translates to the introduction of Art. 14c EnWG, which enables market-based procurement of flexibility services in the distribution grid.[63]

When considering the implementation of the provisions of this paragraph, it is worth taking a look at the results of the BMWK-funded research programme SINTEG (Smart Energy Showcases projects). Among other prototypes for flexibility platforms, the so-called ENKO flexibility platform was created, on which flexibility services were traded in real operation.[64] The platform was used in the federal state of Schleswig-Holstein. However, the processes, products and market roles defined for the ENKO platform are a valuable template for the design at the federal level.[65]

In this context, the pending design of Art. 14a EnWG is also worth taking a look at. An amendment of Art. 14a EnWG was aimed at introducing an instrument for peak load smoothing. The bill concerns changes that would allow grid operators to disconnect electric cars or heat pumps remotely if flexibility were needed, ultimately reducing the need for grid expansion at the lower levels. After several studies, workshops and public consultations, the draft bill was withdrawn on 17 January 2021. According to the latest regulatory developments in this area, the BNetzA seconded to adopt nationwide regulations based on which DSOs and their customers are obliged to conclude agreements on the network-oriented management of controllable consumer units; to this end, the BNetzA will also have to develop corresponding criteria on the basis of which these agreements will be concluded.

4.4 Voltage control

In order to keep the voltage within specified limits, grid operators primarily use reactive power. As mentioned in sub-chapter 3.4, market procurement for reactive power has been decided, following the proposals from the SDL-Zukunft project. A three-pillar concept with freedom of choice was presented (provision of reactive power on the basis of the specifications in the technical connection guidelines, market-based procurement or provision from the grid operator's own resources).

An important element of the 3-pillar concept is also the structured and coordinated exchange of reactive power between grid operators of connected grid levels.[66] Final approval lies with the BNetzA, and a concrete design of the procurement systems is currently being developed. The technical concepts for the active power-independent provision of reactive power (so-called STATCOM capability) are mature, but are not being used extensively.[67]

4.5 Frequency control: The 50.2 Hz problem – why a forward-looking adaptation of requirements is necessary

In Europe, the reference frequency is 50 hertz (Hz). While slight fluctuations are quite common, the frequency should be maintained at this level, otherwise problems arise in the case of stronger variation. In 2005/2006, VDE FNN formulated a guideline ("Self-generation plants on the low-voltage grid") whereby RE plants should be switched off immediately and disconnected from the grid in case of an overfrequency of 50.2 Hz. As a result, a large number of smaller power generation plants (e.g. photovoltaic plants) would switch off at the same time, leading to a significant drop in the electricity supply and ultimately a possible blackout.[68]

These connection guidelines were introduced based on the assumption that RE would only account for a small proportion of generation. However, with the dynamic expansion of photovoltaics, all those plants threatened to destabilise the grid in the event of simultaneous disconnection. Hence, an acute need to change this emerged.

To this end, the then Ministry for the Environment and the Ministry for Economics, together with grid operators and associations, developed precautionary measures; the System Stability Ordinance (SysStabV) came into force on

26 July 2012, essentially regulating the retrofitting of more than 300,000 existing photovoltaic (PV) systems.[69] The ordinance stipulated that the retrofitted PV systems would in future disconnect from the grid in a staged process and no longer simultaneously at an overfrequency of 50.2 Hz.

The grid operators were responsible for implementing this retrofitting. The retrofitting had to be individual and one had to practically visit every plant. However, the implementation of such an extensive retrofitting proved to be very complex and difficult. The German Association of Energy and Water Industries (BDEW) was therefore asked to help with the implementation of the SysStabV.

In short, VDE FNN did not foresee the dynamic expansion of photovoltaics in the subsequent years when formulating the connection guidelines in 2005/2006. As a result, costly retrofitting of existing plants had to be carried out. Such pitfalls shall be avoided in future by foresighted adaptation of the connection guidelines.

4.6 Future considerations – stakeholder opinions

Ancillary services from renewables are expected to become even more present in the public discourse on the next stage of the energy transition. The interviews provided great insights on what the future development of ancillary services might look like. When asked about introducing further service contributions, the interviewed wind power plant operator mentioned that the provision of secondary regulation has been extensively discussed. In this case, despite the potential technical feasibility of such a service, the interview partner has explained the constraints that make something like this not possible right now. Firstly, if the requirement for secondary regulation considers an increase in the power output reference point, increased generation could not be ensured by plant operators due to the nature of wind energy and its intermittency. It would likely not only require a variation of the weather forecast, but also an immediate response and action from the plant operators.

Regarding other potential service contributions, the interview partner has presented interesting aspects for the utilisation of wind farms for carrying out black start processes. A corresponding method has been proposed to the experts of a relevant TSO, which takes the form of introducing an existing facility which combines wind power generation and a battery energy storage system (BESS). In this case, a scenario was developed in which the hybrid facility of the wind turbines and the battery would energise transmission lines of 110 kV and 20kV. The large power requirements could be met with the installed battery capacity. Hence, according to the study, the wind turbines could energise their connecting-to-grid transformers at a time interval of around 10 hours and, considering the n-1 criterion, the power supply from the hybrid facility could be ensured for more than 14 days.

In an interview with a power plant and BESS operator, it was mentioned that connected battery systems can currently contribute to the primary frequency control and are classified as a remunerated service. In the future, under qualification processes, battery secondary control could be included as well. In this interview, particular emphasis was also given to the utilisation of hybrid systems, as they are expected to be the driver for the future integration of renewables. The implementation of such systems requires oversized converters, which would offer the potential for power reserves. On this point, the interview partner was again keen to stress the distance between the TSOs and technological developments, particularly in the field of power electronics. The technical solutions exist and are ready to be implemented if there is a corresponding incentive for marketing them. And the regulatory framework is responsible for that. However, it was pointed out that wind turbine and battery hybrids raise concerns about incremental costs, as the framework of grid requirements is not yet clearly defined. In any case, the key driver here is to enhance predictability for the grid operation (bottleneck management).

From the point of view of TSOs, the distributed assets can be enhanced with additional capabilities for ancillary services. Among others, extended voltage support with STATCOM operation, grid forming converters for black start services, virtual inertia and increased short circuit contribution by converters form possible scenarios that may prevail in the ongoing evolution. All these possibilities will be investigated to gain a deeper understanding of their operational margins and interface to the grid.

When asked about further ancillary services that can be utilised in the future, the interviewed DSO expressed the requirement of extended voltage control with the introduction of grid-forming inverter functionalities for black start operation. Aside from that, several possibilities can be identified, such as the contribution of short circuit power or support for harmonic filtering. In these cases, the most important criterion for grid operators is the full verification and analysis of the behaviour and the impact of these contributions on system stability and supply security.

Another plant operator pointed out that, in the current context and given the increasing complexity of the energy market and the demands on producers, the affected actors should be open to tried and tested as well as new technologies. Grid-forming inverters, for example, are a credible technology that can provide answers to the challenges of moving away from conventional generation plants. Along with this, other technologies such as energy storage and electrolysers are emerging on a large scale. The coordination of all these technological solutions and their potential benefits can become a reality in the existing framework.

The interviewed industrial players pointed out that, in the short run, many industrial stakeholders will invest in own (backup) generation as well as BESS. However, one of the two interviewed stakeholders mentioned that they would rather use these investments on BESS for emergency power aspects rather than to provide ancillary services to the TSO. Nevertheless, both stakeholders were positive in the fact that their production sites will contribute to voltage stability in the future.

5 Conclusions

In view of increasing electricity consumption, a potential doubling of peak load as well as renewable generation capacity compared to today, several challenges (but also opportunities) will arise for the German electricity grids by 2050. At the same time, as conventional generation is gradually phased out, the technical features that otherwise contributed to stability (i.e. inertia) are declining. RE power plants are now called upon to fulfil these tasks. This requires a constant re-evaluation of how ancillary services need to change and further evolve to accommodate the system's needs.

In Germany, the topic has developed positively and extensively in recent years, driven partly by the developments at European level. Several discussions with all involved stakeholders have been initiated throughout the years to identify the best way forward. The results of these discussions are also depicted in the interview results: Most stakeholders have acquired enough experience in the field to be able to provide a clear image of what can be expected in the future. This ongoing debate is not expected to be completed anytime soon; it will continue to be necessary to discuss and define the design of ancillary services as well as the requirements for RE power plants, so that the corresponding processes and technologies can be designed accordingly.

When looking at ancillary services provision, there are currently three main options: through binding grid connection guidelines, markets or the grid operator. Which of the three is the most efficient option must be evaluated on a case-by-case basis, depending on actor structures and market design. The interviews highlighted the divergence in the different stakeholders' opinions; open and constructive dialogue on the evolution of ancillary services procurement is therefore strongly encouraged.

However, all interviewed stakeholders were confident about one thing: The level of power quality has remained and will remain high throughout the energy transition. Even though increasing fluctuations are observed, this does not affect the maintenance of the level of supply security. This is also partly ensured by the individualised behaviour of each unit in the event of a failure, something which was not necessarily the case in the past.

In order to optimally replace conventional power plants in the provision of ancillary services and ensure grid stability, RE power plants should be ideally combined with storage solutions. An open issue which will have to be resolved in the near future is the provision of adequate incentives to providers of ancillary services; most interviewees identified this as a crucial aspect to accelerate the transition to fossil-free providers and enhance the further development of the ancillary services market.

The ongoing changes in the electricity system dictate that, now more than ever, the provision of ancillary services must remain secure, reliable and economically viable. Ultimately, this can only be ensured through the efficient utilisation of the capabilities of the RE power plants and through the continuous adaptation of existing regulations.

In any case, it is important to anticipate changes in order to be able to equip RE plants and amend any procurement processes with sufficient lead time. Proactively dealing with any regulatory or technological issues that could emerge in this area is the best way forward. Plants that are operated in Germany today must still be able to be operated safely enough in the climate-neutral power system of tomorrow.

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FINAL REPORT

Interviews: Ancillary service provision by decentral units

Deutsche Energie-Agentur GmbH

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1 EXECUTIVE SUMMARY

In the context of the Sino-German energy partnership, on behalf of the German Energy Association (DENA) a series of interview are conducted by DNV with different stakeholders of the electricity system, aiming to provide implications for the German framework in particular. Especially it is of interest to which extent the stakeholder's opinions are harmonizing or whether still exists contrary standpoints. The findings from the interviews are summarised in this report, whereby stakeholder's viewpoints were anonymised but categorized per stakeholder group.

For the purpose of this study, DNV has performed the series of interviews with representatives of stakeholders from the sectors of grid, industrial stakeholders and plant developers/operators. For the preparation of the interview meetings, the teams of DENA and DNV agreed on a set of stakeholder group specific questions with the view to drawing the most valuable conclusions possible on this matter. The covered topics have been the actual and in future potentially provided ancillary services and the respective framework for stakeholder's access.

The interviews have revealed useful information on topic of ancillary services from decentral sources. A main conclusion is that increasing integration of renewables must be accompanied with their efficient involvement to system stability and security. Even older types of wind turbines are being utilized for basic services like voltage control. According to the inputs of plant operator representative, the market is promising to accept additional services such as black-start capability, more efficient voltage support and reactive power and supply through FACTS, short circuit provision etc. Similar views have been expressed by the grid operator representative exept for blackstart services which is still seen as service of conventional plants. Both sides aim to follow the trends to a more decentralized system.

However, the existing framework of legal, regulatory and grid requirements has specified the norms for solutions and concepts that are technically possible, reasonable, and beneficial for the public. The maturity of the market for additional services in the future is in great dependence on when arising uncertainties and challenges are addressed for ensuring optimized operation and supply security. The traditional energy sector and the reliance on large producers is offering its position to new grid technologies, hybrid solution giving shape to a decentralized landscape. These changes require the form of a well-defined roadmap. How fast and, above all, wisely this process will be carried out is a matter of diverse and thorough investigation.

2 INTRODUCTION

This report presents the outcomes of the interviews that have been prepared by DNV in collaboration with the team of experts from DENA. The interviewed German stakeholders have been selected from the sectors of grid and plant operation as well as industry considering the size of their expertise and experience, the level of their position alongside with the impact of their organisations on the matter of ancillary services from decentral units focussing especially on converter-based RES farms and BESS. The acquired responses have enlightened all the major aspects of the analysed topic unfolding the existing and potentially upcoming framework of the participation of decentral units in contributing to the overall system security including grid stability.

3 INTERVIEW PREPARATION

3.1 Definition of stakeholder groups to be interviewed

For fulfilling the goals of this study, it has been important to call on a significant range of experts from the electricity sector. Considering this priority, it has been ensured that the selected interview partners can bring together a deep insight of the analyzed subjects highlighting useful aspects of what are ancillary services already implemented for provision by decentral units and what needs to be developed in future. Representants of the following stakeholder groups were asked to join stakeholder group specific interviews:

- Grid operators: Transmission and distribution system operators,
- Developers and operators of decentral units like RES farms or BESS,
- Industrial stakeholders,
- Regulatory agencies.

3.2 Development of stakeholder group specific questionnaires

The aim of the conducted interviews has been the presentation of all the main aspects and perspectives on the applied and potential ancillary services that can be provided by decentral units, especially converter-based RES farms and BESS.

The questions that have been addressed to the participating partners during the interviews are shown below. The summary of interview findings and respective comments are presented in following chapters. The content of the answers is presented in an aggregated and anonymous form.

3.2.1 Interview questions per stakeholder group

3.2.1.1 Developers and operators of decentral units like RES farms or BESS

- What kind of ancillary service contributions do your plants already make today?
- How effective do you consider the measures taken by the grid operator and the regulator in the past ten years for ancillary service contributions by decentral plants (especially RE, BESS)?
- Do you see any constraints that make it difficult for you to make ancillary service contributions?
- Which ancillary service contributions must be provided by you free of charge, which are remunerated, and which are provided voluntarily free of charge?
- Are the markets good as they are, or should they be changed to serve the needs?
- What other contributions to system sustainability could your plants already make today in addition to these?

- Are you actively following the discussion around expected future requirements for system service provision in order to be prepared as an operator of decentral plants?
- Under which conditions could you imagine additional contributions to ancillary service provision in the future, such as extended voltage stability through STATCOM, grid-forming converters for black start services, provision of artificial inertia, increased short-circuit current contributions, filtering of harmonics as a contribution to voltage quality, etc.?
- Germany is currently in the process of integrating RE in SDL provision. Agreements have been reached for non-frequency ancillary services, for other ancillary services the process is still ongoing. Looking back, what has gone well so far in the integration of ancillary services from RES plants in Germany and what can we do better?

3.2.1.2 Grid operators: Transmission and distribution system operators

- To what extent are decentral units (esp. RES, BESS) connected to your grid already involved in the provision of ancillary service contributions?
- What kind of ancillary service contributions have you made binding through grid codes, and which of them are remunerated?
- In addition, what kind of contributions to ancillary services are procured on the market against remuneration?
- Are the markets good as they are, or should they be changed to meet demand?
- In your opinion, what other ancillary services should be additionally provided by decentral units in the future, including extended voltage regulation by STATCOM, grid-forming converters for black start services, provision of (artificial) inertia, increased short-circuit current injections, filtering of harmonics as a contribution to voltage quality, etc.?
- How are you actively following the discussion around future requirements for ancillary services provision in order to be prepared as transmission grid operators?
- What are your views on the establishment of local-regional ancillary services market mechanisms, e.g. for the procurement of grid congestion management measures, black start/grid reconstruction, provision of increased reactive power or short circuit current contributions?
- When do you think it will be possible in the long term to completely dispense with conventional power plants for the provision of ancillary services? And what will it take to achieve this?
- If grid-forming converters are also to be introduced on a larger scale in the EU in the future, how can this be done harmoniously between the various ENTSO-E members so that undesirable controller influences can be largely limited?
- Will we have to make concessions in the medium to long term compared to the currently very high quality and security of electricity supply?
- In Germany, RES is currently being integrated into the provision of ancillary services. Agreements have been reached for non-frequency-linked ancillary services, for other ancillary services the process is still ongoing. In retrospect, what has gone well so far in the integration of ancillary services from decentral units in Germany and what can be done better?

3.2.1.3 Industrial stakeholders

- To what extent are you already involved in the provision of ancillary services?
- Do you see any hindering boundary conditions that make it difficult for you to access the provision of system service contributions, e.g. through DSM, BESS, etc.?

- Do you have or have you had problems with the current power supply incl. voltage quality?
- Do you already operate or are you planning to invest in your own decentral energy generation or electricity storage facilities?
- Today, battery storage systems can technically react much faster than the requirements for primary control power demand. From this, some stakeholders (especially manufacturers and operators of battery storage systems) deduce that in order to utilise this additional technical potential, another very fast control reserve (cf.: Ireland/GB) will be introduced. What is your opinion on this? Would this bring significant added value and would it be easy to implement?
- To what extent does increasing your security of supply play a role in this, so that, for example, attention is paid to grid-forming properties or the like?
- To what extent are you planning to switch completely to electric processes in the long term?
- Will it be possible or necessary to cut back on the current very high quality and security of electricity supply in the medium to long term?
- In Germany, RE is currently being integrated into the provision of SDL. Agreements have been reached for non-frequency-linked ancillary services, for other ancillary services the process is still ongoing. Looking back, what has gone well so far in the integration of ancillary services from RES plants in Germany and what can we do better?

3.2.1.4 Regulatory agencies

- To what extent are decentral plants (esp. RES, BESS) connected to the grid operators in your area of responsibility already involved in the provision of ancillary services?
- What kind of ancillary services are bindingly demanded by grid codes, and which of them are remunerated?
- In addition, what kind of ancillary services are procured on the market against remuneration?
- In your opinion, what other ancillary services contributions are to be additionally provided by decentral plants in the future, including extended voltage control by STATCOM, grid-forming converters for black start services, provision of artificial inertia, increased short-circuit current contributions, filtering of harmonics as a contribution to voltage quality, etc.?
- Which of these might be more likely to be reflected in grid codes on a mandatory basis, and which might tend to be procured on a market basis?
- As can be seen from the example of reserve gas turbines, grid boosters, STATCOM, MSCDN, in future system services in Germany will increasingly be provided from the grid operators' asset portfolio. To what extent will the costs be weighed against market procurement for respective decisions in the Netherlands?
- How do you view the establishment of local-regional ancillary services market mechanisms, e.g. for the procurement of measures for grid congestion management, black start/grid reconstruction, provision of increased reactive power or short-circuit current contributions?
- When do you think it will be possible in the long term to completely dispense with conventional power plants for the provision of ancillary services? And what will it take to achieve this?
- Today, battery storage systems can technically react much faster than the requirements for primary control power demand. From this, some stakeholders (especially manufacturers and operators of battery storage systems) deduce that in order to utilise this additional technical potential, another very fast control reserve (cf.: Ireland/GB)

will be introduced. What is your opinion on this? Would this bring significant added value and would it be easy to implement?

- Will we have to cut back on the current very high quality and security of electricity supply in the medium to long term?
- In Germany, RES is currently being integrated into the provision of ancillary services. Agreements have been reached for non-frequency-linked ancillary services, for other ancillary services the process is still ongoing. In retrospect, what has gone well so far in the integration of ancillary services from decentral units in Germany and what can be done better?

4 INTERVIEW OUTCOMES

In this chapter, the outcomes of the performed interviews are presented in the following sections. Overall, the key points can be summarized in Figure 4-1. It should be noted that there was no response from regulators to the call for an interview. However, the initial design of the interviews has included topics and questions for this category of stakeholders.

Figure 4-1: Summary of key points and topics that are related to the decentral provision of ancillary services

4.1 Developers and owners of decentral units like RES farms or BESS

In total three different project developers/operators participated out of four contacted ones.

4.1.1 Interview Partner 1

In this case, the interview partner represents an independent wind energy producer and is responsible for the processes of planning, development, building and operation of wind parks. During the interview, it has become quite clear that wind energy producers have the capability to ensure system stability providing basic services, while the technological progress and the new features of wind turbines shall bring further functionalities that could enhance the spectrum of their contribution.

Existing and potential ancillary services

To the first question on actual provided services by wind turbines that are performed today, the interviewee has prioritized the importance to consider a distinction between TSOs and DSOs. The reason for this is related to the fact that the two parties can form different market areas for the wind plant operators. In other words, apart from common requirements, the spectrum of the provided services may not be identical for the transmission and distribution operators, as their scale size is different implying different features, requirements and subsequently market opportunities.

Specifically, as regards the content of the question, the interviewee has mentioned several services already offered and required by both types of grid operators. Thus, voltage control, active power regulation in context of grid congestion management and primary frequency control (FCR, based on BESS) belong to the range of services with which wind farms are contributing to the system stability. The active power control for grid congestion management is exclusively performed with down-regulation referring to the operating mode of derating and curtailment control strategies that include the modification of power setpoint or the rotor speed set-point. Aside from that, the offered services are complemented with power factor control and reactive power regulation. Regarding the latter, the use of FACTS is performed to meet the corresponding requirements for reactive power compensation.

For introducing further service contribution, also the provision of secondary regulation (aFRR) has been discussed. In this case, despite the potential technical feasibility of such service, the interview partner has explained the constraints that something like this is not possible right now for business case reasons. On the one hand, in order to generate positive secondary regulation, wind production would have to be continuously lowered, which is currently not profitable compared to the revenues on the electricity market. On the other hand, a very high power availability is required by the transmission system operator, with regard to the quality of the local wind production forecast it would mean a multiple impact of the wind power still marketable on the electricity market.

Regarding other potential services contribution, the interview partner has presented interesting aspects for the utilization of wind farms for carrying out black start processes. It has been explained that they proposed a respective method to the experts of relevant TSO by introducing an existing facility which combines wind power generation and a battery energy storage system (BESS). In order to secure the restart of the WTG, the required reactive power for the cable network could be provided via an emergency power system and installed BESS power connected to the wind farm grid, so that the WTGs could be kept under voltage and the formation of condensation in the WTG transformers could be avoided, which would otherwise have meant a 12 to 24 hours later WTG restart. Moreover, the functionality of fiber optic based communication could be assured and selected WTGs could be restarted within the islanded wind farm in order to recharge the BESS, until the TSO provides voltage again and the wind farm con be briefly switched of completely ahead of re-energizing via the transmission grid.

Following the description of further ancillary services, the interview partner has elaborated more on the nature of boundary conditions that limit the utilization of wind turbines. It has been explained that despite of the available technology, the regulatory authorities need to encourage the creation of the prerequisite legal framework that would activate this potential. However, such context right now has not been realized yet.

Services pricing, market maturity and ongoing discussion

The completion of the first part of the interview has addressed the topics of the first three questions. Following this, the discussion has continued with the scope to obtain a deeper understanding on the views of the interview partner on how mature the market is for introducing and commercializing the contribution of decentral units' contribution to the system stability. Finally, it has been specified which of the mentioned services should be classified as mandatory (not remunerated), as bilateral agreements (voluntary, remunerated) and as procured (market tendering) based on their capacity and commitment.

For the experts of plant operation, it is evident that the potential that can arise from the wider use of RES and especially wind turbines for the system stability need to attract higher attention from the relevant authorities and policy makers. For the last twenty years, a well-defined framework of prequalification has been a reality and should be bridged with the deployment of a more favorable environment. It pertains the consolidation of policies that promote the wider substitution of the conventional power plant by renewables in the field of the provided ancillary services. The previous examples of black start and secondary regulation have been used as characteristic cases, where the corresponding framework of requirements could be developed and specified in a more "friendly" path for actualizing this potential market.

In parallel with this expectation, there is a steady attempt to follow initiatives that aiming to implement such practices. As an example, a collaboration project has been mentioned in which the operation of the wind farm is assessed for the provision of short circuit capability. Moreover, it is undoubted that a more complete utilization of FACTS shall be beneficial for more efficient reactive power compensation and constitutes one of their constant considerations. On the other hand, the contribution of wind farms to harmonic filter services has not been a requirement yet. Finally, fast frequency response (FFR) will be probably included in the service contribution in the future as new types of wind turbines are steadily introduced in operation.

4.1.2 Interview Partner 2

For this interview, the invited stakeholder represents a plant operator and developer being responsible for product management and innovation use cases with focus especially on the development of grid-forming services that can be provided by BESS. As in the previous case, the interviewee confirmed the current utilization of the decentral units for the provision of basic ancillary services. Aside from that, the discussion revealed on the one hand the existing potential of hybrid systems (RES + BESS) for the more comprehensive provision of ancillary services and on the other hand described the inadequacy of the regulatory framework to keep up with the new technological possibilities.

Existing and potential ancillary services

Beginning with the provided services today, the connected BESS can contribute to the primary frequency control (FCR) classified as market based remunerated service. In future, BESS could also be pre-qualified and provide secondary control (aFRR) in Germany. Not considered as ancillary services but also describing a future use case is seen in the wholesale market/arbitrage application. Moreover, requirements for power-factor control are in force but they vary depending on the voltage connection level and the generator type (B, C and D). Regarding incentive measures and actions from the regulatory authorities, the interview partner has noted that throughout the last years, the utilization of BESS to contribute with ancillary services has been motivated from the regulation point of view due to the consideration of BESS as critical grid technology for the system stability.

Following this answer, the interviewee elaborated on the boundary conditions that decelerate or even prevent the provision of ancillary services from renewable energy and BESS. In the same spirit as the previous interviewee, the inadequacy of the regulatory framework and its divergence from current technological capabilities were identified as the main obstacles to taking this case forward. From a technical point of view, system operators face particular challenges in identifying appropriate and available points of connection to the grid. This effort is made more difficult because battery systems are still today treated within the framework of the grid codes, either as producers or as consumers. This cannot be viable and in no case compatible with the current technological capabilities of these systems. The battery is not just a power absorption or power output element. It is above all a storage device and should be treated as such. The management of the available electricity in grid power flows could be optimized by consolidating the contribution of storage technologies and ultimately defining them in the regulatory framework. Such a development would encourage the identification and regulation of existing markets and thus facilitate the development of the widespread use of renewable energy sources and storage technologies for the provision of ancillary services.

At the same time, the interviewee raised the issue of the inconsistency of regulatory rules for storage technologies. This is yet another factor in the establishment of a non-uniform and ill-defined market which is not in line with existing technological possibilities. A direct consequence of this situation is the reluctance of developers to carry out new projects that could theoretically contribute to ancillary services. In other words, unlocking the market cannot be possible if advanced technologies are significantly limited in the number of benefits they can offer.

Finally, in addition to the limitations of the regulatory framework, the installation and management of batteries must be carried out in a way that minimizes noise pollution levels. Since such systems are installed close to residential areas, they must be required to have effective systems to prevent the resulting noise.

Services pricing, market maturity and ongoing discussion

With the priority of contributing to the stability of the network, the compensation for reactive power and consequently the control of the power factor are ancillary services offered free of charge by BESS. On the contrary, the primary control (FCR) is remunerated but questionable remains the sense of the double hump curve as prequalification criteria, which forces double capacity design.

As regards the question on the maturity of the markets, the discussion moved back to the mismatch between the regulatory framework and technical capacities as regards the inclusion of ancillary services. The interviewee stressed once again that central to this discrepancy is the current treatment of batteries exclusively as either consumers or producers. Such a view corresponds to a technological reality of the past and not of the present. An important step in the development of the market would also be the further specification of compliance rules. In addition, more economic incentives need to be created so that the ancillary services of the renewables can be extended, for example to the provision of power reserves. As another responsibility to the managers, the need to clarify the framework for services and whether they really want to move in that direction was recognized. Particular emphasis was also given to the utilization of hybrid systems, as they are expected to be the driver for the future integration of renewables. The implementation of such systems requires oversized converters which will objectively bring the potential for power reserves. Again on this point, the interview partner was keen to stress the distance between the TSOs and technological developments, particularly in the field of power electronics. The technical solutions exist and are ready to be implemented if there is a corresponding incentive for their marketing. And the regulatory framework is responsible for that. However, it was pointed out that wind turbine and battery hybrids raise concerns about incremental costs as the framework of grid requirements is not yet clearly defined. In any case, however, the key driver in this case is to enhance predictability for the grid operation (bottleneck management)

According to the interviewee, the important role of the academy should also not be underestimated. As the market can be linked to existing developments and skills developed in the context of scientific research, technical possibilities and proposals for optimizing energy production and storage technologies can be communicated in a more structured way. Therefore, according to the interviewee, the regulators should listen to the results of this work. In this way, a quantification of the contribution of the new network technologies will be achieved, as the technical parameters for the provision of ancillary services and the resulting advantages will be understood by all the stakeholders.

Finally, as regards the ongoing discussion on this matter, the interviewee mentioned the involvement of many actors and stakeholders, which is well known. There are many conflicting views and assessments on the subject, which makes it necessary to formulate a common platform for dialogue. In this communication, the engineering side of the debate must be the mainstay, so that a clear hierarchy of necessary policies can emerge.

Future trends and assessment of past actions

When asked under what circumstances the plant operators would imagine additional ancillary services, it was again stressed that the whole portfolio of services could be implemented. As regards the integration of FACTS (STATCOM, grid-forming inverters, etc.), additional investment is needed. In particular for the black start a combination of clarification of the framework of requirements and the cases where it is to be applied is needed. The promotion of BESS is the key as it will encourage the application of hybrid solutions. As to the mode of ancillary provision of services, this must be clear, either mandatory or remunerated. As for other short circuit capability services, this possibility is not yet mature while harmonic filtering is also less possible.

For the actions undertaken in the past at country level, some possibilities for more efficient implementation have been identified. In particular, the certification procedures were not sufficient to promote new network technologies, in particular hybrid solutions. In addition, there are still economic barriers to market activation. All in all, the interviewee concluded that an environment of greater flexibility and more direct decision-making would have been more supportive of the whole process.

4.1.3 Interview Partner 3

For this interview, the invited stakeholder represents a plant operator and developer. In this case too, the interviewees confirmed the existing situation of utilisation of wind farms for the provision of all those ancillary services described and required in the grid connection regulations. At the same time, they described a similar finding with previous plant operators on the gap between the current regulatory framework and the market potential that can result from the technological capabilities of renewable energy sources.

Existing and potential ancillary services

When asked as to the type of ancillary services they provide as plant operators today, initially voltage and active power control were mentioned as key contributors to system stability, always in line with the requirements for PQ regulation set by the grid operators. Of particular interest was their reference to the topic of the contribution to the reduction of harmonics into the network by the installation and operation of proprietary filters, also always in line with the framework set for the management of the network. On a voluntary basis, the only ancillary service they provide is primary control reserve (FCR). Finally, it was noted that in the past there was an intention for extended reactive power provision for the medium and high voltage grid with wind turbines, but nowadays the rating of wind turbines is that efficient that no buffer is more available for such extra services.

Regulatory framework for decentralized plants, constraints, and services pricing

The discussion then moved on to issues concerning the effectiveness of the policies and measures taken by network managers and other regulators over the last ten years to promote ancillary services from decentralized generation units. In a similar vein to previous interviewees from the plant operator sector, the assumption for the last decade is that it has been the starting point for initiating a dialogue among relevant stakeholders on the potential for decentralized entities to contribute to the provision of ancillary services beyond the minimum threshold set by the codes and network managers. Responding to the characteristics and prospects of a deregulated energy market model, plant operators identified opportunities to develop new business opportunities based on the technological capabilities of their units. Simply put, it describes a kind of different recognition of where the boundary of the determination between mandatory and paid ancillary service provision is set.

In fact, judging from the results of the previous interviews, plant operators are seeking to derive more and more technological potential from their installations in a favourable incentive environment set by network operators and the general regulatory framework. However, from the responses given there seems to be a divergence between the scope of network regulations and the desire of plant owners to expand their business planning. Among other things, there is the impression that the design of the systems is to a certain extent restrictive in order for synergies to emerge. The area in which plant operators are therefore called upon to push the boundaries of their business in terms of the provision of ancillary services is characterised by a considerable degree of complexity. This, combined with constraints of bureaucratic nature, if not discouraging, introduces ambiguities and delays in the path to a holistic exploitation of decentralised units.

Finally, an additional parameter was noted which will be considered by the stakeholders in the next period. The development of wind farms (offshore and onshore) needs to take into account the corresponding extensions to the grid to which they will be linked. Therefore, if the approval of the connection of a decentralised unit relates to a connection system for which either an extension or reinforcement of the grid is required and at the same time the compensation of reactive power is mandatory, this implies an increase in costs. On this point, therefore, the planning of the generation must go hand in hand with the planning of the network.

Market readiness and improvement margin

Already from the responses received, it was clear from the interviewees' impression that there is room for improvement in order to create incentives for the development of the ancillary services market. As stated in the previous interview, in this case it was also understood that more effective communication could contribute to an initial alignment between stakeholders in terms of the provision of ancillary services. For example, the market for reserves can be further opened up if a common costing framework is clearly defined, especially looking at the capacity of plant operators to establish hybrid operations with BESS for providing positive reserve power.

Ongoing discussion and future trends

As already made clear in earlier interviews, the debate on the optimal use of decentralized units is extremely lively and interesting. Plant managers are striving to promote and harmonize not only with market trends but also to act as a bridge between scientific knowledge and actual application. In this particular case, the interviewees' company maintains channels of communication with both the network operators and the scientific community. As for the network managers, the current conversation concerns the promotion of the black start idea and communication systems, while as for the scientific research, collaborations were mentioned to carry out studies on grid spinning, energy storage and the role of grid-forming converters and higher short circuit capacity replacing conventional power plants.

Conditions for additional ancillary services and assessment of past actions

The evolution of the transmission and distribution network with the parallel move away from conventional electricity generation plants has resulted in a tightening of the framework of requirements for network operators. Operators and owners of plants are required to improve the operation of their units, to enter into partnerships with operators of other systems (BESS) and to equip the systems with FACTS. In this way, they can achieve greater flexibility and harmonize with higher ratings. In this case technical feasibility and profitability analysis shall be combined for ensuring sustainable planning and development.

Overall, the process of using decentralized production units for the provision of ancillary services has progressed positively in Germany, as the degree of clarification of the regulatory framework and uniformity for all parties involved has increased. Another positive aspect is the achievement of individualization of the behavior of each unit in the event of a failure, which was a serious problem in the past. However, for the future, a reassessment of the current situation is needed. In the current context and given the increasing complexity of the energy market and the demands on producers, the interviewees ask whether it is wise to use the same tools and methods. Grid-forming converters, for example, are a credible technology that can provide answers to the challenges of moving away from conventional generation plants. Along with this, other technologies such as energy storage and electrolysers are emerging on a large scale. The coordination of all these technological solutions and their potential benefits can become a reality in the existing framework. The interviewees therefore ask whether a new prioritization of stakeholders is considered necessary to avoid unnecessary burdens and unsustainable solutions.

4.2 Grid operators: Transmission and distribution system operators

In total three different grid operators from transmission and distribution level participated out of seven contacted ones.

4.2.1 Interview Partner 1

In this case, the interview partner has been a senior expert in the field of grid operation. Its department is responsible for the operational scenarios for the relevant grid area. The performed discussion revealed interesting views on current trends for utilizing the service contribution from renewables, as a significant number of wind parks with diverse form and installed capacity are interconnected to the grid and are fully used for the basic grid services. Therefore, the expressed opinions are quite useful, as grid operators constitute one of the major drivers in the transition of the energy landscape.

Existing ancillary services and grid code requests

The high integration of RES into the relevant grid area has been highlighted. There exists a number of directly connected wind farms with installed capacity from 100 MW to 500 MW and except a very old farm all of them are contributing with the basic services to the system security. Static voltage control, reactive power supply and participation in fault clearance (FRT) give the current picture of wind farms' ancillary services. Of course, factors like the age of the wind farm have an impact on how the generating facilities are prioritized in terms of utilization for the service provision.

As regard the grid codes, the core consideration of the interviewee has been that the TSOs aim to develop norms that describe requirements and standards technically feasible and realistic. Requirements for voltage control and reactive power supply are included in the current grid code and are obligatory and not remunerated. On the other hand, black start capability is classified as remunerated, same as curtailment respectively redispatch services. Moreover, short circuit current supply is a voluntary service and can be provided based on bilateral agreements. In general, a requirement is to be financially remunerated to the procurement party by the TSO when it is related with unique and individual agreements. Nonetheless, if a requirement is to be fulfilled for a uniform and larger market then it is classified as obligatory and not remunerated.

Further services for procurement and market potential

Currently, the market conditions do not allow the utilization of renewables for integrating further services that are technically feasible though e.g. secondary (aFRR) or tertiary (mFRR) regulation. At this point, an alignment in views with the respective arguments of the plant operator representative has been observed. The economic environment should have been more favorable and beneficial for this purpose for overcoming existing constraints such as the intermittent nature of weather forecast.

Following this, the interview partner has commented the progress in the respective market development as a process with uncertainties and complicated topics to be addressed. The ongoing transition with the closure of conventional plants has an actual impact on the system stability (loss of inertia, lower short circuit capability, dynamic control, redesign of protection schemes etc.) Raising challenges like frequency balance or voltage stability that must be tackled with the assessment and promotion of new solutions. The critical question that needs to be answered is how the promoted business model can be actualized with the new technologies such as grid forming converters, hybrid systems of STATCOM and synchronous condensers. Within a range of technical options that are under development or even actual implementation, it is an open query how decentralized solutions can be efficiently integrated.

Future requested services from TSO point of view

As an actual driver of the energy transition, from the point of view of TSOs, the distributed assets can be enhanced with additional capabilities for ancillary services. Among others, extended voltage support with STATCOM operation, grid forming converters for black start services, virtual inertia and increased short circuit contribution by converters describe possible scenarios that may prevail in the ongoing evolution. All these possibilities shall be investigated for acquiring a deeper understanding of their operational margins and interface to the grid. As previously, it is mentioned that there are pending questions indicating though an obvious tendency and key message that the energy landscape is shifting to more autonomous and “self-serving” solutions.

Local and regional market mechanisms, moving away from conventional generation

To the question on views regarding the development of market mechanisms that shall support the procurement of decentralized system services, as previously it has been denoted that the closure of conventional power plants reflects the efforts of a market model in which smaller network “cells” define the system operation. As the current network is still relying on the utilization of large producers (conventional plants), the uncertainties of the future decentralized phase must be addressed. The specification of decentralized market is deemed as critical step in the roadmap of forming additional requirements and rights for producers and assets.

Challenges in supply security

The utilization of decentralized generation for ancillary services implies concerns on the security of electricity. The ongoing studies and practices focus on optimizing the operation of decentralized assets to retain and to improve security standards, as diverse stakeholders are involved in the ongoing transition. The complexity of the market model has resulted in the specification of many aspects that must be coordinated for shaping the path for the required actions to a more decentralized environment.

4.2.2 Interview Partner 2

For this interview, the invited partners are senior experts in market and system management representing a transmission system operator. As in the previous case, the views of the operators are of particular value, as their decisions determine the regulatory framework of the energy market and thus the development of the corresponding projects. It is therefore to be expected that the perspectives of network operators differ from those of producers.

Existing ancillary services and grid code requests

The interview started with the first question concerning the decentral units and their contribution today to system stability with the ancillary services. The participation of the large conventional generating units in ancillary services has decreased, resulting in the entry into the corresponding market of decentral renewable energy plants (esp. curtailment resp. grid congestion management, voltage control) and BESS mainly connected to MV level but providing FCR. Decentral units are not ready for the provision of black-start services since grid restoration as very complex process with many stakeholders needs to remain as simple as possible. The market platform for provision of control power in turn is technology open.

However, the further integration of decentral units into the provision of ancillary services is a process that raises important technical challenges. Many factors are involved which means that assessing stakeholders' views makes the process even more complex.

Further services for procurement and market potential

The market for ancillary services should not be treated as one. In this sense, the needs and criteria of electricity transmission operators differ in some respects from those of electricity distribution operators. This means that the markets are also differentiated. According to the representatives, for the existing market-based ancillary services the market needs to be strengthened esp. with regard to the distribution level, as renewable energy sources are increasingly being integrated at this level.

The closure of conventional generation units leads to lower inertia margins, lower short-circuit capacity, less reactive power provision, etc. In turn, such a situation makes it necessary to approach and promote new solutions where decentral units will provide these services. Especially inertia will become big issue. But rotating masses will always remain in the EU network in the next 15 years, synchronous machines will not disappear, but conventional power plants will do. However, not all future converters have to be grid-forming.

At the level of transmission system operators, the development of this market is proceeding steadily even that the interviewees state that the process of transition to a full replacement of conventional generation units requires a cautious approach. However, certain processes at ENTSO-E and within the policy could be accelerated.

Challenges in supply security

For the representatives of the TSO, the questions are more political in nature. The expected decisions are not only determined by the existing technical possibilities, but mainly by what is considered economically viable and efficient. It is a multi-stakeholder process that takes time and requires special attention. Institutions like ENTSO-E can also contribute even more to the creation of a clearer framework.

4.2.3 Interview Partner 3

This interview was conducted with a DSO representant having the responsibility for the asset management and high voltage resort. In contrast to the two abovementioned interviews with participation of TSO representants, this interview allows now a deeper insight into the challenges and ancillary services provision at the distribution network level.

Existing ancillary services and grid code requests

At the DSO network level the following ancillary services are typically required: Congestion management (curtailment/redispatch), provision of reactive power by all connected plant operators, and primary control (FCR) provision through BESS. The primary voltage control shall be carried out in principle in compliance with the power factor following the corresponding setpoint of power factor and reactive power which can vary throughout the day. According to the network code, reactive power provision is described as binding ancillary service. Redispatch services are not requested by the grid code but need to be provided by law with renumeration.

Market potential and further services for procurement from DSO point of view

According to the interviewee, the discussion for acquiring further ancillary services from the decentralized units is always open (e.g., inertia, redispatch studies). From the perspective of a grid operator the first priority is to verify the technical feasibility and the beneficial impact of such market. However, if the capability of individual producers is deemed necessary for the grid support, then bilateral and remunerated agreements between the two parties can be established. Concerning further ancillary services that can be utilized in the future, the interviewee expressed the requirement on extended voltage control with the introduction of grid-forming converter functionalities for black start operation. Aside from that, several possibilities can be identified, for instance, the contribution of short circuit power or the support to the filtering of harmonics etc. In these cases, the criterion that dominates for the grid operators is the full verification and analysis of the behavior and the impact of these contributions to the system stability and supply security. The ongoing discussion within the area of responsibility of the DSO extensively refers to requirements on voltage control and the respective estimation of reactive power provision from the renewable generators.

Local and regional mechanisms for ancillary services away from conventional generation

The development of the regulatory mechanisms for the ancillary services is in dependency on the maturity of the respective market. The size of the market will determine the complexity degree of these mechanism and the pricing policies. Regarding the provision of ancillary services and the transition path from the conventional power plants to the decentralized generating units, the current network is still relying on the utilization of large producers. Their replacement by grid-forming converters and potential introduced uncertainties must be thoroughly assessed for defining additional requirements and rights for producers and assets.

With regard to voltage control, the extended provision of reactive power e.g. based on STATCOM is expected to be important for the future. However, the establishment of a respective market is not seen as preferable, in case that additional reactive power needs to be purchased bilateral contracts are the better solution. Looking at the provision of inertia, this is also seen as important aspect and can be related to decentral units connected to the distribution level however it needs to be organized by the TSO having the responsibility for the stability of frequency. A need for higher short circuit contribution is not recognized at the distribution level, but adaptation of the protection schemes might be necessary in future. Also, there is no clear need for additional harmonic filtering. Looking at the further decarbonization of the electricity system, the inertia provision will in any case play a crucial role.

Challenges in supply security

In the distribution network, the DSO has not detected any actual challenge which could endanger the maintenance of the level of supply security. However, there are energy market related risks which can cause challenges for the supply of supply. Especially the question still needs to be solved how to shift the renewable energy surplus from the summer period to the winter period.

4.3 Industrial stakeholders

In total two different industrial stakeholders participated out of three contacted ones.

As the transition from conventional large power plants to decentralised units raises questions about security of supply for industrial consumers, the latter are called upon to play a more active role in ensuring the stability of the system. Compared to the past, large industries, in the context of investment policies, are seeking to enter the field of ancillary services by integrating new technologies with which they can achieve the electrification of their manufacturing processes. Therefore, in order to develop a more comprehensive view on the provision of ancillary services, further outreach to industry stakeholders was undertaken.

4.3.1 Interview Partner 1

In this case, the interviewee comes from the chemical industry and is a leader in its field of activity. The representatives of the company interviewed are heads of the departments for power management and power supply. The information shared by them revealed additional aspects of the issue, offering in some places a more realistic picture of the impact of decentralised units and their utilization for the provision of security and ancillary services.

Involvement in the provision of ancillary services and possible boundary conditions

Apart from the provision of fast and immediately switchable loads (until the end of respective market end of June 2022) also aFRR and mFRR is provided. Also filtering of harmonics is done according to the grid code requirements, but only for own harmonics. Moreover, contribution to the voltage stability is realized among others via tappable transformers (to stick to the required cos(φ) corridor). An operating range so that the power factor is in the inductive range e.g., from 0.91 to 0.95 is accepted by the grid operator so that no penalty costs from the grid operator are imposed.

The interviewees underline clear barriers in context of the provision of ancillary services: It is incomprehensible why the regulation and the markets for quickly and immediately interruptible loads were abolished end of June 2022. This is diametrically opposed to the advancing energy transition. Also, the 7000h rule to benefit from reduced grid tariff according to $ 19(2) StromNEV must be mentioned as counterproductive: This rule no longer serves any purpose at all, now that all base-load power plants are disappearing from the market. Last but not least, sticking to a cos(φ) corridor is an old strategy which doesn’t fit to the extending cable networks and fluctuating infeed situation anymore, this prevents an active voltage support.

Possible power quality issues

When asked about power quality and possible deviations observed in relation to the range defined by the network code, interviewees reported that the overall picture does not show any problems. However, they pointed out that in the high voltage (110kV) grid there are noticeable voltage fluctuations during the periods when renewable electricity from PVs enters the grid. However, grid faults have not occurred. Regarding other types of problems that may arise due to harmonics or short-circuit power, the picture is also positive.

Investments on decentralized energy generation and electricity storage facilities

Due to the new landscape that is emerging with the replacement of traditional large-scale power plants by decentralized plants, interviewees were asked whether they either already or in the future intend to invest in the operation of their own autonomous power plants and in electricity storage systems. Their investment plans include photovoltaic plants, but not energy storage systems. Emergency power generators exist, but they are only used for emergency power supply and damage prevention in the event of a power failure.

Importance of supply security

The supply security for the activities of this industry is achieved through the use of hydropower plants next to the factory whose installed capacity is sufficient to meet the relevant demand in the event of disconnection from the main grid resulting in island operation. The available power would also be sufficient to supply small villages in the surrounding, but it is not yet proved with respective black-start and local grid restoration tests.

Electrification processes, future compromises in power quality

Regarding the electrification of industrial processes taking place and the replacement of conventional forms of energy (oil, gas, etc.), interviewees described that many processes are already carried out using electricity as a source of energy. Concerning possible future compromises, as the closure of large conventional power plants and the transition to decentralised power plants and renewables constitute a pathway with critical questions to be answered, interviewees believe that on the short run many industrial stakeholders will invest in own (backup) generation, on the long run the electricity system may be sufficiently reliable again. Also, a complaint is that the development of the normative framework always lags behind by a long way.

4.3.2 Interview Partner 2

The second interview with an industrial stakeholder was also conducted with a (global) leader in its field (metal production), having a heavy energy consumption for the production processes whereas the main processes are not electrified. The interviewee is responsible for the power supply of the different production sites.

Involvement in the provision of ancillary services and possible boundary conditions

Apart from participation in the load shedding cascade and the cos(φ) requirement to be met in accordance with the grid code, there is no requirement on the part of the transmission system operator to whose grid the various production sites are connected. However, it could be expected in the future that the production sites will be included in active voltage support. The production processes do not allow for DSM. Also, there is no active role in frame of the grid restoration concept of the TSO.

Possible power quality issues

So far, there have been no problems with power quality; only events such as thunderstorms have led to voltage problems from time to time. Harmonics, which are caused in particular by the converters used, are filtered out according to the specifications of the grid code.

Investments on decentralized energy generation and electricity storage facilities

Self-generation takes place at the production sites, whereby the process gases produced are converted into electricity, thus reducing the need to purchase natural gas. In addition, hydrogen is now increasingly being used in the production process in order to be able to offer C02-reduced products on the market. The available factory sites are not sufficient for the installation of RES farms. BESS plants are under discussion, but no decisions have been made yet, especially since the use cases are not yet concrete.

Importance of supply security

In the event of power outages, the top priority is the orderly shutdown of production processes. Emergency power generators are in use at key locations to prevent plant damage in the event of blackouts. Likewise, if investments would be made in BESS, they would be used for emergency power aspects rather than to provide ancillary services to the TSO.

Electrification processes, future compromises in power quality

The interviewee underlines that there is the strategic goal to convert all production processes into climate friendly ones within the next 13 years. This will be achieved by both, electrification and more utilization of hydrogen. A full electrification is not possible due to the special nature of production processes.

4.4 Regulatory stakeholders

Out of three contacted regulatory agencies no one showed willingness to participate.

5 KEY FINDINGS & CONCLUSIONS

The interviews revealed that progress has been made in recent years in the integration and inclusion of decentralised units in the provision of ancillary services. The current discussion is about expanding the use of renewable energy sources and in combination with storage technologies to replace large conventional power plants in the provision of ancillary services and ensuring grid stability. Divergent incentives were noted in some areas between the relevant stakeholders as to the possibility of accelerating this transition. This chapter therefore presents the main findings and some conclusions that emerged during the interviews.

1. **Overall findings**

   i. Decentralized plants (RES, BESS) are already being utilized to provide a range of ancillary services (esp. contribution to voltage control, control power, grid congestion management). However, there is openness and to large extent already readiness to provide more intensively ancillary services (esp. extended reactive power, short circuit provision, partly black-start services).

   ii. Grid operators and the corresponding network codes constitute the major drivers for establishing conditions of uniformity in terms of requirements.

   iii. There is room for improvements in order to create incentives for the development of the ancillary services market. However, the incentives for potential new market of ancillary services raised by developers and plant owners do not always tend to meet the priorities of grid operators for technically feasible solutions.

   iv. On the contrary to a more business-oriented mindset from the point of view of developers and owners, the main concern of the grid operators is to understand all the aspects and possible impacts of the decentralized generating units on the grid and the end consumers. Therefore, the development of identified potential markets is dependent on the continuous performance of system studies to cover the whole spectrum of the topic.

   v. Bilateral and renumerated agreements between the grid operators and developers/owners are already in place mostly to address local requirements for increasing the efficiency in grid operation.

   vi. More efficient communication is required to align the relevant stakeholders in terms of updating the agenda on the potential of the decentralised units for the provision of ancillary services.

2. **Developers and owners of decentral units like RES farms or BESS**

    i. It is acknowledged that the decentral units contribute significantly to voltage regulation, this can be more extended in future also building on adapted converters and FACTS like STATCOM.

    ii. The certification processes from grid operators are deemed not sufficient to further promote new network technologies, in particular regarding hybrid solutions but also control power and blackstart provision.

    iii. Grid-forming converters may be a credible technology that can address the challenges of moving away from conventional generation plants.

    iv. All in all, the process of integrating decentralized units into the provision of ancillary services has progressed positively in Germany.

    v. However, for the future, a reassessment of the current tools and methods is needed due to the given increasing complexity of the energy market and the demands on producers.

    vi. Finally, the grid operators should allow for more innovation projects in order to derive important implications for new grid code releases directly from related field tests and not just from theoretical studies and laboratory tests.

3. **Grid operators: Transmission and distribution system operators**

    i. First of all, the stability of the current electricity system is still relying on the utilization of large conventional plants.

    ii. Although decentral units are proven providers for reactive power and curtailment/redispatch services, the utilization of renewable generation esp. for frequency related ancillary services still implies concerns on the security of electricity looking at the limited availability.

    iii. The reactive power provision based on decentral units could be even further extended in future.

    iv. Same as grid forming capability for converters which is also expected to contribute to provision of inertia, short circuit power and reduce harmonics.

    v. But for blackstart services, decentral units are not yet in scope, the focus is on larger units and as much as possible simple approaches considering the overall complexity of the grid restoration process.

    vi. For the provision of ancillary services with local or limited regional effect like for provision of reactive power, short circuit power, redispatch services, considering the limited number of bidders resp. limited liquidity, instead of introduction of respective markets rather bilateral contracts is seen as reasonable approach.

    vii. The expected decisions are not only determined by the existing technical possibilities, but mainly by what is considered economically viable and efficient.

4. **Industrial stakeholders**

    i. The interviews showed a mixed picture: Industrial player with high attention on ancillary services provision versus another industrial player with pure focus on the core production business and all required measures to prevent own damages in case of loss of supply.

    ii. It is criticised that the regulations and the markets for quickly and immediately interruptible loads were abolished end of June 2022.

    iii. Also, the 7000h rule to benefit from reduced grid tariff according to $ 19(2) StromNEV was mentioned as counterproductive for the future transition of electricity supply.

iv. Sticking to a cos(φ) corridor instead of active voltage support is underlined as not adequate anymore.

v. Apart from provision of ancillary services, the further electrification, conversion to hydrogen to reduce and replace of fossil fuels is of high priority.

vi. Despite the current high level of supply security, confidence in the same is now falling significantly, so that investments in emergency power supply concepts are given higher priority.

6 OVERVIEW

The following table summarizes the interviewee's views on a promising future framework for ancillary services provision.

Table 6-1: Overview of classification of ancillary services from decentral units according to the views of the interviewed stakeholder groups

Ancillary service		Obligatory (not remunerated)	Bilateral contracts (voluntary, paid)	Market tendering (voluntary, paid)
Grid congestion management	Capacity	Grid operator ×1, Developer ×1	Grid operator ×1, Developer ×3	Industry ×2, Developer ×1
	Activation	Grid operator ×1, Developer ×1	Grid operator ×1, Developer ×2	Grid operator ×3, Industry ×2, Developer ×3
Control power provision	Capacity	Grid operator ×1		Grid operator ×3, Industry ×2, Developer ×3
	Activation			Grid operator ×1, Industry ×2, Developer ×3
Inertia provision	Capacity	Industry ×1, Developer ×2	Grid operator ×1, Developer ×1	Grid operator ×1, Industry ×2, Developer ×2
	Activation			
Voltage control / reactive power	Capacity	Grid operator ×3, Industry ×1, Developer ×2	Grid operator ×3, Industry ×1, Developer ×3	Grid operator ×2, Developer ×1
	Activation	Grid operator ×2, Developer ×1	Grid operator ×3, Industry ×1, Developer ×3	Grid operator ×2, Developer ×1
Short circuit power	Capacity	Grid operator ×2, Developer ×2	Grid operator ×1, Industry ×1, Developer ×2	Developer ×2
	Activation			
Blackstart / grid restoration	Capacity		Grid operator ×2, Developer ×3	Grid operator ×2, Industry ×1, Developer ×2
	Activation		Grid operator ×1	Grid operator ×1
Filtering of harmonics	Capacity	Grid operator ×1, Developer ×1	Grid operator ×2, Industry ×1, Developer ×2	Developer ×2
	Activation			

Grid operator (yellow)
Industry (pink)
Developer (green)

APPENDIX – CLASSIFICATION OF ANCILLARY SERVICES

The following tables indicate the classification of the system services from wind parks according to the interviewees as mandatory (not remunerated), as bilateral agreements (voluntary, remunerated) and as procured (market tendering) based on their capacity and commitment.

Table A0-1 Classification of ancillary services from decentral units according to the views of the Plant Operators / Interview Partner 1

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity		✓	✓
	Activation		✓	✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity			✓
	Activation	✗	✗	✗
Voltage control / Reactive power supply	Capacity		✓	✓
	Activation		✓	✓
Short circuit current supply	Capacity		✓	✓
	Activation	✗	✗	✗
Black-start / grid restoration	Capacity		✓	✓
	Activation			
Filtering harmonics	Capacity		✓	✓
	Activation	✗	✗	✗

Table A0-2 Classification of ancillary services from decentral units according to the views of the Plant Operators / Interview Partner 2

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity	✓	✓	
	Activation	✓		✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity	✓		✓
	Activation	✘	✘	✘
Voltage control / Reactive power supply	Capacity	✓	✓	
	Activation		✓	
Short circuit current supply	Capacity	✓		✓
	Activation	✘	✘	✘
Black-start / grid restoration	Capacity		✓	✓
	Activation			
Filtering harmonics	Capacity	✓	✓	✓
	Activation	✘	✘	✘

Table A0-3 Classification of ancillary services from decentral units according to the views of the Plant Operators / Interview Partner 3

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity		✓	
	Activation		✓	✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity	✓	✓	
	Activation	✗	✗	✗
Voltage control / Reactive power supply	Capacity	✓	✓	
	Activation	✓	✓	
Short circuit current supply	Capacity	✓	✓	
	Activation	✗	✗	✗
Black-start / grid restoration	Capacity		✓	✓
	Activation			
Filtering harmonics	Capacity		✓	
	Activation	✗	✗	✗

Table A0-4 Classification of ancillary services from decentral units according to the views of the Grid Operators / Interview Partner 1

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity	✓		
	Activation			✓
Frequency control / balancing	Capacity	✓		✓
	Activation			✓
Inertia	Capacity	✓		
	Activation	✗	✗	✗
Voltage control / Reactive power supply	Capacity	✓	✓	✓
	Activation		✓	✓
Short circuit current supply	Capacity	✓		
	Activation	✗	✗	✗
Black-start / grid restoration	Capacity			✓
	Activation			
Filtering harmonics	Capacity		✓	
	Activation	✗	✗	✗

Table A0-5 Classification of ancillary services from decentral units according to the views of the Grid Operators / Interview Partner 2

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity	Cost compensation		
	Activation	✓		✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity			
	Activation	✘	✘	✘
Voltage control / Reactive power supply	Capacity	✓	✓	✓
	Activation	✓	✓	✓
Short circuit current supply	Capacity	✓		
	Activation	✘	✘	✘
Black-start / grid restoration	Capacity		✓	✓
	Activation		✓	✓
Filtering harmonics	Capacity	✓		
	Activation	✘	✘	✘

Table A0-6 Classification of ancillary services from decentral units according to the views of the Grid Operators / Interview Partner 3

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity		✓	
	Activation		✓	✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity			✓
	Activation	✘	✘	✘
Voltage control / Reactive power supply	Capacity	✓	✓	
	Activation	✓	✓	
Short circuit current supply	Capacity		✓	
	Activation	✘	✘	✘
Black-start / grid restoration	Capacity		✓	
	Activation			
Filtering harmonics	Capacity		✓	
	Activation	✘	✘	✘

Table A0-7 Classification of ancillary services from decentral units according to the views of the Industrial Stakeholders / Interview Partner 1

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity			✓
	Activation			✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity			✓
	Activation	✘	✘	✘
Voltage control / Reactive power supply	Capacity	✓		
	Activation			
Short circuit current supply	Capacity			
	Activation	✘	✘	✘
Black-start / grid restoration	Capacity			
	Activation			
Filtering harmonics	Capacity			
	Activation	✘	✘	✘

Table A0-8 Classification of ancillary services from decentral units according to the views of the Industrial Stakeholders / Interview Partner 2

Ancillary service		Mandatory, not remunerated	Bilateral contracts (voluntary, remunerated)	Market procurement/exclusion (voluntary, remunerated)
Grid congestion management / redispatch service	Capacity			✓
	Activation			✓
Frequency control / balancing	Capacity			✓
	Activation			✓
Inertia	Capacity	✓		✓
	Activation	✘	✘	✘
Voltage control / Reactive power supply	Capacity		✓	
	Activation		✓	
Short circuit power	Capacity		✓	
	Activation	✘	✘	✘
Black-start / grid restoration	Capacity			✓
	Activation			
Filtering harmonics	Capacity		✓	
	Activation	✘	✘	✘

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